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SIMBIOS Project 1999 Annual Report

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Preface

The purpose of this technical report is to provide current documentation of the the Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Project activities, NASA Research Announcement (NRA) research status, satellite data processing, data product validation, and field calibration. This documentation is necessary to ensure that critical information is related to the scientific community and NASA management. This critical information includes the technical difficulties and challenges of combining ocean color data from an array of independent satellite systems to form consistent and accurate global bio-optical time series products. This technical report is not meant as a substitute for scientific literature. Instead, it will provide a ready and responsive vehicle for the multitude of technical reports issued by an operational project.

The SIMBIOS Science Team Principal Investigators (PIs) original contributions to this report are in chapters four and above. The purpose of these contributions is to describe the current research status of the SIMBIOS-NRA-96 funded research. The contributions are published as submitted, with the exception of minor edits to correct obvious grammatical or clerical errors.

Table of Contents

Chapter 1

An Overview of SIMBIOS Project Activities and Accomplishments During FY99

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The purpose of this annual report is to review and document the activities and accomplishments of the Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Program including those of the Project Office at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and the SIMBIOS Science Team. The accomplishments of the Project's first year are documented in McClain and Fargion (1999), and this report provides an annual update. In the past year, the Project Office completed many tasks and established stronger working relationships with a number of international projects and investigators. This chapter will review the SIMBIOS Project Office activities and the second chapter will summarize the accomplishments and status of the SIMBIOS Science Team.

In 1999, the ROCSAT Ocean Color Imager (OCI) Taiwan, the IRS/P-4 Ocean Color Monitor (OCM) India, and the KOMPSAT Ocean Scanning Multispectral Imager (OSMI) from South Korea were launched. The SIMBIOS Project will assist these projects as opportunities for collaboration develop either through direct communication or through the International Ocean Color Coordinating Group (IOCCG). The Project Office is also prepared to assist the Moderate Resolution Imaging Spectroradiometer (MODIS) Oceans Team in its validation efforts once the Terra platform is launched. The Project was recently selected by Japan's National Space Development Agency (NASDA) to be a member of the Advanced Earth Observing Satellite-II (ADEOS-II) Global Line Imager (GLI) Calibration and Validation Team and by the Centre National d'Etudes Spatiales (CNES) for ADEOS-II Polarization Detecting Environmental Radiometer (POLDER) Team membership. ADEOS-II is scheduled for launch in November 2000.

SIMBIOS Project Office Status

The SIMBIOS Project Office is co-located with the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project and shares the same management infrastructure. In FY99, the Project Office completed its staffing program, i.e., all positions were filled to a level commensurate with the Project's budget. Many positions are shared or co-funded by SeaWiFS because the nature of some tasks are common to both projects, yet do not require a full time person for each, e.g., the educational outreach and science support coordinator. Figure 1 and Table 1 illustrates the present project organization and staffing plan. The data processing systems, as originally scoped, have been procured and are operational. These systems are incrementally upgraded to ensure the greatest computational capability and efficiency possible within the Project's budget.

In order to better communicate with the ocean color community, the Project greatly expanded its web site (http://simbios.gsfc.nasa.gov) to include, among other things, monthly reports of the Science Team investigators. The SIMBIOS web site is organized to serve as the main information resource to access the Project activities, Project Office and Science Team. The web site is organized under five main topics: News and Information, Support Services and Schedule, Project Status, Instrument Pool, and Contacts. All sections are updated as needed. The Project Office, in an effort to educate and promote the concept of an organized program of sensor cross-calibration and validation, send representatives to several international conferences (Table 3). In several cases, the SeaWiFS-SIMBIOS booth was manned as well.

SIMBIOS Science Team Administration

The Project Office drafted the SIMBIOS NASA Research Announcement (NRA) which went through three iterations with NASA Headquaters (HQ), the final being submitted in August. The NRA had an expected release date of November from NASA HQ. NASA HQ manages the process of team selection, but the SIMBIOS Project Office handles the team contracts and final budget negotiations. The Science Team meeting was held in Annapolis, Maryland on September 13-15, 1999. Nearly all Science Team members were in attendance or were represented by one of their staff (in only one case was a team member not able to attend). Also, the IOCCG was invited, and most attended or sent representatives. The Project provided travel support for most of the IOCCG participants. Finally, the Project held formal reviews of each Science Team investigation. For those under contract, the reviews were provided to the GSFC Procurement Office under a new regulation to conduct annual evaluations for the record.

All contracts, with the exception of one, were renewed for the third (and final) year.

SIMBIOS Calibration Round-Robin

The main parts of the round-robin over the past year have been (1) the completion of the SeaWiFS Transfer Radiometer-II (SXR-II) including operating and data logging software, and (2) evaluation of the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) laboratory calibration using the SXR-II. High altitude AVIRIS underflights of SeaWiFS can provide top-of-the-atmosphere radiances for direct comparison with SeaWiFS, especially for the 765 and 865 nm bands where vicarious calibrations using the Marine Optical Buoy (MOBY) are not possible. However, the AVIRIS calibrations must be accurate at the ± 2% level to be useful. An initial calibration experiment at the Jet Propulsion Laboratory was conducted, but problems with the SXR-II were identified after the experiment which rendered the evaluation suspect. A second experiment is being scheduled for early 2000.

Another activity related to the calibration round-robin is the commercialization of the SeaWiFS Quality Monitor (SQM; Johnson et al. 1998). Early in the SIMBIOS program, seed funds were provided to Satlantic, Inc. and Yankee Environmental Systems, Inc. to develop commercial versions of the SQM. Both companies have done so and, during 1999, the SIMBIOS Project provided a detailed evaluation of the Yankee Environmental prototype.

Ocean Color Satellite Data Processing

During FY99, the Project conducted extensive studies of the calibrations and derived products from the Ocean Color and Temperature Scanner (OCTS) the POLDER instrument, and the Modular Optoelectronic Scanner (MOS). The work with the OCTS and MOS were completed and the evaluations of POLDER are ongoing. In all cases, the work was in collaboration with instrument team members associated with the respective missions. More specifically, the work on OCTS included the following:

- Evaluation of the postlaunch postlaunch calibration of the visible bands was completed using coincident water-leaving radiance data from the MOBY (D. Clark, PI).

- Comparisons of SIMBIOS Project derived level-2 products, level-2 products from NASDA, and *in situ* observations were completed and posted on the SIMBIOS web site.

- Completion of level-0 and -2 processing of all OCTS data collected at the Wallops Flight Facility (WFF). The data were processed using code developed within the SIMBIOS Project Office which was made available to the ocean color user community via the SeaWiFS Data Analysis System (SeaDAS). The data products can be displayed using a browser and were left online for the user community to download for nearly eight months.

Work with MOS included the following:

- Completion of an evaluation of the MOS on-orbit calibration and level-2 processing code (Wang and Franz, 1999). A MOS processing module has been incorporated into SeaDAS.

- Purchase and installation of a ground station subsystem for MOS at WFF. The subsystem was purchased from an Indian firm, Antrix, Corporation Ltd., which delivered, installed, and tested the subsystem hardware and software.

- Commencement of routine MOS data reception and archiving at the SIMBIOS Project. All MOS data collected at WFF can be browsed and ordered from the SIMBIOS Project.

Work with POLDER consists of both satellite data analysis and evaluation of *in situ* data from SIMBAD. SIMBAD is an instrument designed to collect above-water reflectance data and is the primary field instrument used by the POLDER science team for validation. POLDER activities include the following:

- Evaluations of the Rayleigh radiance tables used for operational POLDER processing and the POLDER science team's methods for vicarious calibration.

- Comparison of level-2 products generated by the SIMBIOS Project and by CNES with *in situ* data. As with OCTS, MOBY was used for vicarious calibration of the visible bands.

- Purchase of two different SIMBAD instruments (8 and 11 band models) and field data collection (8 band instrument) for comparison with in-water measurements of reflectance.

Support for Field Operations

During the first two years of SeaWiFS operations, the SIMBIOS Project provided support for 125 cruises. Support can include orbit analyses for cruise track planning, as well as real-time image data sent directly to the vessel.

During 1999, the SIMBIOS Project also initiated an effort to participate on at least one field deployment with each SIMBIOS Science Team member during the three-year period of performance. In FY99, members of the SIMBIOS staff participated in six field experiments with different PIs. The Project also continued coordination of the instrument pool and initiated upgrades of the micropulse lidar and one of the

PREDE sun photometers. The PREDE upgrade consisted of the addition of a stabilizer for deployment on ships. The Project has a second PREDE is integrated with a stabilizer which was deployed during the Indian Ocean Experiment (INDOEX) on the RV *Thompson*.

Aerosol Robotic Network (AERONET)

In FY99, the re-engineering of the original 12 CIMEL sun photometers purchased by the Project was completed. The re-engineering included a number of modifications to "harden" the instruments for deployments in marine environments. SIMBIOS sun photometers were installed at coastal sites in Lanai (Hawaii), Bahrain, South Korea, Ascension Island, WFF, Tahiti, and Turkey (Black Sea). Negotiations for installations in the Azores and Australia are near completion. Finally, equipment developed at the University of Lille (France) for the calibration of polarized channels in the sun photometers was purchased and installed at the GSFC calibration laboratory used by the AERONET group.

Plans for FY2000

Several specific tasks and activities have been identified for the coming year.

- POLDER evaluations: The work described above will be completed.

- SeaWiFS evaluations: Participation in the ongoing improvements to the SeaWiFS calibration and data processing algorithms will continue. The SeaWiFS Project anticipates complete reprocessings on an annual basis so as to incorporate the latest algorithm and product revisions.

- NRA recompetition and contract negotiations: Once the NRA is released, members of the Project will be involved in the proposal evaluations, selection panel, and contract negotiations.

- Chlorophyll-a Round-robin: This activity has been designed to evaluate the differences in fluorometric and high performance liquid chromatography (HPLC) pigment analyses between several U.S. laboratories presently providing data to the Project.

- AVIRIS evaluation: The calibration experiment described above will be completed.

- SeaWiFS Bio-optical Archive and Storage System (SeaBASS) redesign: A complete redesign of SeaBASS will be undertaken to make the data in the database more accessible and to increase its flexibility.

- SeaWiFS Bio-optical Algorithm Mini-workshop: (SeaBAM) data set reconstruction. A second SeaBAM activity will be initiated to update the original SeaBAM data set and the algorithm evaluations (O'Reilly et al. 1998).

- New mission support: The Project will work with the OCI, OCM, OSMI, and MODIS programs to provide validation data and whatever assistance possible. Preparations for evaluating GLI products will begin.

- Data merger: In order to prepare for the eventual merger of different ocean color data sets, the Project will consider the OCTS-POLDER and SeaWiFS-MODIS combinations for merger algorithm evaluation purposes.

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O'Reilly, J. E., S. Maritorena, B. G. Mitchell, D. A. Siegel, K. L. Carder, S. A. Garver, M. Kahru, and C. McClain, 1998: Ocean color chlorophyll algorithms for SeaWiFS, *J. Geophys. Res.*, 103(C11), 24,937-24,953.

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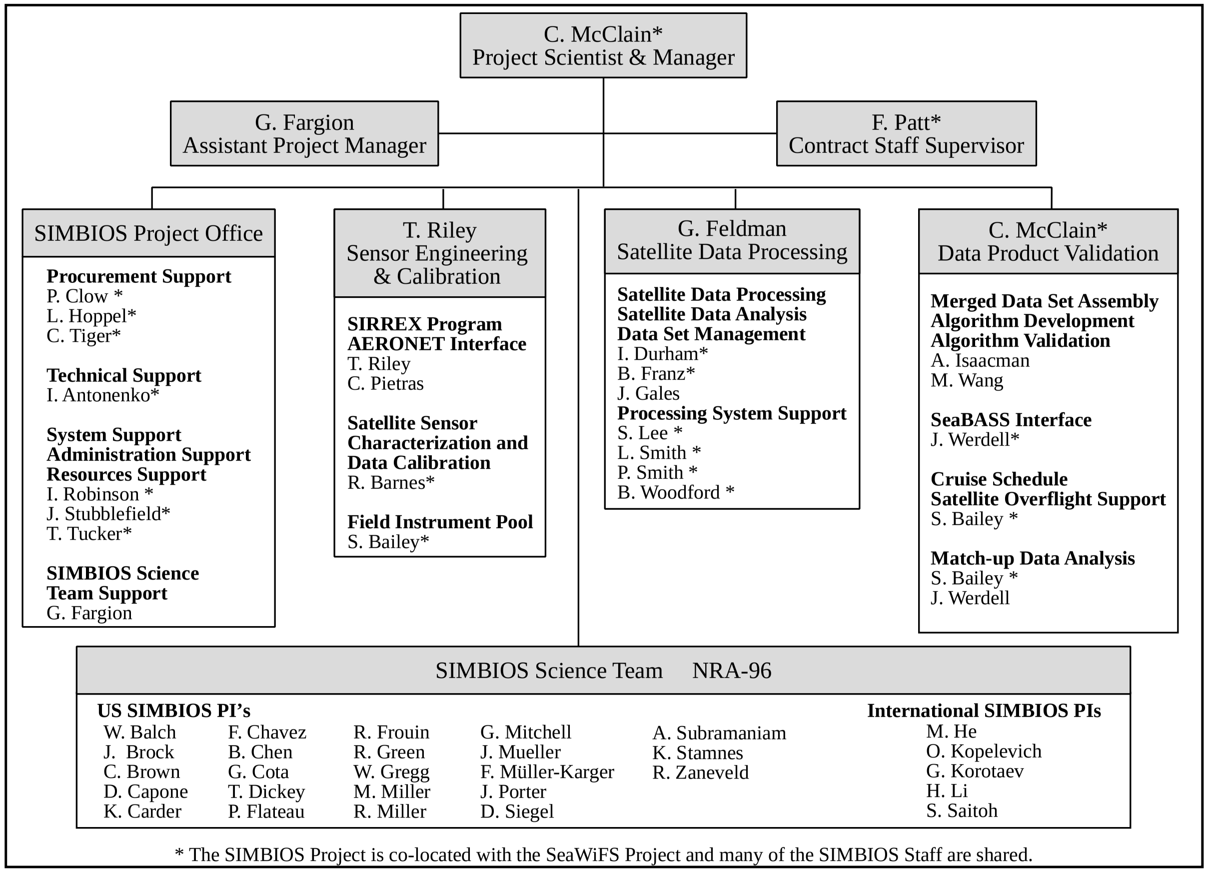

Figure 1. SIMBIOS Project organization chart

Table 2. SIMBIOS Project

SIMBIOS Project Address	
NASA/Goddard Space Flight Center (GSFC) SIMBIOS Project Code 970.2, Building 28 Greenbelt, MD 20771 Telephone: (301) 286-6800 FAX: (301) 286-0268 E-mail: project@simbios.gsfc.nasa.gov	
SIMBIOS Project Personnel	
Irene Antonenko*	SAIC General Sciences Corporation
Sean Bailey*	FutureTech Corporation
Robert Barnes *	SAIC General Sciences Corporation
Patty Clow *	NASA
Giulietta Fargion	SAIC General Sciences Corporation
Gene Feldman *	NASA
Ian Durham *	SAIC General Sciences Corporation
Bryan Franz *	SAIC General Sciences Corporation
Joel Gales	FutureTech Corporation
Lynne Hoppel *	NASA
Alice Isaacman	SAIC General Sciences Corporation
Sung Lee *	SAIC General Sciences Corporation
Charles McClain *	NASA
Fred Patt *	SAIC General Sciences Corporation
Christophe Pietras	SAIC General Sciences Corporation
Tom Riley *	NASA
India Robinson *	NASA
Linwood Smith *	FutureTech Corporation
Paul Smith *	SAIC General Sciences Corporation
Judy Stubblefield*	SAIC General Sciences Corporation
Camille Tiger *	NASA
Tamara Tucker *	SAIC General Sciences Corporation
Menghua Wang	Univ. of Maryland Baltimore
Jeremy Werdell*	SSAI Corporation
Bill Woodford*	FutureTech Corporation
Note: total civil servant staff ~ 2.5 man year	

* shared with SeaWiFS Project

Table 3. Conferences at which the SIMBIOS Project staff either presented papers or manned the SeaWiFS-SIMBIOS booth.

Conference name, date and location	Booth	Presentations
5th Environmental Conference on Remote Sensing of Marine & Coastal Environments, October 5-7, 1998, San Diego, California.	✔	✔
IOCCG Meeting , November 5-7, 1998, Hawaii.	✔	✔
Ocean Optics XIV, November 10-13, 1998, Hawaii.	✔	✔
Japan-U.S. Workshop on Ocean Color, November 15-16, 1998, Hawaii.	✔	✔
Ocean Community Conference '98, November 16-19, 1998, Baltimore, Maryland.	✔	
American Geophysical Union Fall Mtg., December 6-10, 1998, San Francisco, California.	✔	✔
ALPS99 Mtg. (CNES), January 18-22, 1999, Méribel, France.		✔
1999 American Society of Limnology and Oceanography Aquatic Science Mtg., February 1-5,1999, Santa Fe, New Mexico.	✔	
SeaWiFS Postlaunch Algorithm Workshop #1, March 18-19, 1999, Greenbelt, Maryland.		✔
ADEOS-II Workshop (NASDA), March 29-April 2, 1999, Tokyo, Japan. (Material provided to Dr. J. Dodge, NASA HQ)		✔
3rd Annual MOS Investigators Mtg., April 21-23,1999, Berlin, Germany.		✔
1999 Oceanography Society Scientific Mtg., April 27-30,1999 Reno, Nevada.	✔	
Mini-Workshop on Case-2 Algorithms, May 18, 1999, MBARI, Moss Landing, Californa.		✔
SeaWiFS Post-launch Algorithm Workshop #2, July 28-29, 1999, Greenbelt, Maryland.		✔
Oceans '99 (Marine Technology Society, Institute of Electrical and Electronic Engineers), September 13-16, 1999, Seattle, Washington.	✔	
Europto Conference (Society of Photo-Optical Instrumentation Engineers), September 20-24, 1999, Florence, Italy.		✔
ADEOS-II Workshop (NASDA), December 6-10, 1999, Kyoto, Japan.		✔
International Symposium on Ocean Color Remote Sensing and Cabon Flux and the Japan US Working Group on Ocean Color (JUWOC), December 13-15, 1999, Chiba, Japan.		✔

Chapter 2

SIMBIOS: NRA Contracts

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2.1 CONTRACT OVERVIEW

The second-year SIMBIOS NRA contracts ended in the July-September 1999 time frame. The SIMBIOS Project scheduled a telephone conference (telecon), of about 30-45 minutes, with each PI and other appropriate staff during the month of June. Prior to the telecon, the SIMBIOS Project reviewed each contract, the statement of work, and the agreed to deliveries. The Project Office followed the same procedure used in 1998 and coordinated an inside panel with key contract and project personnel to perform an across-the-board evaluation of all funded contracts (Table 1).

The four categories to be evaluated are suggested in the "Evaluation of Performance" from the Federal Acquisition Regulation (FAR) 42.15 and NASA FAR Supplement (NSF) 1842.15 or NASA form 1680 used by GSFC. Under the "quality" category the following are considered:

- data quality and completeness;
- ancillary information provided on the data (metadata);
- the data's usefulness in relation to SIMBIOS goals, i.e., calibration, validation, and algorithm development; and
- quality of technical reports.

The "time" category is a mixed bag, but is viewed with respect to data and documentation (monthly and year-end reports, and special topic publications) and delivery times. Under the "other" category is considered:

- scientific publications and scientific achievements;
- science team collaboration and involvement; and
- other significant events occurring during the contract period evaluated.

As a result of the formal evaluation and telecon with the SIMBIOS PIs, all but two investigators were evaluated as good or very good. The GSFC Procurement Office implemented and executed 20 third-year options, closed one contract, and gave an 8-month no cost extension to one contract.

Table 1. Contract evaluation key personnel

Contracting Officer:	Lynne Hoppel
Contracting Assistant:	Camille Tiger
Resource/Financial Officer:	Patty Clow
Assistant Project Manager:	Giulietta Fargion
Project Manager:	Charles McClain

Presently, the Project has in place 19 contracts and two interagency agreements. Further details are given in Table 2. The SIMBIOS Program has established a worldwide ongoing data collection program via the SIMBIOS Science Team and AERONET. Data provided to the SIMBIOS and SeaWiFS Projects are summarized in Figures 1 and 2. From 1997 to July 1999 the SIMBIOS Program sponsored and supported over 130 oceanographic cruises. Some cruises, such as INDOEX, on which SIMBIOS PIs participated, lasted several months. Table 3 shows partial data submitted to SeaBASS by the funded PIs.

2.2 SCIENCE TEAM

NASA SIMBIOS Science Team PIs were composed of those selected under the NRA-96. Some members of the MODIS Ocean Teams, and certain members the SeaWiFS Project, are considered informal members of the Science Team. There are many more U.S. and international co-investigators and collaborators actively participating in the international SIMBIOS program. This year, three PIs moved to different institutions, and two PIs resubmitted proposals for continuation of awarded research. The SIMBIOS Science Team meeting is held each year, and information and documentation produced in the previous three meetings (1997, 1998, and 1999) are posted on the SIMBIOS web-site. During the last Science Team meeting (September 13-15,1999, Annapolis, Maryland), the SIMBIOS Project suggested the following areas for improvement to the Team members:

- Matchup effort: water-atmosphere-satellite;
- Complete cruise information along with the data submission;
- Improved information across the Team;

- Timely submission and enhanced quality of monthly web reports and TM contributions;
- Faster notification to the Project of PI publications; and
- Standardized publication acknowledgements, such as "this research was supported under the SIMBIOS NASA contract # ",

Chapters 4 to 26 contain the individual PI's contributions to SIMBIOS and describe the funded research topics, field studies activities, and ongoing research results.

Table 2. SIMBIOS contracts and Government Interagency Agreements *.

Principal Investigator	Contract Number	Begin Date	End Date	Monthly Report	End-year TM	Cruise Report Metadata	Special Topic TM	Field Data Within 3 or 6 Months	Algorithm Development	Science Team Meeting
William Balch	97268	9/97	9/2000	√	√	√		√		√
J. Brock / C. Brown	*	7/97	7/2000	√	√	√		√		√
D. Capone / E. Carpenter	97131	9/97	9/99	√	√	√		√		√
D. Capone / A. Subraniam	99232	9/99	9/2000	√	√	√		√		√
Ken Carder	97137	9/97	9/2000	√	√	√		√		√
Francisco Chavez	97134	9/97	9/2000	√	√	√		√		√
Glenn Cota	97132	9/97	9/2000	√	√	√		√		√
Tom Dickey	97127	7/97	7/2000	√	√	√		√		√
Dave Eslinger	97133	9/97	5/99	√	√	√		√		√
Robert Frouin	97135	9/97	9/2000	√	√	√		√		√
Robert Green	*	8/97	8/2000	√	√	√		√		√
Watson Gregg	*	2/97	2/2000	√	√	√			√	√
Rick Miller	*	12/97	12/2000	√	√	√		√		√
Greg Mitchell	97130	8/97	8/2000	√	√	√		√	√	√
Jim Mueller	97126	8/97	8/2000	√	√	√		√		√
Frank Müller-Karger	97128	8/97	8/2000	√	√	√		√		√
Dave Siegel	99083	2/99	11/2000	√	√		√		√	√
Dave Siegel	97125	7/97	7/2000	√	√	√	√	√		√
Ron Zaneveld	97129	8/97	8/2000	√	√	√	√	√		√
Piotr Flatau	97139	9/97	5/2000	√	√	√		√	√	√
Mark Miller	*	9/97	9/2000	√	√	√	√	√		√
John Porter	97136	9/97	9/2000	√	√	√		√		√
Knut Stamnes	97138	9/97	9/99	√	√	√	√	√	√	√
Knut Stamnes	92238	9/99	9/2000	√	√	√	√	√	√	√

Table 3. SIMBIOS supported data submitted to SeaBASS from 1997 to 07/99

Principle Investigator	**University or Laboratory**	**Optics Data**	**Pigment Data (Chl)**	**AOP data**	**AD or other**
William Balch	Bigelow Labs	7 AT	261		
J. Brock / C. Brown	USGS / NOAA	115	140	1 AT	
Capone/Subraniam	U. of Southern Ca	88	34	210	AD
Ken Carder	U. South Florida	25	25		
Francisco Chavez	Mont. Bay ARI	116 + 2 Moor	334+ 2 Moor.		
Glenn Cota	ODU	412	92	1 AT	
Tom Dickey	UC SantaBarbara	7 Moor.			
Dave Eslinger	NOAA/CSC	403	90		
Piotr Flatau	Scripps, UCSD			22	
Robert Frouin	UCSD / Scripps	304+AT		304+AT	
Robert Green	JPL				other
Watson Gregg	GSFC				
Mark Miller	BNL	14		99	
Rick Miller	Stennis Space Ctr.	197	172	2 AT	
Greg Mitchell	Scripps, UCSD	240	344	1 AT	
Jim Mueller	San Diego St. U.	161		70	AD
Frank Müller-Karger	U. South Florida	162	82		
John Porter	U. Hawaii				
Dave Siegel	UC Santa Barbara				AD
Dave Siegel	UC Santa Barbara	2701	93	13 AT	
Knut Stamnes	Stevens Inst. Tech.				AD
Ron Zaneveld	OSU	59			
TOTAL 1997 data sets 48 1998 data sets 70 07/1999 data sets 23		5009 + 8 AT + 9 Moor.	1676 + 2 Moor.	705+ 19 AT	

AT = along track; Moor. = moorings; AOT = aerosol optical thickness;
AD = algorithm development; other = AVIRIS

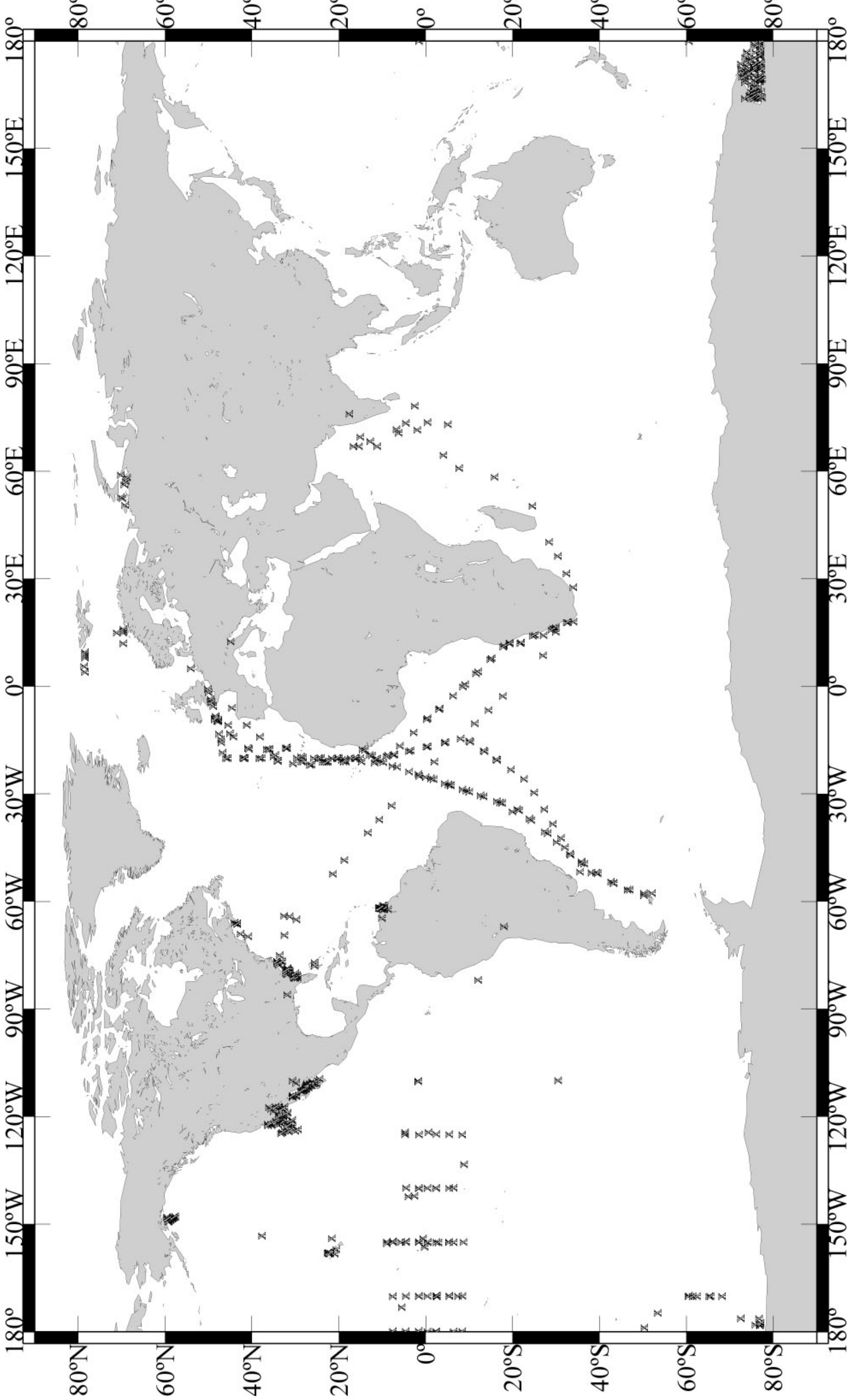

Figure 1. Bio-optical data submited to SeaBASS from 1997 to July 1999.

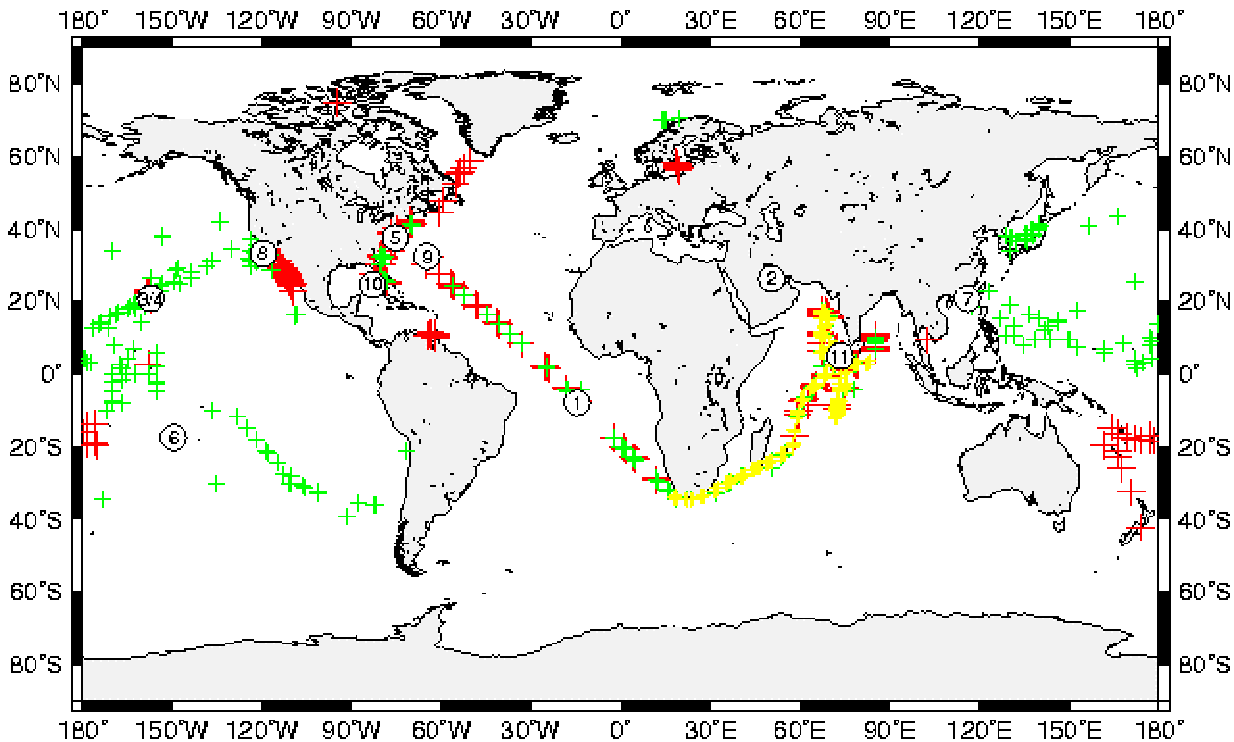

Figure 2. Atmospheric data submitted to SeaBASS from 1997 to July 1999; CIMEL stations are numbered: Ascension Island (1), Bahrain (2), Lanai (3), Honolulu (4), WFF Virginia (5), Tahiti (6), South Corea (7), San Nicolas (8), Bermuda (9), Dry Tortugas * (10) and Kaashidhoo (11). * MODIS Oceans Team supported.

Chapter 3

SIMBIOS Project Data Processing and Analysis Results

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Sean Bailey
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Jeremy Werdell
Science Systems and Applications Inc., Greenbelt, Maryland

3.1 INTRODUCTION

During the year, SIMBIOS Project Office has fostered several international collaborations (Table 1) between the various space agencies and science working groups. The Office has done this to assist in solving common technical and scientific problems, as well as to leverage limited individual project resources as much as possible. Specifically, some of the common scientific problems are (1) to quantify the relative accuracies of the products from international ocean color missions, (2) to improve the level of confidence and compatibility among the products, and (3) to generate merged, improved Level-3 products. For each sensor, the SIMBIOS Project reviews the sensor design and processing algorithms being used by the particular ocean color project, compares the algorithms with alternative methods when possible, and provides the results to the appropriate project office, e.g., CNES and NASDA. The SIMBIOS Project Office accomplishments during 1999 year are summarized under (a) satellite data processing, (b) data product validation, and (c) sensor engineering and calibration activities and are described below.

3.2 SATELLITE DATA PROCESSING

One of the primary goals of the SIMBIOS Project is to develop methods for meaningful comparison and possible merging of data products from multiple ocean color missions.

Direct comparison of such products is complicated by differences in sensor characteristics and processing algorithms, as well as spatial and temporal coverage. During 1999 the Project concentrated its efforts on the following color missions: MOS, OCTS and POLDER.

3.2.1MOS Data

On 27 February 1999, the SIMBIOS Project began operating a receiving station at NASA's Wallops Flight Facility (WFF) to acquire data from the German Modular Optoelectronic Scanner (MOS) onboard the Indian IRS-P3 spacecraft. The data from the Wallops groundstation are processed at NASA's Goddard Space Flight Center, with routine distribution of Level-0 datasets to the German Remote Sensing Data Centre (DLR-DFD). Figure 1 shows the region of coverage over which the IRS-P3 spacecraft is visible to the Wallops groundstation, with all possible MOS ground tracks superimposed.

Coverage limits are shown for antenna elevation minima of 0, 3, and 8.5 degrees. The Wallops station is currently attempting to acquire the spacecraft at 3-deg elevation, but some western passes may be limited by obstructions of up to 8.5-deg elevation. After a pass is acquired at Wallops, the raw files are transferred to the SIMBIOS Project at NASA's Goddard Space Flight Center via an automated FTP process. The raw files are then converted to level-0 format through a software package provided by ISRO. Unfortunately, the level-0 software requires human intervention, which limits full

Table 1. SIMBIOS Project international collaborations (1988-1999)

SIMBIOS Science Team (NRA-96)	**SIMBIOS Collaborations: satellite ocean color**
Mingxia He Ocean Remote Sensing Institute Ocean University of Qingdao, China Gennady K. Korotaev Marine Hydrophysical Inst., National Ukrainian Academy Of Science, Sevastopol, Ukraine Oleg Victorovich Kopelevich Ocean Optics Laboratory Moscow, Russia Hsien-Wen Li and Wei-Peng Tsai College of Science & Engineering National Taiwan Ocean University,Taiwan Sei-ichi Saitoh and Ichio Asanuma Dept.of Fisheries Oceanography and Marine Sciences, Hokkaido University, Japan	David Antoine Laboratoire de Physique et Chimie Marines Villefranche sur Mer, France Hajime Fukushima School of High Technology for Human Welfare Tokai University, Japan Olivier Hagolle Centre National d'Etudes Spatialle, Toulouse, CEDEX, France Jean-Marc Nicolas Laboratorie d'Optique Atmospherique (LOA) Universite' de Lille, France A. Neumann, G. Zimmermann and H. Krawczyk, DLR Institute of Space Sensor Technology and Planetary Exploration, Berlin, Germany Francis Xavier National Remote Sensing Agency Hyderabad, India
SIMBIOS Collaborations: *in situ* data	**SIMBIOS Collaborations with IOCCG**
Pierre-Yves Dechamps Laboratorie d'Optique Atmospherique Universite' de Lille, France Christophe Menkes Laboratoire d'Océanographie Dynamique et de Climatologie, Orstrom, France Andre Morel Laboratoire de Physique et Chimie Marines Villefranche sur Mer, France Matt Pinkerton Natural Environment Research Council, Plymouth Marine Lab, England Marcel Wernand Netherlands Institute for Sea Research The Netherlands Giuseppe Zibordi Joint Research Centre Space Applications Institute Ispra (Varese), Italy	Nicolas Hoepffner Joint Research Centre Space Applications Institute Ispra (Varese), Italy Andre Morel Laboratoire de Physique et Chimie Marines Villefranche sur Mer, France Trevor Platt Scientific Committee on Oceanic Research (SCOR)/ IOCCG Nova Scotia, Canada Venetia Stuart SCOR, IOCCG Nova Scotia, Canada

automation and adds some delay to the processing stream.

The resulting level-0 files are made available to DLR-DFD for further processing and distribution. In addition, the SIMBIOS Project is processing the data through level-1B using the standard software provided by the German Institute for Space Sensor Technology (DLR-ISST) (Neumann et al., 1995). All data processed by the SIMBIOS Project is made available through the MOS browse system at http://simbios.gsfc.nasa.gov/.

The level-1B data can be processed to level-2 using a SIMBIOS-developed software tool which applies the standard SeaWiFS algorithms of Gordon and Wang (1994). This Multi-Sensor level 1 to level 2 tool (MSL12), which is distributed with the SeaDAS software package, is currently capable of processing data from SeaWiFS, MOS, OCTS, and POLDER using identical algorithms, and it has been applied in previous studies of MOS-SeaWiFS cross-calibration (Wang and Franz, 1999).

The addition of a MOS groundstation at NASA's Wallops Flight Facility adds value to the MOS sensor through increased geographic coverage. In addition, it increases the opportunities for locating clear scenes of near-contemporaneous MOS and SeaWiFS imagery. This data will be used by the SIMBIOS Project for cross-calibration studies, atmospheric correction and bio-optical algorithm development, and data merger studies, and is made freely available to the public in accordance with the data distribution policies of DLR-ISST. The direct participation of the SIMBIOS Project in the MOS project helps to foster international collaborations that can only serve to enhance the quality and consistency of future ocean color products.

3.2.2 OCTS Data

The Ocean Color and Temperature Scanner (OCTS) is an optical radiometer which flew on the Japanese ADEOS spacecraft from August 1996 to June 1997, collecting 10-months of global ocean color data (Kawamura, 1998). During the ADEOS mission lifetime, approximately 450 GB of real-time, 700m-resolution OCTS data was collected by the SeaWiFS project through NOAA ground stations at Wallops, Virginia and Fairbanks, Alaska.

The archive consists of 337 scenes of the U. S. East Coast and 1311 scenes over Alaska. Following the work performed in 1998 to enhance the algorithms and software used to process the OCTS data (Reference the 1998 TM here), the entire U.S. East Coast archive was reprocessed through Level-0, and the products were distributed to the Ocean Color community though the SIMBIOS OCTS browser (available at http://simbios.gsfc.nasa.gov/).

OCTS Validation

An extensive set of *in situ* data taken during the time of the OCTS mission was made available to the SIMBIOS Project for match-up analysis from the SeaBASS database (Hooker et al., 1994). Over 600 data points taken on 134 separate days exist in this set. Preliminary processing of these matchup points was previously performed (McClain and Fargion, 1999).

Reprocessing of the OCTS *in situ* matchups to data taken from the SeaBASS database was performed in mid-1999. Matchup data from Wallops level 0 data and from level 1B data files supplied to the SIMBIOS Project by NASDA/EORC were processed to level 2 using MSL12 and the calibration coefficients used to process the Wallops data set. As before, files in the GSFC Wallops archive which matched *in situ* data points were processed from level 0 to level 2 using SIMBIOS navigation methods and calibration, while level 1B data files supplied to the SIMBIOS Project by NASDA/EORC were processed to level 2 using SIMBIOS calibration.

Satellite normalized water-leaving radiance (nLw) values were extracted from the level 2 records and acceptable pixels within a 1.05-km radius were weighted by the inverse of their distance to the matchup site and then averaged to derive nLw values for comparison to *in situ* data. In the case where no "bow tie" effect was present in the OCTS scan geometry, this technique usually resulted in obtaining data from 9 pixels in a square centered about the in situ data point. Matchup values were also calculated for an area within a 2-km radius if there were not enough acceptable pixels within the 1.05-km limit.

In situ data was also reprocessed to generate theoretical nLw values using ozone data derived from climatology and a set of lookup values of Rayleigh, k-ozone, and extraterrestrial solar irradiances developed by Menghua Wang. These theoretical *in situ* nLw values were then compared to the weighted average nLw satellite values. Insofar as possible, the matchups of satellite to in situ data were judged acceptable by the same criteria used to judge SeaWiFS matchups to *in situ* data . The nLw and chlorophyll a matchup procedure and analysis for SeaWiFS data are described in Schieber et al. (in press).

Specifically, matchups were rejected if:

- the time difference between satellite and *in situ* measurements was more than 4 hours (6 hours for chlorophyll);
- difference in solar zenith angle was more than 15º;
- *in situ* data were from a duplicate cast and had a lower value of nLw (490) than other casts;
- wavelengths of *in situ* data differed from OCTS wavelengths by more than 5 nm ;
- satellite data coefficient of determination (the ratio of standard deviation to average) was greater than 0.5;
- the standard deviation of the satellite data was greater than ½ the value of the *in situ* measurement;
- the usable number of satellite pixels was less than 5.

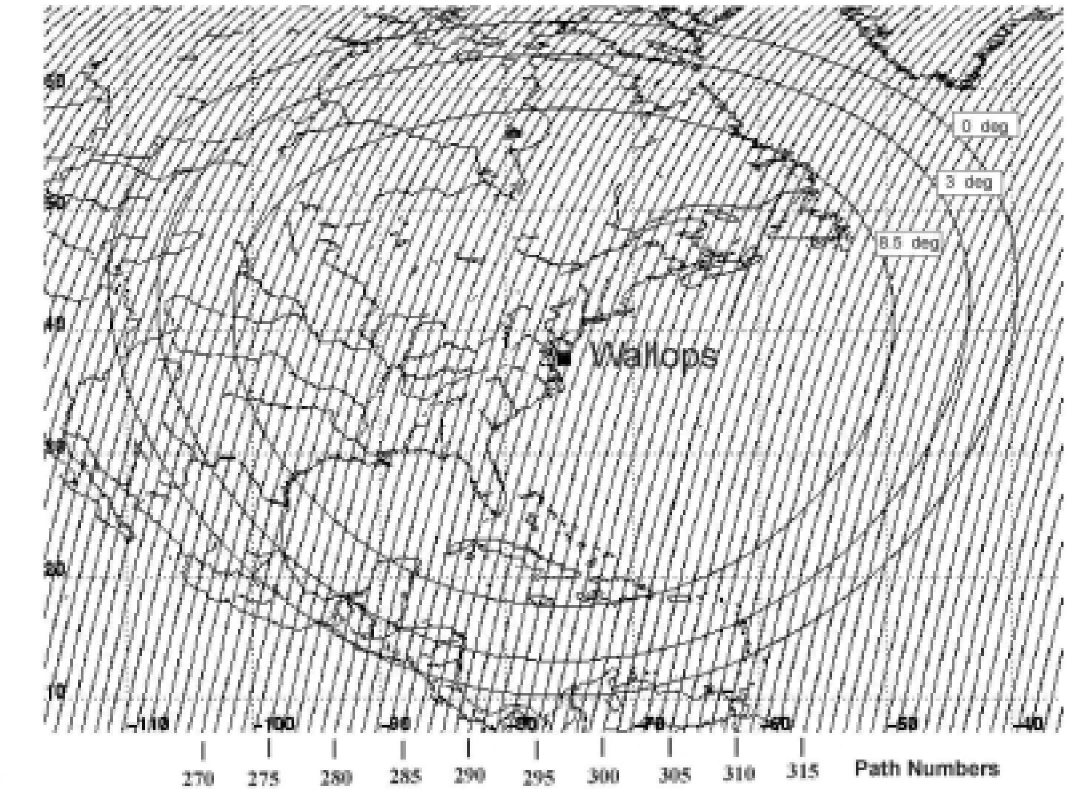

Figure 1. IRS-P3 visibility map for the Wallops groundstation (courtesy of DLR).

Table 2. Summary of SIMBIOS OCTS Matchup Validation Results

	SIMBIOS PROCESSING		
WAVELENGTH	Total	Avg Satellite/In Situ Ratio	Avg # of Pixels/ Match
412 nm	19	1.207	8
443 nm	19	1.048	8
490 nm	20	.9939	8.15
520 nm	13	.9963	10.8
565 nm	9	1.048	9.5
670 nm	7	1.828	11

SeaWiFS matchups routinely screen satellite data for flagged values and accept or reject them based on which flags, if any, are present. Comparable tests could not be performed for the OCTS matchups since the version of SIMBIOS processing used did not output flag values to the level 2 data sets. Because of the small number of matchups, those for which some bands failed the above criteria while other bands passed were included in the final analysis. Reprocessing of *in situ* data increased the number of matchups somewhat, from 13 to 18 acceptable matchups in Band 3, the “best” channel, to the data processed from NASDA level 1B to level 2 using SIMBIOS methods. One fewer matchup was deemed acceptable for Band 3 for the Wallops level 0 data (the point lost was one where the satellite standard deviation was unacceptably large). Several sets of nLw matchup data were accepted using both methods, Table 2 summarizes the results of the matchups to non-MOBY data.

Data which had 5 or more satellite pixels within a 2-km radius are included in this Figure 2. The results from the SIMBIOS processing of the NASDA level 1B data are generally reasonable for Bands 1-5. The larger ratios of satellite to in situ data seen in the Wallops data set may be due to the data being taken from only two investigators, from two different dates. Detailed statistics, matchup plots, tables, and thumbnail pictures of each matchup may be viewed on the WWW at http://simbios.gsfc.nasa.gov/~alice/OCTS_MATCHUP_SUMMARY.html.

Chlorophyll Algorithm Study

OCTS chlorophyll derivations using three different chlorophyll algorithms were compared to *in situ* chlorophyll measurements in the SeaBASS/SeaBAM data set. The algorithms used are the current chlorophyll algorithm used by NASDA on OCTS data ("OCTS-C"), the SeaWiFS chlorophyll algorithm tuned to the OCTS instrument by J. O'Reilly and S. Maritorena ("OC2"), and chlorophyll deived from NDPI pigment (R. Frouin). Comparisons of chlorophyll distributions and time series of in situ data were compared to OCTS data and to SeaWiFS 8-day chlorophyll averages.

We used in situ data from the Sargasso Sea/Bermuda area taken between July 1979 and 1990-1998 and comparisons using all in situ data, then generated the same comparisons using only in situ data taken between November and June, the time frame of the OCTS flight. We found that chlorophyll distributions for the OCTS-C and OC2 algorithms were in general agreement with the data while the NDPI algorithm showed a higher distribution (Figure 2). Detailed results of the study may be found at http://simbios.gsfc.nasa.gov/~alice/Sargasso/chl_comps/Chlorophyll_Comparison.html

3.2.3POLDER Data

The Multi-Sensor level-1 to level-2 (MSL12) software was enhanced to include processing capabilities for standard POLDER level-1B products. This capability has enabled the SIMBIOS Project to perform an independent calibration of POLDER, using standard SeaWiFS atmospheric correction algorithms (Gordon and Wang, 1994) and *in situ* data from the Marine Optical Buoy (MOBY) (Clark et al., 1997). Since POLDER can acquire as many as fourteen near-contemporaneous views of each location, at a variety of scattering angles, the POLDER data provide the SIMBIOS Project with an opportunity to make a direct test for geometric dependencies in the water-leaving radiances retrieved with the SeaWiFS atmospheric correction alghorithm.

For the present study, the multiple views of each MOBY matchup were treated independently in deriving the calibration gains. By inversion of the Gordon and Wang algorithm, each MOBY water leaving radiance measurement was propagated to the top of the atmosphere and combined with the predicted atmospheric path radiance for each POLDER viewing geometry. The predicted top of atmosphere radiances were then compared with the POLDER Level-1B radiances to derive the individual gain corrections required to make the POLDER measurements match the predicted radiances. The individual calibration gains were then combined by a simple average to form the final calibration in each POLDER band. The results are listed in Table 3, with the equivalent POLDER project calibration shown for comparison.

Table 3. Standard POLDER ocean color vicarious calibration coefficients, as compared with the calibration corrections derived by SIMBIOS.

Band	POLDER	SIMBIOS
443	1.072	1.013
490	1.042	0.971
565	1.000	0.953
670	1.000	1.004
765	1.000	1.008
865	1.000	1.000

POLDER Matchup Analyses

Progress has also been made in the latter part of the year on POLDER data. The CNES has kindly provided the SIMBIOS Project with POLDER level 1 and level 2 data corresponding to the SeaBASS data base and to the dates and locations used in the Sargasso Sea study performed on OCTS data (web page at http://simbios.gsfc.nasa.gov/~alice/Sargasso/Sargasso.html).

A preliminary calibration of the POLDER data has been performed and MSL12 was updated to allow SIMBIOS processing of POLDER level 1 data to level 2. Due to the directionality and larger pixel size of the POLDER, different matchup criteria were used. Acceptance criteria for POLDER *in situ* matchups:

- due to the large POLDER pixel size (approximately 7 km. at the Equator), only a one-to-one match of in situ data to a unique POLDER pixel was done;
- for investigators having multiple measurements on the same day, measurements closest in time to the POLDER overpass were selected. In the case of duplicate in situ measurements tagged with the same time, those with highest nLw (490) were used;
- difference in solar zenith angle between POLDER *and in situ* less than 15 degrees;
- solar zenith angle measurement less than or equal to 60 degrees; and
- *in situ* measurements were accepted only if they were taken between 0900 and 1500 local time (computed strictly by longitude) for all measurements except chlorophyll measured in the field, for which a ± 6 hour time window in either direction was allowed. The time window for nLws was determined from Bermuda Test Bed Mooring data which indicated that nLws decrease at earlier or later times of day.

Due to the directionality property of POLDER, as many as 14 different satellite matches to a given *in situ* measurement were theoretically possible. In actuality, the number of directional matches was usually on the order of 8 to 10. Simply performing a straight line fit to the data yielded the results shown in Table 4, which should be regarded as preliminary. In particular, Table 4 contains results from MOBY and Marine Optical Characterization Experiment (MOCE) (D. Clark, PI) scenes which were used in the initial calibration of the POLDER performed by the SIMBIOS Project; these results will be omitted in subsequent validation studies. We also performed matchups of POLDER level 2 data with data from the SeaBASS data set; our results were comparable to those obtained by Dr. J-M Philippe at the Laboratoire d' Optiques Atmospheriques in Lille, France. All preliminary POLDER matchup results may be found at http://simbios.gsfc.nasa.gov/~alice/polder_matches/INDEX.html

3.2.4 Future Validation Activities

In the near future, the SIMBIOS Project plans to attempt another vicarious calibration of the POLDER, possibly taking into account effects of the instrument's directionality. In addition, the Sargasso Sea study performed on OCTS data will be repeated using POLDER data coincident in locations and dates. At the conclusion of these efforts, we will intercompare the POLDER and OCTS by examining data which has been processed from level 0 or 1 to level 2 using identical SIMBIOS atmospheric correction methods.

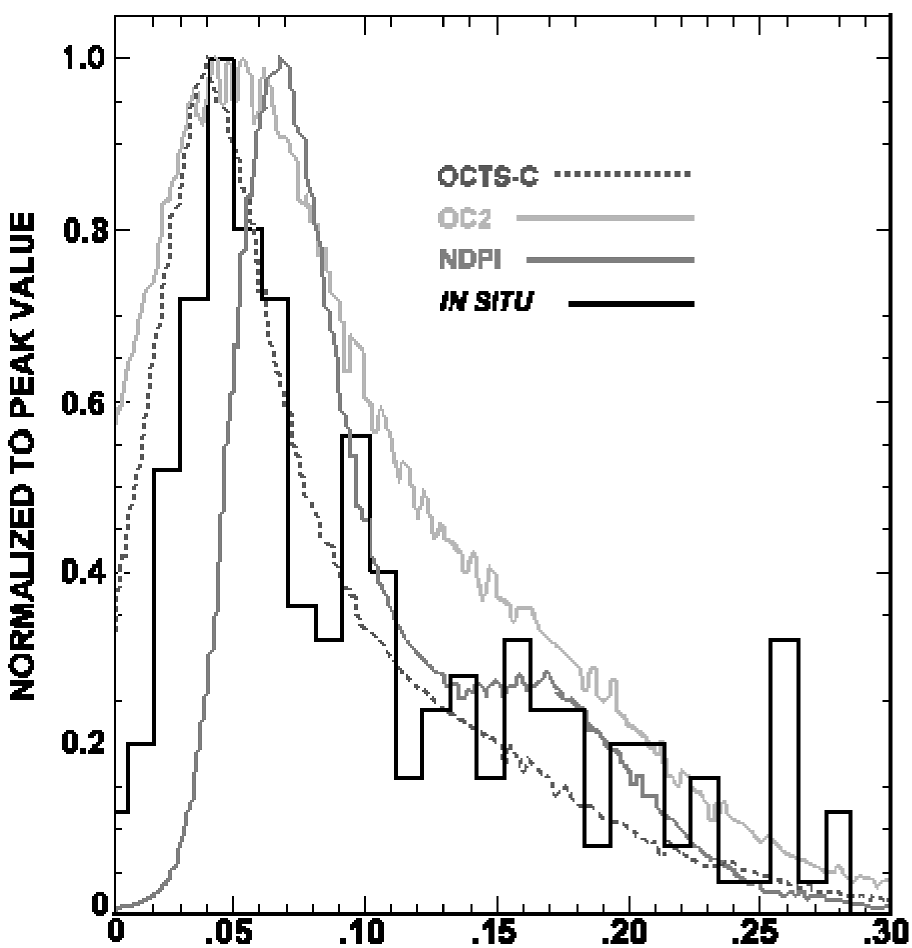

Figure 2. In situ chlorophyll values from 30 box between longitudes –65.70 to –62.70 and Latitudes 300 and 330. OCTS satellite data for 6 scenes.

Table 4. Preliminary POLDER Matchup results: straight line fit to data

WAVE-LENGTH	# Matchups	Total # Directions	Slope	Offset
443 nm Band	40	422	.897	-.40
490 nm Band	40	422	.387	.20
565 nm Band	20	227	.658	-.01

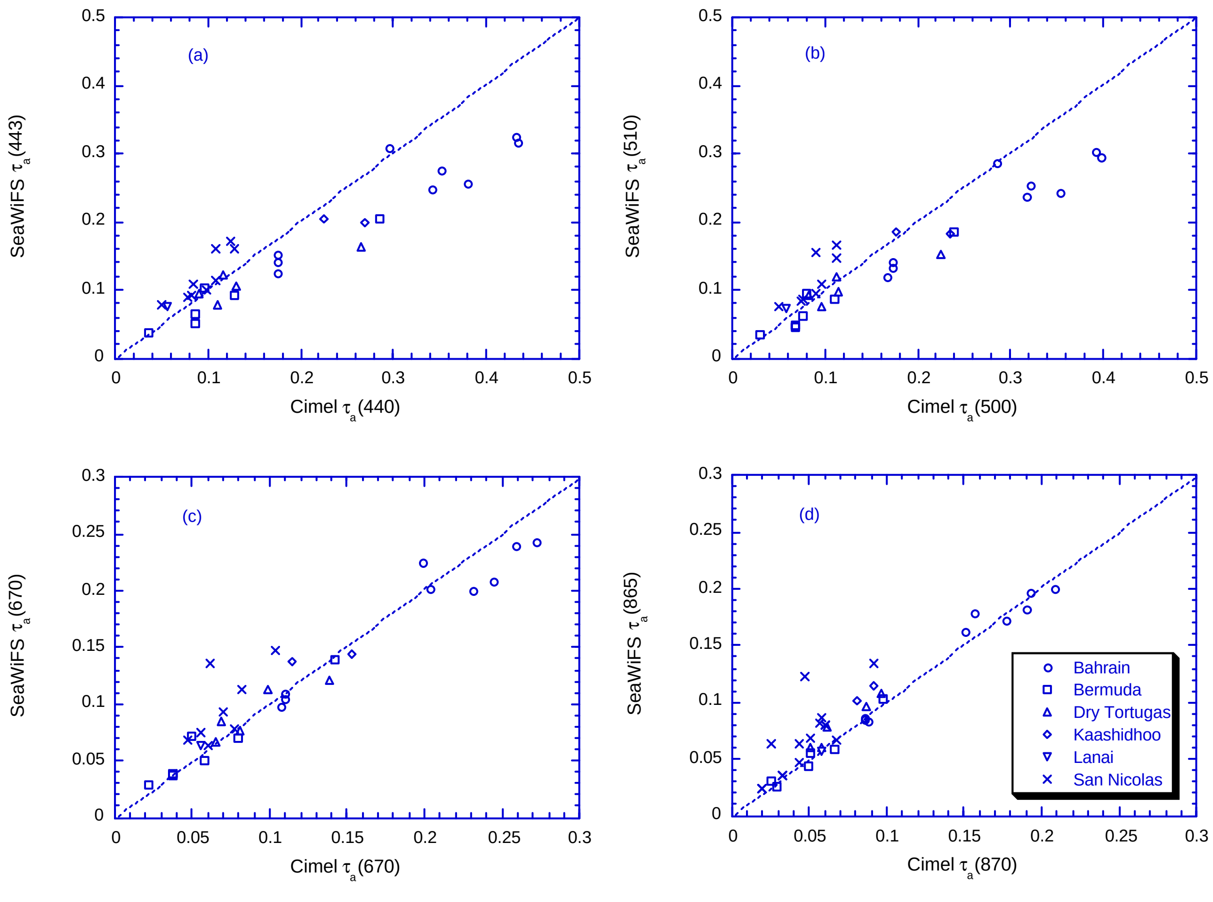

Figure 3. The retrieved SeaWiFS aerosol optical thickness compared with the ground in situ measurements from the various AERONET stations for (a) 440 nm; (b) 500 nm; (c) 670 nm; and (d) 870 nm.

3.3 PRODUCT VALIDATION

We are continuing our efforts in comparing and validating the SeaWiFS aerosol optical products with the *in situ* measurements mainly from the data of the AERONET. As in our previous report (McClain and Fargion, 1999), SeaWiFS has tendency of overestimating aerosol optical thickness with respect to the *in situ* measurements. Herein, some updates of comparison procedures and new results are presented and discussed.

SeaWiFS Data Acquisition

The SeaWiFS aerosol optical thickness (AOT) data were obtained by spatially co-locating a 25x25 pixel grid box around the pixel containing the ground-based measurement station, thereby providing a maximum of 625 SeaWiFS retrievals in each matchup. A spatial homogeneity (uniformity) test in the retrieved $\tau_a(865)$ was then conducted to screen thin cirrus and high altitude aerosol contamination because the *in situ* and satellite measurements are often looking through different atmosphere paths. Only those satellite data sets which passed the spatial homogeneity test were used for the matchup analyses.

In Situ Data Acquisition from Cimel

A select group of the ground stations from AERONET was chosen. These instruments were located at either coastal or island stations and were operational for a reasonable length of time after SeaWiFS went into operation. Table 5 provides the AERONET station name, location (latitude and longitude), and the corresponding responsible AERONET PIs. Currently, efforts are underway to include additional AERONET stations. The retrieval of data from AERONET has been automated to facilitate the matchup analyses. Once per month, a script is automatically run to access the AERONET database and retrieve τ_a data for the predetermined sites.

Table 5. AERONET sites used for aerosol matchups analyses.

Station	Latitude	Longitude	AERONET PI
Bahrain	26.32	50.50	C. McClain*
Bermuda	32.37	-64.70	B. Holben
Dry Tortugas	24.60	-82.80	K. Voss & H. Gordon
Kaashidhoo	4.97	73.47	B. Holben
Lanai	20.83	-156.99	C. McClain*
SanNicolas	33.26	-119.49	R. Frouin

* SIMBIOS Project Office

For the matchup purpose, the ground-based measurements from AERONET were first reduced to include only those records that fall ±3 hr of the SeaWiFS overpass for a given station. These records include the aerosol optical thickness measured at the four spectral wavelengths (440, 500, 670, and 870 nm). As an initial quality control step, the data were averaged and some variation parameters were computed to screen possible cloud contamination. Only those data sets which have low temporal variations (stable atmosphere) were then further reduced to ±1 hr of the SeaWiFS overpass and used for the matchup analyses. Usually, the Cimel instruments routinely take one measurement every 15 min near local noon; therefore, for a given SeaWiFS file, there may be as many as eight AERONET measurements that qualify as a match for the 2 hr time window. The strategy in the validation study is not to compromise good data with bad data for the purpose of more matchups, i.e., it is preferred to screen out some good data to keep the high quality of data sets.

AOT Results

The SeaWiFS derived aerosol optical thicknesses with those from the ground in situ measurements were compared. Figures 3 (a)- 2 (d) provide overall comparison results of $\tau_a(\lambda)$ between SeaWiFS and Cimel measurements at the four wavelengths 440, 500, 670, and 865 nm. The Cimel measurements were from the AERONET stations listed in Table 5. The number of data contributed to each plot in Figure 3 from individual stations, from the top of the list to the bottom in Table 5, is 9, 8, 5, 2, 1, and 8. The station of Lanai, therefore, only contributed one point, whereas Bahrain has nine points in Figures 3(a)- 3(d). The dotted lines in Figure 3 are the 1:1 line. Although the comparison results vary both in time and location, Figure 3 shows that the comparisons agree reasonably well at the longer wavelengths (670 and 865 nm) for most of the AERONET stations.

There is no obvious bias in the retrieved aerosol optical thicknesses. This implicitly indicates that the calibration at the SeaWiFS 865 nm is reasonably accurate. At the short wavelengths, however, it appears that SeaWiFS has the tendency of overestimating $\tau_a(\lambda)$ with respect to the in situ measurements, in particular, for the relatively large aerosol optical thicknesses ($\tau_a > 0.15$). This is most evident with the SeaWiFS $\tau_a(443)$ comparison results.

Some possible sources that contributed to the comparison differences are from both satellite measurements (calibration, aerosol models, and cloud and thin cirrus contamination) and *in situ* data (mainly from instrument calibration and cloud contamination). More studies are needed to understand all of these.

AOT Cross Calibration Experiment

During the first week of August 1999 an experiment was conducted at the “Acqua Alta” Platform of the CNR of Venice (Italy). This experiment was in collaboration with Dr.

Giuseppe Zibordi of the Joint Research Center of Ispra (Italy) and Dr. Stan Hooker of NASA GSFC. A SIMBAD radiometer, and Microtops and CIMEL sun photometers were operating concurrently to allow direct solar and above water measurements. The CIMEL and Microtops instruments collected AOT; SIMBAD instrument collected AOT and water leaving radiances data. On the only clear day, August 3, the AOT daily averages were computed and are summarized per wavelength in Table 6. The results presented herein are to be considered preliminary. In spite of higher AOT from the Microtops at 440nm, good agreement was observed. The 870nm channel was used as a reference channel. Using the OC2 algorithm (O'Reilly et al., 1998) we computed the chlorophyll a based on the remote sensing reflectance ratios at 490nm and 560nm. Water leaving radiances and chlorophyll-a, are shown in Figure 4. More details on sun photometer operation and calibration are posted at: http://simbios.gsfc.nas a.gov/Sunphotometers/calibration.html

3.3.1 SeaBASS INTERFACE

The SIMBIOS Project maintains the SeaBASS as an archive for in situ products used in scientific analyses (e.g. product verification and bio-optical algorithm development). Stored data include measurements of water-leaving radiance, chlorophyll-a, and other related optical and pigment measurements collected on ships, moorings, and drifters. (McClain and Fargion, 1999). Information on the original SeaBASS design is provided in the SeaWiFS Technical Report Series Volume 20 (Mueller and Austin 1995). A current description of the SeaBASS system is available via the World Wide Web at http://seabass.gsfc.nasa.gov.

The SeaBASS bio-optics database contains data from over 200 experiments, encompassing more than 9000 data files. Presently, data are stored as simple, flat (two-dimensional) ASCII text with standard metadata headers to fully define each file. The headers contain information on date, time, location, investigators involved, values measured, units, and other related descriptive information. The SIMBIOS Project designed the format to ensure that data files were simple, yet comprehensive, globally compatible among different computer platforms, and effortlessly ingested into the database. Specific information and examples of the data format can be referenced at the SeaBASS web site.

The data format has not changed significantly during the past year of the SIMBIOS effort. A single mandatory metadata header ("/data_status=" accepting "preliminary", "update", "final") has been added to aid in tracking the status of newly submitted data. The SIMBIOS Project uses this information to determine if a file contains data from a new cruise ("preliminary") or updated (e.g. recalibrated or reprocessed) data from a previous cruise ("update", "final"). The "final" status is appropriate when data are not to be updated again. Similarly, protocols for format checking and data submission have not been altered over the past year. The SIMBIOS Project currently uses a PERL script feedback program known as FCHECK to maintain the standard format for incoming data files. Contributing researchers can test their data for compatibility with the SeaBASS format from any platform by e-mailing their files to fcheck@seabass.gsfc.nasa.gov. Once the data files meet SeaBASS format requirements, the contributor may send their data files and related documents (e.g. cruise reports, readme and calibration files) to the SeaBASS archive via file transfer protocol (FTP). The SeaBASS Administrator moves the files into their appropriate position in the archive and ingests the files into the SeaBASS database. Password secure web access to the data files, the database, and supporting documentation is available at the SeaBASS web site. For additional information on format checking and data security issues refer to the SIMBIOS Project 1998 Annual Report (McClain and Fargion, 1999). The procedures for water-leaving radiance, normalized water-leaving radiance, and chlorophyll-a match-up analyses have changed little during the past year of the SIMBIOS effort. Each match-up file format follows a similar logic to that of the other SeaBASS in situ files. Data are structured in standard ASCII columnar format with standard metadata headers; each record, however, has predefined data fields:

- year, month, day, hour, minute, second, latitude, longitude,
- L_w412, L_w 443, L_w 490, L_w 510, L_w 555, L_w 665,
- E_s412, E_s443, E_s490, E_s510, E_s555, E_s665, K_d490, chlorophyll-a.

Specific information on the match-up analyses and protocols may be found in the SeaWiFS Postlaunch Technical Report Series Volume 9 (Schieber et al., 1999).

Future Plans

The SeaBASS system will undergo several major changes in the coming year. First, the match-up analysis procedures will be modified concurrently with the next reprocessing of SeaWiFS data. The most significant alterations include (1) a change in Level 2 processing code from ANLY (l2gen) to the Multisensor Level-1 to -2 (MSL12) program and (2) a generalized file format which allows for additional field parameters to be included (e.g. L_w and E_s values at wavebands other than those of SeaWiFS). Second, the Project intends to reconfigure the SeaBASS database system. The following activities are considered to be the important in the design of the new system: (1) increasing the number of tables in the relational database to improve data normalization, (2) reconfiguring the system to take advantage of multiple processors and increased physical storage space, (3) generating stored system procedures for internal SIMBIOS Project Office accounting purposes, and (4) including all metadata and data information into the database to improve its ability to search for or query archived parameters.

Table 6. AOT retrieved on August 3 1999 Averaged between 8am and 12am on Acqua Alta Platform from CIMEL, Microtops and SIMBAD sun photometers.

	CIMEL	Microtops	SIMBAD
440 nm	0.336	0.360	-
443nm	-	-	0.324
490nm	-	-	0.261
500nm	0.273	0.284	-
560nm	-		0.203
670nm	0.146	-	0.134
675nm	-	0.154	-
870nm	0.080	0.080	0.081
940nm	-	0.069	-

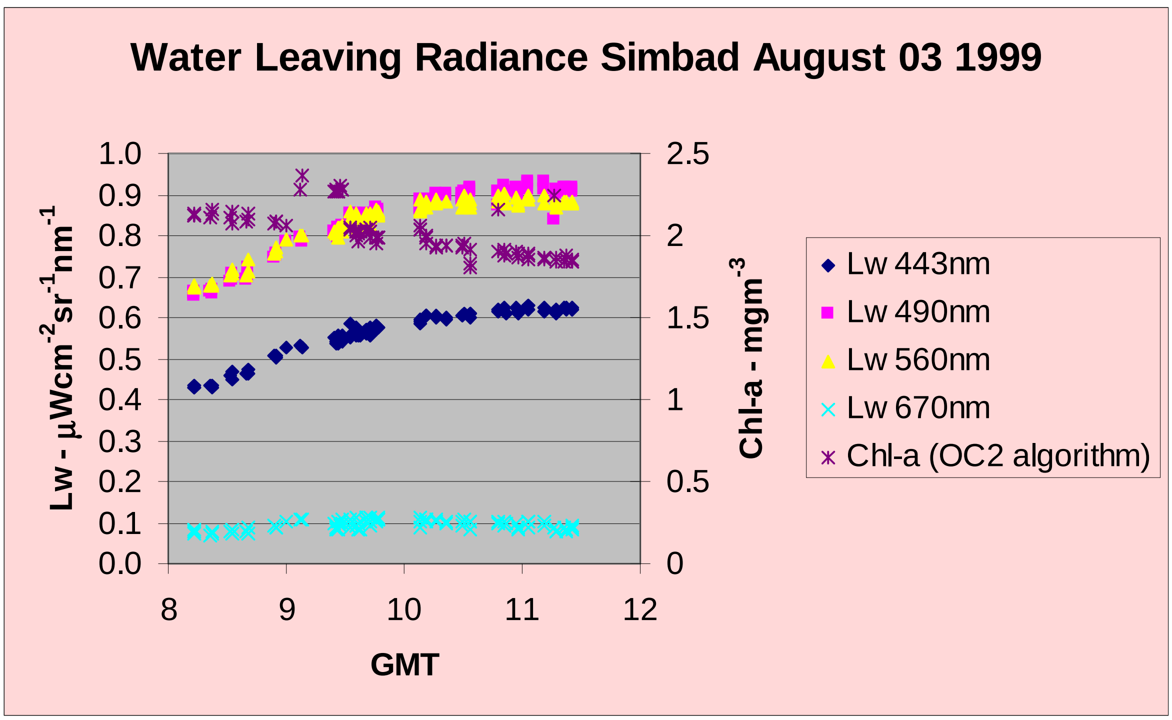

Figure 4. Water leaving radiances retrieved from SIMBAD radiometer on August 3, 1999.

Table 8. Table of SIMBIOS supported cruises with services provided.

Cruise Location	Begin Date	End Date	On-board LAC	Over-flight Prediction	Near Real Time Imagery	Instrument Pool Use	Principal Investigator
SOIREE	19990101	19990303	✓		✓		Steve Groom
ANTARES4	19990104	19990223	✓	✓	✓		J. Le Fevre
CalCOFI	19990109	19990131		✓	✓	✓	Greg Mitchell
BBOP/BATS124	19990111	19990115				✓	Dave Siegel
INDOEX	19990114	19990401	✓	✓	✓	✓	Piotr Flatau
FEB99SAB	19990210	19990224		✓		✓	Ajit Subramaniam
BATS Validation #25	19990302	19990306					Dave Siegel
EPS-A Test Flight	19990316	19990429		✓			J.H.M. Hakvoort
Baltic Sea	19990316	19990316		✓			Peter Land
Landsort Deep	19990330	19990427		✓			Peter Land
Bay of Biscay	19990401	19990416		✓	✓		Jean-Noel Druon
AR04-99	19990402	19990410		✓	✓		Douglas Phinney
HOTS	19990413	19990415	✓	✓			John Porter
N.Pac. Subtrop. Gyre	19990420	19990508	✓	✓	✓		Carrie Leonard
GOCAL99-A	19990421	19990502		✓		✓	Jim Mueller
AMT8	19990425	19990607	✓	✓	✓		Stan Hooker
OMEX 64PE138	19990426	19990507			✓		Marcel Wernand
Japan Sea	19990501	19990615		✓	✓		Robert Arnone
Yarmouth-Portland	19990510	19991001		✓	✓	✓	Barney Balch
Helgoland	19990511	19990613		✓			J.H.M. Hakvoort
HX222 Inner Front	19990520	19990620		✓			Stephan Zeeman
HOTS	19990527	19990531		✓			John Porter
CARIACO	19990602	19991220	✓	✓		✓	Frank Muller-Karger
US East Coast	19990616	19990622		✓	✓		Stephan Howden
AREX-99	19990620	19990805		✓			Dariusz Stramski
OCE96-17680	19990623	19990708		✓	✓		Barney Balch
South China Sea	19990701	19990731	✓	✓		✓	Richard Miller
EQUALANT	19990706	19990820			✓		J. Etcheto
Chukchi Sea	19990707	19990730	✓	✓		✓	Glenn Cota
HOTS	19990712	19990716	✓	✓			John Porter
Gotland	19990714	19990815		✓	✓	✓	Peter Land
SML99	19990720	19990723		✓	✓		Heidi M. Sosik
Bay_of_Biscay	19990722	19990915		✓	✓		Jean-Noel Druon
Venice Tower Experiment	19990802	19990806	✓	✓		✓	Giuseppe Zibordi
CalCOFI	19990807	19990829		✓			Greg Mitchell
Heincke 99	19990824	19990827		✓	✓		Hans Barth
US East Coast	19990825	19991015		✓	✓		Stephan Howden
SEINESAT	19990825	19991001		✓	✓		Jean-Noel Druon
PROSOPE	19990904	19991003	✓	✓	✓		Stanford Hooker
OSCOPE	19990920	19991030	✓	✓	✓		Rik Wanninkhof

Cruise Location	Begin Date	End Date	On-board LAC	Over-flight Prediction	Near Real Time Imagery	Instrument Pool Use	Principal Investigator
SeaWiFS Validation Cruise #2	19991001	19991021		✓	✓		Dennis Clark
Black Sea	19991001	19991031		✓	✓	✓	Robert Frouin
AVARIS-CalCOFI	19991001	19991031		✓			Robert Green
CalCOFI	19991003	19991031		✓			Greg Mitchell
Cimar5	19991020	19991114	✓	✓	✓		W. Scott Pegau
TrichoToto	19991026	19991129	✓	✓	✓	✓	Ajit Subramaniam
GoCAL-99B	19991027	19991108		✓	✓	✓	Jim Mueller

Table 8. SIMBIOS Pool Instruments

Instrument	Quantity	Description	Manufacturer	Custodian(s)
MicroTops II Sunphotometer w/GPS	12	5 channel handheld sunphotometer w/Garmin GPS-38	Solar Light Company	SIMBIOS Project
HISTAR Package*	1	2 hyper-spectral absorption/beam attenuation meters mounted on a cage with a SeaBird CTD	WETLabs, Inc	Zaneveld/Pegau
Hydroscat 6	3	backscattering meter	HOBILabs	Siegel Carder Mitchell
Pure Water System	3	Water purification system for calibration of WETLabs AC-9 and HISTAR absorption and attenuation meters	Barnstead	Zaneveld/Pegau
AC-9	3	absorption/beam attenuation meter	WETLabs, Inc.	Cota Capone Muller-Karger
SIMBAD	5	5 channel radiometer and sunphotometer		Frouin
SeaWiFS Multichannel Profiling Radiometer	2	Free-fall profiling radiometer measuring Lu(z), Ed(z), Es, Lu(1m) with cables, deck unit and PC with data acquisition and processing software	Satlantic, Inc.	Capone Chavez
Micropulse LIDAR	1	Continuous operation LIDAR system	SESI	SIMBIOS Project
Prede Sunphotometer	2	Automated ship-board sunphotometer	Prede	SIMBIOS Project
Cimel Sunphotometer	12	Marine-hardened, automated sunphotometer	Cimel	SIMBIOS Project

* The two WETLabs Histar instruments for this package have been replaced with two WETLabs AC-9's until such time as the Histar instrument provides reliable data.

3.3.2 SUPPORT SERVICES

In an effort to improve the quality and quantity of calibration and validation data sets, the SIMBIOS Project offers several support services to field investigators. These services include; scheduling of on-board LAC recording for SeaWiFS; overflight predictions for operational sensors (currently SeaWiFS, OCTS and MOS-B); near real time SeaWiFS imagery for cruise locations; and optical instrumentation from a pool of investigator- and project-owned instruments. These services may be requested via the World Wide Web at http://simbios.gsfc.nasa.gov. In return for these services, the SIMBIOS Project requests that the field investigators provide *in situ* validation data to the Project's bio-optical archive, SeaBASS. Since January of 1999, when these services were initially offered, the SIMBIOS Project has supported 47 cruises (Table 7).

Scheduling SeaWiFS On-board LAC Recording

Since much of the world ocean is not covered by a SeaWiFS HRPT station, high-resolution data may be recorded onboard the SeaWiFS sensor. As a service to the science community, the SIMBIOS Project in conjunction with the SeaWiFS Project can schedule SeaWiFS onboard LAC for cruises that occur outside HRPT coverage. SeaWiFS has the ability to record a maximum of 10 minutes of high-resolution data per downlink. Typically, a 30-second interval is allotted for LAC target, which corresponds to 180 scan lines or approximately 200 km along track at nadir. Detailed information on LAC scheduling is available on the SIMBIOS web site.

Overflight Predictions for Operational Sensors

For calibration and validation purposes, *in situ* measurements should be made as close to the sensor overflight time as is possible. To aid investigators in determining when sampling should occur, the SIMBIOS Project offers overflight predictions for all operational ocean color remote sensors. Currently, the sensors supported are SeaWiFS, MOS-B and OCI. With the launch of Terra upcoming, MODIS will be added to this list. Detailed information on overflight predictions is available on the SIMBIOS web site.

Near Real Time SeaWiFS Imagery

In addition to providing predictions for satellite overflight times, the SIMBIOS Project offers near real time imagery of the operational SeaWiFS products in JPEG format to cruises at sea. These images provide field investigators with additional information with which they may maximize *in situ* sampling of transient oceanographic features. The default specifications for the images provided include:

- available LAC, HRPT, and GAC;
- chlorophyll-a and pseudo-true color images;
- 2-degree box about a designated location or the entire designated region ;
- image width of 600 pixels ;
- minimum percent valid chlorophyll pixels: 5%;
- images may be customized to best accommodate individual investigators needs. Detailed information on near real time imagery is available on the SIMBIOS web site.

Instrument Pool

The SIMBIOS Project provided funding to several of the science team members for the purchase of *in situ* ocean optical instrumentation. The funding was provided with the stipulation that these instruments would be made available for three years to an instrument pool to be maintained by the Project Office. The Project augmented this instrument pool with atmospheric instrumentation. Table 8 summarizes the instruments available.

Satellite Data

The SIMBIOS Project collected OCTS data for the East Coast of the United States while the ADEOS satellite was operational. These data have been processed using code developed in house and are available through a browse utility linked to the SIMBIOS Project's web site. The Project also routinely collects MOS data for the East Coast of the U.S. while the instrument is in ocean viewing mode. As with the OCTS data, these data are made available to the public via the SIMBIOS Project web site.

3.4 SENSOR ENGINEERING AND CALIBRATION

Eight SIMBIOS CIMEL sites have been confirmed (delivered or negotiated) and include Lanai Hawaii (with backup in Honolulu), Ascension Island, Bahrain, Tahiti, Wallops Island (Virginia, USA), South Korea, and Erdemli (Turkey). The next sites projected for implementation by January 2000 are The Azores and Perth (Australia).

The remaining two SIMBIOS CIMELs, one as a backup, are deployed at Goddard Space Flight Center. Twelve Microtops, two SIMBADs and one PREDE Mark II sun photometer were deployed in several cruises between 1998 and 1999. The data collected by the Project is displayed for this period in Chapter II, Figure 2.

Sun Photometer Calibration: Non-Polarized Channels

The calibration of the sun photometers was described in McClain and Fargion (1999). Details on operating the sunphotometer instrument, calibration and the theoretical principles are posted at http://simbios.gsfc.nasa.gov/Sunphoto meters/calibration.html.

This year the twelve Microtops, two SIMBAD and two PREDE sun photometers of the SIMBIOS instrument pool, were calibrated after each and every cruise deployment. The in-house processing code was updated. This code allows inter-calibration with a CIMEL as the reference instrument based on the time to time voltage ratios. Some of the updated modifications allow for the avoidance of TOA or V0 computation for an air mass higher than 3. In this way V0 is not calculated for low sun zenith angles due to possible unstable atmosphere. The first and last calibration for the Microtops #3773, the SIMBAD #972306 and the PREDE #PS090063 are shown in Table 9.

With the V0 are displayed the standard deviation ΔV0 corresponding to the atmosphere variation during the calibration or due to the time difference with the CIMEL reference. Clear days are selected as "calibration" days if they have a variation ΔV0/V0 less than 1% (Table 9). We have found that the optics and filters of the instrument can change quite a lot after one year of use. In the case of the PREDE #PS090064 the variations could reach 5%. Several factors lead to the degradation of the calibration and the effect strongly depends of the wavelength. Thus the Project recommends a frequent schedule of calibrations for each field experiment in order to retrieve the most accurate AOT.

Sun Photometer Calibration: Polarized Channels

The calibration of the polarized version of the CIMEL sun photometers was described in McClain and Fargion (1999).

The first polarized sun photometer (#191) of the SIMBIOS Project was deployed in Erdemli (Turkey). Table 10 displays the calibration results: slope (δp), intercept (P_0) and linear squared fit applied to the degree of polarization given by the device and plotted versus the degree of polarization measured by the polarized CIMEL #191.

Table 10

Instrument #	δp	P_o	R^2
191	1.0676	-0.0203	1

Above Water Radiometer Calibration

The SIMBAD radiometer is also an above water radiometer (in addition to being a sun photometer). The optics and filters are the same but the electronic gain is different. The calibration is performed using a 6" integrated sphere at GSFC. Two SIMBAD instruments were calibrated on August 12, 1999. Table 11 shows the reflectance per count obtained using two lamps or six lamps.

Data Format and Processing Protocol

A proposal for a standardized data format was presented and agreed to at the 3rd SIMBIOS team meeting. The processing protocol retrieves spectral AOT from the raw direct solar measurements and computes the water vapor amount and the AOT spectral dependence. The processing code generates an output file that will be stored in the SeaBASS database. The data processing was described in McClain and Fargion (1999).

Table 9. Top of Atmosphere (TOA) signals and standard deviations for the sun photometers determined by transfer calibration from a calibrated CIMEL at GSFC between August 1998 and September 1999.

Microtops #3773	**440nm**	**500nm**	**675nm**	**870nm**	**940nm**
08-20-1998	1238±7	988±4	1219±5	825±3	1428±8
06-09-1999	1239±5	986±4	1200±1	825±1	1402±9
SIMBAD #97206	**443nm**	**490nm**	**560nm**	**670nm**	**870nm**
08-20-1998	389688±1641	475830±922	403397±954	421155±2357	305400±314
09-23-1999	379513±2390	467164±818	392986±871	415745±932	300079±2204
PREDE #PS090064	**440nm**	**500nm**	**675nm**	**870nm**	**940nm**
10-16-1998	1.36±0.003E-04	2.79±0.02E-04	3.52±0.02E-04	2.77±0.01E-04	2.61±0.01E-04
09-23-1999	1.30±0.002E-04	2.72±0.005E-04	3.40±0.01E-04	2.67±0.004E-04	2.67±0.02E-04

Table 11. Calibration coefficient for SIMBAD # 06 and 09 on August 12, 1999.

SIMBAD #972306	**Lamps**	**440nm**	**490nm**	**560nm**	**675nm**	**870nm**
06	6	3.818±0.006	2.192±0.0015	2.432±0.002	4.229±0.002	8.029±0.002
	2	3.806±0.001	2.159±0.002	2.419±0.002	4.220±0.001	8.035±0.002
09	6	4.931±0.003	2.425±0.002	2.695±0.003	4.312±0.004	8.277±0.0025
	2	4.902±0.003	2.390±0.001	2.686±0.0005	4.303±0.0005	8.293±0.001

Calibration Round Robin

NASA personnel carried the SeaWiFS Transfer Radiometer SXR-II S/N-04 to JPL in July 1999 and took calibration measurements of the AVIRIS calibration lamp and plaque. Upon return the SXR-II was tested against the GSFC large integration sphere and two of its channels (1 and 6) were found to have significantly changed since the last calibration in April. Final analysis of the AVIRIS data is delayed until the problem with the SXR-II is resolved. Tests comparing the first SXR S/N-01 and the SXR-II S/N-04 are currently in progress.

Yankee Environmental SQM

NASA personnel tested the Yankee Environmental SeaWiFS Quality Monitor (SQM) in a mock sea cruise for over a month using the SXR-II as the reference instrument. This field light source met its specifications for stability in laboratory conditions. The high light setting may be brighter than desired for calibration of most underwater radiometers. A final report awaits resolution of the SXR-II problem.

3.5 SIMBIOS COMPUTING RESOURSES

The SIMBIOS computing facility contains a variety of equipment types (Figure 5). The main goal of the facility is to provide computational support for the following areas:

- routine bulk data processing,
- large scale analysis and match-up between sensors,
- focused analysis on data subsets, and
- storage of large sensor data sets.

Co-location of the facility with the SeaWiFS Project continues to benefit the Project by making available other resources such as high-quality color printers, network equipment, and other supporting equipment. Large-scale tasks such as bulk data processing and large-scale analysis tasks are performed by two Silicon Graphics (SGI) Origin 2000 servers. Each system has 6 processors and approximately 3 gigabytes (GB) of RAM. The influx of large data sets for additional sensors requires increasing amounts of disk space, especially when performing comparative analysis. The Data Processing server has 90 GB of disk space and the Data Analysis server has 374 GB of total disk space. Long term storage of data sets is handled by the 6 TB tape library attached to the Data Analysis server. Silicon Graphics O2 workstations continue to be the system of choice for software development and focused analysis tasks. The sizing of the workstations varies with the task requirements.

SIMBIOS is connected to the Internet via a 100-megabit link, making network transfer of large data sets more feasible. Internal connections are also 100 megabit for rapid transfer of data between the servers and the workstations. Data ingest for SIMBIOS is also done via removable media including CD-ROM, 8 millimeter tape, 4 millimeter (DAT) tape, and DLT media up through DLT 7000. Off-line media storage space is shared with the SeaWiFS Project.

The scope of the group's efforts expanded over the past year, including the addition of the POLDER dataset, installation of a ground station at Wallops Flight Facility to receive MOS data downlinks, and routine processing of MOS data at the Greenbelt site. In support of these efforts, the facility has experienced moderate growth over the past year. A workstation was added to the Project, as well as additional local storage for the workstations and high capacity tape drives for local backup and archival capability.

Each server was upgraded with a FibreChannel interface. The new interface will allow the servers to participate in the SeaWiFS Project Storage Area Network (SAN). Connection to the SeaWiFS SAN will allow the SIMBIOS team to access SeaWiFS data products and ancillary data at a rate of up to 1 gigabit per second. Participation in the SeaWiFS high availability server cluster via Silicon Graphics (SGI) FailSafe software is planned for next fiscal year. Membership in the cluster will give the Project the capability of automatic failover of services from one server to another in the event of a server crash, maximizing resource availability.

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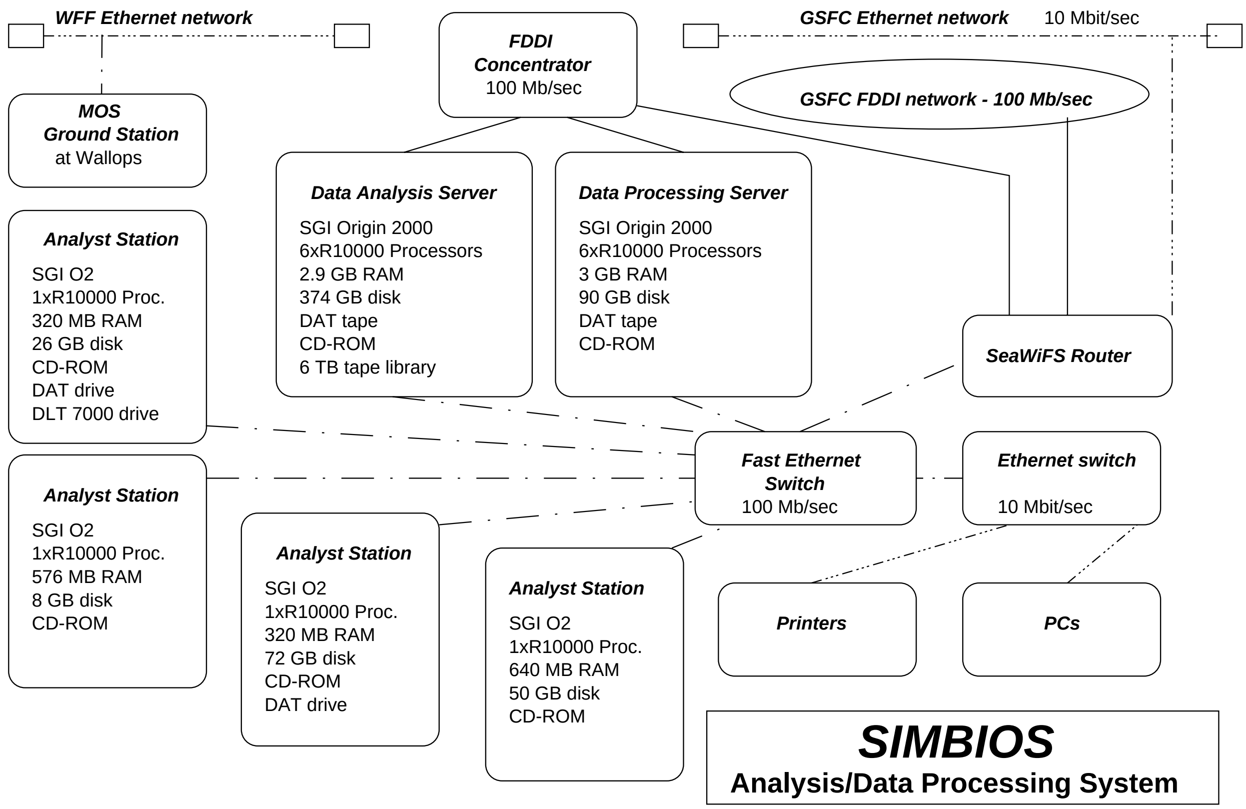

Figure 5. The SIMBIOS computing facility and equipment types.

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Chapter 4

Validation of Surface Bio-Optical Properties in the Gulf of Maine as a Means for Improving Satellite Primary Production Estimates

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4.1 INTRODUCTION

One of the greatest challenges in providing sea-truth data for various ocean color sensors is climatology. This is particularly true in the Gulf of Maine since it is cloudy and foggy more than it is clear; climatology studies show an average of about 1 in 4 days of clear skies and that clear days are slightly more frequent in the late summer and early fall. Our strategy has been to use a ship of opportunity where one has a choice of sampling days. This provides much better flexibility to sample during clear periods with good satellite coverage. Our SIMBIOS contract is to use the M/S Scotian Prince ferry as a ship of opportunity, running between Portland, Maine and Yarmouth (NS). Measurements include continuous, surface, along-track fluorescence, two independent measures of backscattering, total light scattering, absorption, beam attenuation, above-water remote sensing reflectance, calcite-dependent light scattering, temperature, and salinity. Expendable Bathythermograph (XBT) drops allow acquisition of vertical temperature information, useful for defining isopycnal slope, which affects primary production. These data are comparable to a previous program from early 1982, where a Ship Of Opportunity Program (SOOP) was run on the truck ferry, M/V Marine Evangeline, which ran along the same transect (Boyd, 1985). These surface data were combined with satellite-derived sea surface temperature fields to examine the Maine coastal current (Bisagni et al., 1996). Unfortunately, this program stopped in 1982. The ongoing SIMBIOS results will dovetail nicely with the previous work (which also had CZCS coverage) for studying long-term changes in the Gulf of Maine hydrography, bio-optics, and biogeochemistry.

The Gulf of Maine is an ideal site for such a SOOP program. It is a semi-enclosed basin with an average depth of ~150m. Isopycnal slope (and productivity) appears to be strongly topographically driven, with the water column becoming isothermal at the 60m isobath around Georges Bank. Integrated productivity in the region varies seasonally by a factor of 45x (0.1 to 4.4 gC m^{-2} d^{-1}; O'Reilly, 1987), greater than in the California Current (15x variability; 0.2-3.0 gC m^{-2} d^{-1}). The Marine resources Monitoring Assessment and Prediction (MARMAP) data base along the eastern seaboard of the U.S. has been the equivalent to the California Cooperative Oceanic Fisheries Investigation (CalCOFI) data base (west coast) in terms of its sheer size and length of sampling. Unfortunately, MARMAP does not maintain data collection of pigment or inherent optical properties, thus this SIMBIOS Project provides unique data for the region.

4.2 RESEARCH ACTIVITIES

In this SIMBIOS contract, we have completed the following during the second year:

- May-October '99: Twenty cruises aboard M/S Scotia Prince completed between Yarmouth, Nova Scotia and Portland, ME, as required by our contract.
- One 8 day cruise aboard the R/V Linke in the Gulf of Maine.
- Initial data submissions to be followed by more results as discrete analyses of POC/PON, PIC, and cell counts are completed. The final cruise of this year was completed 10/16/99; the following raw data are being worked up for distribution to the NASA SIMBIOS Project as soon as all post cruise calibrations are finished (at ~0.5 km resolution).

Our field measurements include surface flow-through bio-optics, and above-water optical measurements, hydrographic measurements, discrete samples for calibration.

Flow-Through System

Our flow-through system is equipped with several sensors, with data integration and logging performed by National Instruments LabView software run on two pentium processor computers. The system receives time and ship geographic position continually from a Garmin 220 global positioning system, the antenna of which is mounted outside of the ship, off the stern. Seawater first enters a vortex debubbler (SUNY UDB1), then into a 4 foot tall debubbler, equipped with a 1mm screen to keep the largest zooplankton and salps out of the optical instrumentation, then the flow enters an InterOcean thermal conductivity sensor (see below). Following the temperature/salinity measurements, the flow bifurcates into a Turner 10au fluorometer for monitoring underway fluorescence and a tertiary debubbler prior to measurments of light scattering. The fluorometer is equipped with a daylight white F4T5D lamp, blue-violet excitation filter (peak excitation 438nm with half band pass of 380-500nm) and red emission filter (high pass interference filter passing all wavelengths >665nm. Due to fast growing bio-fouling organisms in the Gulf of Maine, the fluorometer is cleaned regularly.

As for the light scattering measurements, the water passes from the tertiary debubbler, via peristaltic pump, into a Wyatt Technologies Model Dawn laser light scattering photometer at a flow-rate of ~9 ml min^{-1}. The photometer operates with an 10 mW Argon ion laser (514 nm) which is directed into the center of a flow-through cuvette, whereupon, seawater is viewed by 15 photodiodes arranged between 21.54^o and 158.14^o. Included in the 18 detectors are two photodiodes for laser power monitoring (one prior to passage through the viewing cuvette, and one post). The laser beam has a $1/e^2$ gaussian beam profile radius of 0.39 mm which makes the effective viewing volume of the light-scattering photometer 0.25 ml. All detectors are scanned at rates up to 400 HZ. In fact, for most flow-through applications, we slow the scanning rate to 200 HZ in order to not sample the same seawater volume twice.

The LabView software, which controls the Wyatt light scattering photometer, can be programmed to calculate averages and standard deviations of seawater volume scattering data to any desired time period. For field applications, we typically average the data for about 50 seconds (which then represents an effective volume viewed of 9ml). The statistics are highly informative for understanding the variance of the optics due to particle types. Because of our interest in calcite, we also measure seawater pH to verify that the pH is sufficiently high such that calcite cannot dissolve. Following the first 50s of measurements done on each raw seawater sample, another peristaltic pump is activated by the LabView control system, which injects 0.5% glacial acetic acid into the flow stream, and mixes it by running it through a Teflon mixing column. This drops the pH to about 5.8 to dissolve any calcium carbonate. Once the pH stabilizes at the more acidic value, volume scattering is re-sampled, and average backscattering re-calculated. The difference between the raw and acidified backscattering values represents the "acid-labile" backscattering. Using field measurements, we have calibrated this acid-labile backscattering to atomic absorption estimates of suspended calcite concentration (r^2=0.83). The time for a complete acidification cycle can be adjusted, but we have preferred to collect average backscattering values such that one complete raw/acidification cycle takes 4 minutes. This means that during any passage, we would be logging a data point about once every 2000 meters. For sea-truth measurements, this is adequate since typically a 3 pixel by 3 pixel area from SeaWiFS is viewed (10.9 km^2).

Water next flows into an AC-9 (Wet Labs, Oregon). This instrument simultaneously measures spectral beam attenuation and spectral absorption at nine wavelengths using a dual path optical scheme. Fundamentally, this consists of two pressure housings, with the absorption and attenuation beam paths in between. The absorption light path passes through a reflective tube while the attenuation light path passes through a non-reflective tube. A rotating filter wheel provides the 9 different wavelengths, between 412-715 nm. The accuracy of the attenuation and absorption measurements are +0.005m-1 with linearity error of +0.1%. With access to attenuation (c) and absorption (a) information, we calculate b (= c - a).

The last in-flow measurement is done by the Hobie Labs Hydroscat-2. This instrument is set to view an enclosed, 20l, sand-blasted, stainless steel containor (painted flat black within). This vessel has a “sweepable” brush inside to remove bubbles from the viewing window. The instrument measures volume scattering at 142^o, and extrapolates to backscattering using an assumed volume scattering function. It makes measurements at 470 and 676nm plus chlorophyll fluorescence.

Above-water optical measurements

Water-leaving radiance and downwelling irradiance (for calculating remote sensing reflectance) is measured from the Scotia Prince ferry using a Satlantic SeaWiFS Aircraft Simulator (SAS). This consists of a radiance sensor mounted on the port bridge wing, and an irradiance sensor mounted on the compass deck, aft of the bridge, as far from any potentially shading structures as possible. The radiance detector views the water forward of any shipwake, at 40^o from nadir. The distance of the sensor to the water is ~30m. The direction of the sensor is changed periodically, as the sun's position changed, so, when possible, the sensor is viewing the water 90^o from the sun's azimuth, free from any sun glint. Protocols for operation and plaque calibration were made according to SeaWiFS technical memorandum #25 and the NASA SeaWiFS SEABOAR Experiment. Data in real time are filtered for sun glint and sea foam by eliminating data with irradiance reflectance >15%. Between the hours of 1000 and 1400, all data are logged at 10Hz. Outside of this time, averages of the glint and foam filtered data are logged every 16 seconds. In addition, we also take Microtops sun photometer measurements when the sun was visible, and the data are offloaded for distribution to SeaBASS.

Hydrographic samples

Temperature and salinity of the surface flow stream is measured with an InterOcean thermal conductivity sensor. It measures salinity with an accuracy of +0.05 Practical Salinity Units and temperature to an accuracy of +0.1^{o}C. Hourly XBT profiles are used to construct one temperature section per trip from which we can calculate isotherm slope (strongly related to gradients in integrated primary production and chlorophyll).

Discrete Samples

Every hour a water sample was taken for suspended $CaCO_3$, particulate organic carbon, chlorophyll, and microscope counts. The technique of Fernandez et al. (1993) was used to measure $CaCO_3$ concentrations. Briefly, 500 ml samples were filtered onto 0.4um pore-size polycarbonate filters, and rinsing first with filtered sea water, then borate buffer (pH=8) to remove seawater calcium chloride. Filters were placed in trace metal free centrifuge tubes with 5 ml 0.5% Optima grade Nitric acid (this will also drive off any 14C activity of the coccoliths). Next, the Ca concentration was measured using atomic absorption spectrometry.

Chlorophyll and particulate organic carbon were measured according to the JGOFS protocols (JGOFS, 1996) H/A filters. A 60ml water sample was taken for coccolithophore and coccolith counts. Brown glass bottles are rinsed 3X with each sample prior to final filling. Samples are preserved with 4% buffered formalin and, after the cruise, settled in 10 ml counting chambers prior to counting detached coccoliths and plated coccolithophores (Utermohl, 1931, 1958). Microscope enumeration of detached coccoliths and plated coccolithophores is made using an Olympus BH2 microscope with polarization optics which allows quantification of birefringent $CaCO_3$ coccoliths, and coccospheres. For statistical reasons, 200 coccoliths or cells were counted from each sample, when available.

All of our data from the previous year have been released to SeaBASS. The data from the 1999 ferry trips are being finalized now, with final checks of vicarious calibrations. They will be released to SeaBASS shortly. The continuous underway data produced in this work is shown below:

- latitude, longitude, time;
- upwelling radiance (uW cm^{-2} nm^{-1} sr^{-1}; at 412, 443, 490, 510, 555, 670 and 685 nm);
- downwelling irradiance (uW cm^{-2} nm^{-1}; at 412, 443, 490, 510, 555, 670 and 685 nm);
- fluorescence (volts) calibrated to hourly discrete chlorophyll samples;
- backscattering (m^{-1}; at 470, 514 and 676 nm; total and acid labile backscattering);
- absorption (m^{-1}; at 412, 440, 488, 510, 555, 630, 650, 676 and 715 nm); and
- attenuation (m^{-1}; at 412, 440, 488, 510, 555, 630, 650, 676 and 715 nm).

4.3 WORK PLAN

Our contract calls for 10 ferry trips next year. We anticipate no problem completing these trips. Moreover, we anticipate no problems in timely data work-up and submission as our processing software is now streamlined for post-cruise calibrations. We will be shipping the Microtops radiometer back to Goddard next week.

ACKNOWLEDGEMENTS

The personnel of the Prince of Fundy, Ltd ferry company have been superb to work with; none of this work could have been accomplished without their exemplary "can-do" attitude. They have offered us the opportunity to install a stainless steel pipe off of their sea chest, so we will not have to install our sampling arm (which has performed well for 30 trips, or ~5200 miles with only one failure). This will streamline our operation significantly in coming years.

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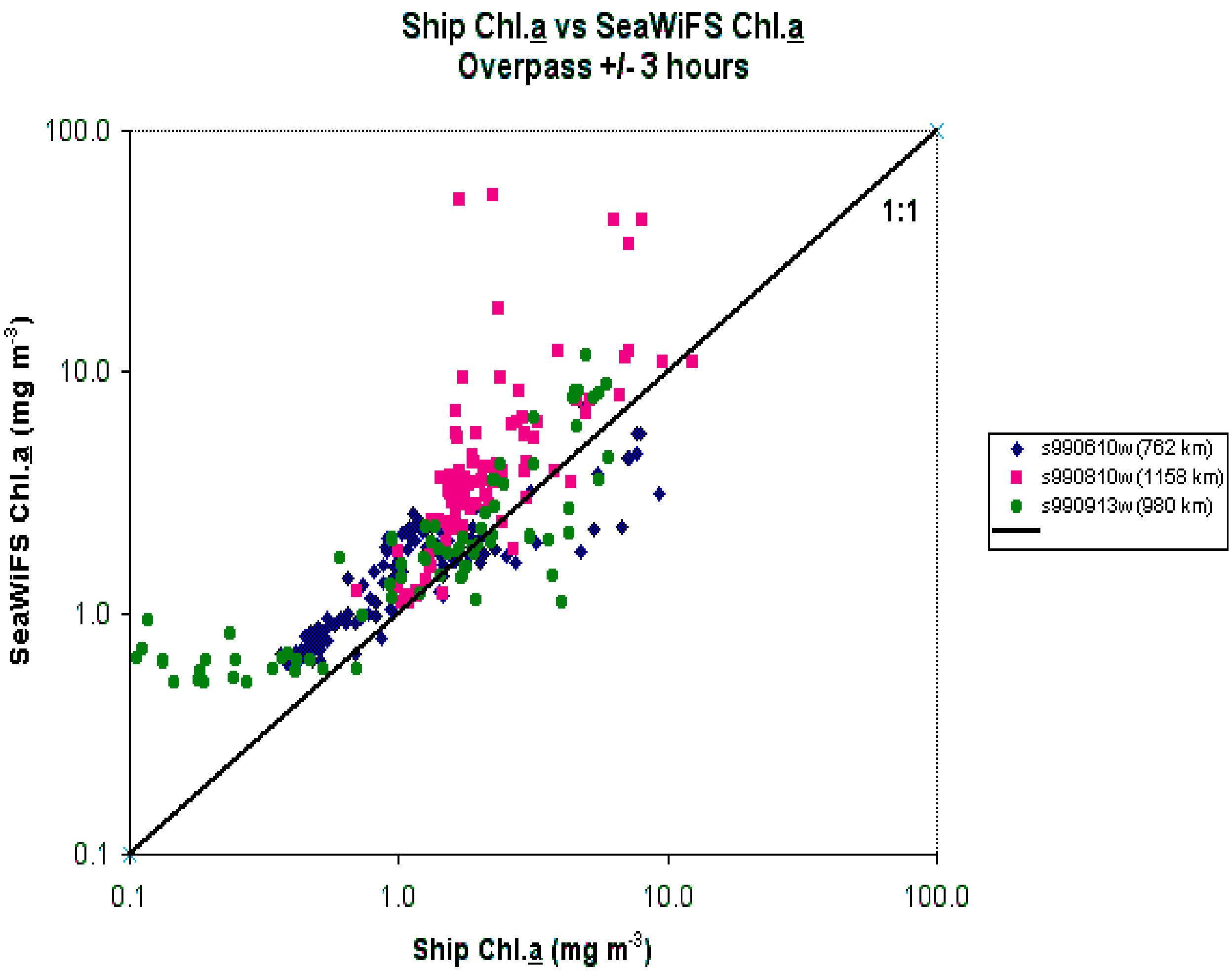

Figure 1. Plot of satellite chlorophyll a vs. ship-measured chlorophyll a for three 1999 SIMBIOS cruises in the Gulf of Maine with clear sky coverage, spread over the sampling 1999 period. Both Case I and particle-laden Case II waters are included in this comparison. Note, that the fit of the 1:1 line is best for the images in which the sensor was closest to nadir viewing (i.e. the sensor was looking through the least atmosphere). Our work in 1998 and 1999 has also shown that case II waters penetrate much farther into the Gulf of Maine than previously thought, causing significant errors in the estimated chlorophyll.

Table 1. List of Cruises and deliverables for FY'99 .

Cruise Location	Cruise Name	Date	Fluorescence	Backscattering	Calcite-dependent backscattering	Absorption	Scattering	Temperature and salinity	MicroTops sun photometer	Stations	Suspended calcite	Chlorophyll	POC/PON	Coccolith and Coccolithoph. Con.	Discrete cell count	L_w and E_d (Satlantic SAS)
Portland, Maine and Yarmouth (NV)	Ferry 1	22-23 May 1999				√	√	√	√	9	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 2	4-5 June 1999	√	√	√	√	√	√	√	9	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 3	5-6 June 1999	√	√	√	√	√	√	√	8	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 4	9-10 June 1999	√	√	√	√	√	√	√	9	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 5	18-19 June 1999	√	√	√	√	√	√	√	10	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 6	19-20 June 1999	√	√	√	√	√	√	√	10	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 7	20-21 June 1999	√	√	√	√	√	√	√	9	√	√	√	√	√	√
Edward Link, gulf of Maine And Georges Bank	8d	28 June-5 July 1999	√	√	√	√	√	√	√	20	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 8	1-2 Aug. 1999	√	√	√	√	√	√	√	8	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 9	9-10 Aug. 1999	√	√	√	√	√	√	√	9	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 10	22-23 Aug. 1999	√	√	√	√	√	√	√	9	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 11	23-24 Aug. 1999	√	√	√	√	√	√	√	8	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 12	11-12 Sept. 1999	√	√	√	√	√	√	√	9	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 13	12-13 Sept. 1999	√	√	√	√	√	√	√	9	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 14	13-14 Sept. 1999	√	√	√	√	√	√	√	8	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 15	22-23 Sept. 1999	√	√	√	√	√	√	√	9	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 16	23-24 Sept. 1999	√	√	√	√	√	√	√	10	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 17	24-25 Sept. 1999	√	√	√	√	√	√	√	9	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 18	7-8 Oct. 1999	√	√	√	√	√	√	√	8	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 19	11-12 Oct. 1999	√	√	√	√	√	√	√	9	√	√	√	√	√	√
Portland, Maine and Yarmouth (NV)	Ferry 20	15-16 Oct. 1999	√	√	√	√	√	√	√	8	√	√	√	√	√	√
Total Stations										**197**						

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Chapter 5

OCTS and SeaWiFS Bio-Optical Algorithm and Product Validation and Intercomparison in U.S. Coastal Waters

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5.1 INTRODUCTION

Monitoring the health of U.S. coastal waters is an important goal of the National Oceanic and Atmospheric Administration (NOAA). Satellite sensors, particularly ocean color sensors, provide the type of measurements and synoptic coverage that can be used to operationally observe and examine the quality of U.S. coastal waters. However, the algorithms used to derive useful geophysical parameters from satellite ocean color data, such as chlorophyll biomass, in coastal waters require development and validation. The majority of available bio-optical algorithms have been derived using assumptions valid only for the open ocean. In the open ocean, it is assumed that other optically active constituents, such as colored dissolved organic matter (CDOM), vary proportionately with chlorophyll concentration. This assumption is generally not valid in coastal waters where other optically active components and pigment concentrations do not covary. In addition, backscattering due to suspended sediments and the influence of the bottom must be taken into account. In this Technical Memorandum, we evaluate the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) chlorophyll a algorithm, OC2, for the South Atlantic Bight (SAB). The SAB consists of a variety of environments including coastal and continental shelf regimes, Gulf Stream waters, and the Sargasso Sea. The biological and optical characteristics of the region is complicated by temporal and spatial variability in phytoplankton composition, primary productivity, and the concentrations of CDOM and suspended sediment. As such, the SAB is an ideal location to test the robustness of existing algorithms for coastal use and the development of new ones.

5.2 RESEARCH ACTIVITIES

Bio-optical measurements were collected at 80 stations during eight cruises (Table 1) conducted in the South Atlantic Bight in order to evaluate and validate the SeaWiFS OC2 (v2) chlorophyll concentration algorithm. The cruises covered a range of seasons (early spring to late fall) and water types (shallow, turbid Pamlico Sound to deep, clear Sargasso Sea) (Figure 1). Optical instruments measured surface spectral downwelling irradiance, in-water spectral downwelling irradiance, and upwelling radiance. Although sampling strategies and instrument packages varied between cruises, a Biospherical Instruments Profiling Reflectance Radiometer (PRR) cage was typically deployed off the stern of the vessel in conjunction with a reference surface unit with matching channels. The PRR optical data were processed using the Bermuda Bio-Optics Project (BBOP) processing software (Siegel et al, 1995). Optical profiles that exhibited evidence of surface perturbations and the effects of passing clouds were excluded from analysis. Deployment of additional optical instruments and the collection of water samples enabled various parameters to be measured, including chlorophyll and pigment concentrations, total suspended solids concentration, and the absorption coefficients of CDOM and particles. Though chlorophyll and pigments concentrations were determined using both fluorometric and High-Pressure Liquid Chromatography (HPLC) techniques, only those estimated using fluorometry were employed in the present analysis. The ratio of the above-water downwelling irradiance to the upwelling radiance propagated through the air-water interface was used to calculate the remote-sensing reflectance, $R_{rs}(\lambda)$, at each station following the technique of O'Reilly et al. (1998).

These *in situ* estimates of $R_{rs}(\lambda)$ were fed into the SeaWiFS OC2 (v2) algorithm to calculate chlorophyll-*a* concentration, OC2, where:

$$OC2 = -0.0929 + 10^{(0.2974 - 2.2429 X + 0.8358 X^2 - 0.00771 X^3)}$$

and $X = \log_{10} \frac{R_{rs}(490)}{R_{rs}(555)}$

To evaluate the geographical and temporal variation in OC2 performance, a ratio (OC2PI) was calculated as the ratio of OC2-derived chlorophyll concentration to the fluorometrically determined chlorophyll concentration (ChlF). An OC2PI value of less/greater than one indicated underestimation/overestimation of chlorophyll by OC2. Refer to Subramaniam et al. (1997a, 1997b, 1997c, 1998, 1999) and Tester et al. (1995) for details on sampling methodology and processing.

5.3 RESEARCH RESULTS

In situ chlorophyll (ChlF) values ranged from 0.16 to 5.20 µg/L with mean value of 1.51 µg/L and a median value of 1.03 µg/L. While many of the high chlorophyll stations lay along the coast and the low chlorophyll (0-1 µg/L) stations were situated along the outer shelf, no distinct spatial pattern was discernible in the *in situ* chlorophyll concentrations. The absence of any obvious pattern in chlorophyll concentration is likely due to the temporal span over which the data were collected and the dynamic nature of phytoplankton biomass in the SAB. For example, surface chlorophyll concentration at a station located at the shelf break in September 1997 was 0.33 µg/L while a station occupied at the same position in November 1998 was 1.11 µg/L. This large variation could be attributable to interactions of the Gulf Stream with the shelf waters (McClain et al. 1984). Mapping the values of OC2PI from all cruises revealed no spatial pattern in the algorithm performance. No correlation between OC2PI and the measured chlorophyll was observed, suggesting that small changes in the coefficients or offsets would not substantially improve the algorithm. Nor was there a correlation between total suspended material and ChlF, implying that in-water scattering was not likely the cause of algorithm failure (data not shown). A large component of the variability in the performance of OC2 was explained by separating the data seasonally into “spring”, i.e. February-May, and “non-spring”, i.e. June-January (Figure 2). During non-spring months, OC2 performance was high (Table 2). During spring months, it was low with a seasonal average of 2.13, indicating an overestimation of chlorophyll concentration using OC2. The spatial distribution and number of stations in the spring and non-spring periods were similar, eliminating geographic bias. The bulk of the variability was attributable to measurements collected at coastal stations sampled during periods of high river run-off. The high CDOM content during months of elevated river discharge yielded low remote-sensing reflectances at 490 nm, Rrs490, independent of the chlorophyll content of these waters. We evaluated the performance of the default SeaWiFS chlorophyll-a algorithm, OC2 (v2), in the South Atlantic Bight by comparing radiometrically-derived chlorophyll concentrations and measured chlorophyll concentrations. The results indicate that biogeographical provinces alone do not improve OC2 performance in the SAB. Seasonal variation must be taken into account. The high variability observed in spring is likely due to the presence of high concentrations of CDOM in shelf waters. For an algorithm to accurately estimate chlorophyll concentration in the SAB, it must explicitly include CDOM as a factor.

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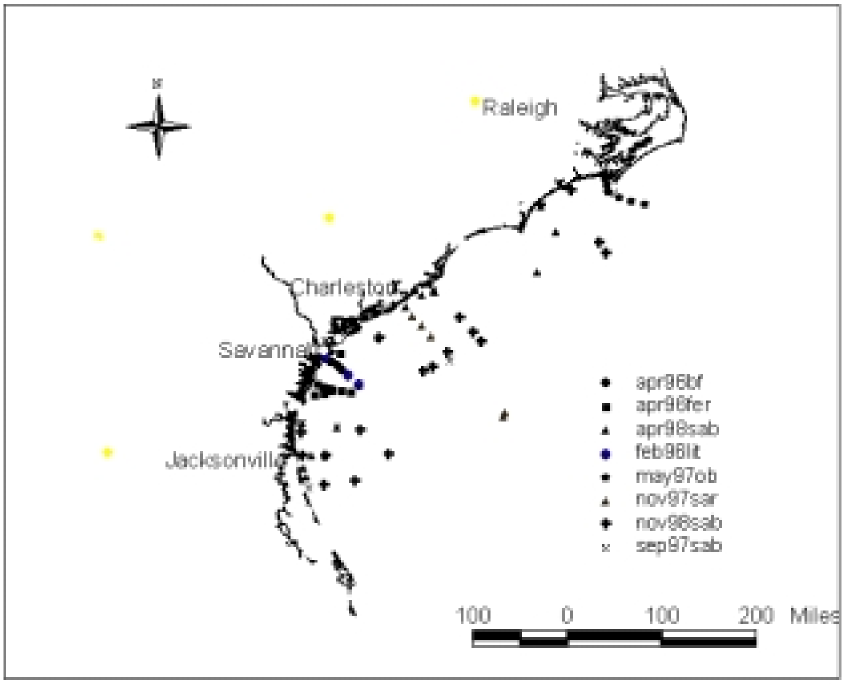

Figure 1. Location of Stations in the South Atlantic Bight.

Table 1. Summary of cruise names, location, dates and sampling platforms used.

Cruise	Dates	Number of stations	Location	Vessel
FEB96LIT	2/22-23/96	3	Georgia Bight	*R/V* Blue Fin
APR96BF	4/3-5/96	2	Georgia Bight	*R/V* Blue Fin
APR96FER	4/22-25/96	12	Georgia Bight	*R/V* Blue Fin
MAY97OB	5/5/97 and 5/8/97	5 and 4	Onslow Bay NC and Pamlico Sound NC	*R/V* Onslow Bay *R/V* Chipman
SEP97SAB	9/5-24/97	8	South Atlantic Bight	R/V Cape Hatteras
NOV97SAR	11/4-5/97	5	Sargasso Sea	*R/V* Palmetto
APR98SAB	4/5-27/98	17	South Atlantic Bight	*R/V* Cape Hatteras
NOV98SAB	10/27/98-11/23/98	24	South Atlantic Bight	*R/V* Cape Hatteras

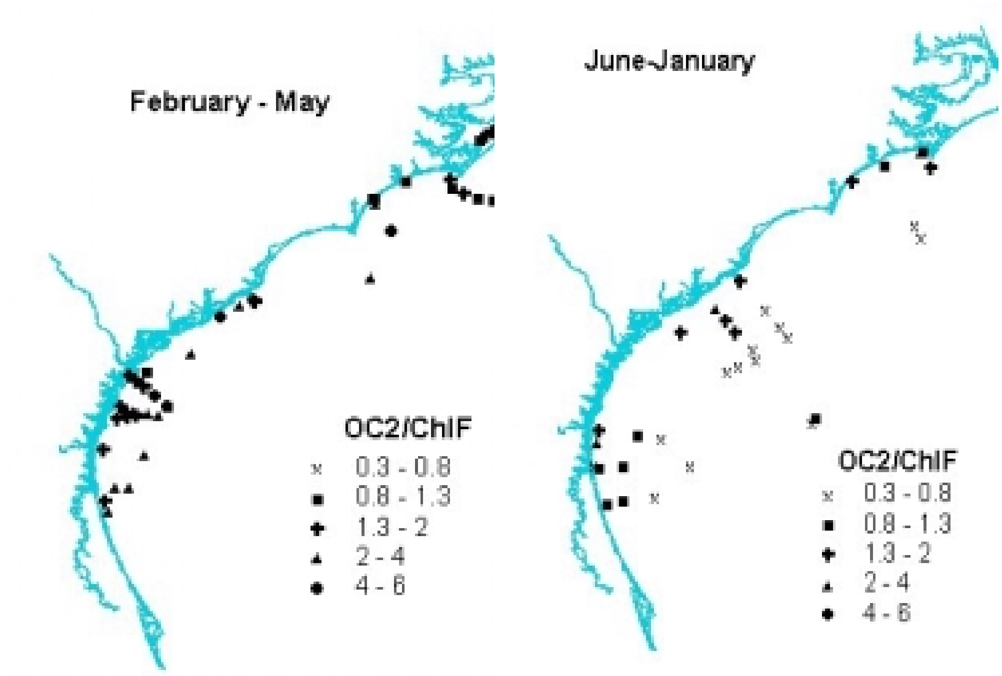

Figure 2. Spatial distribution of OC2PI for "spring" (Left) and "non-spring" (Right)

Table 2. OC2PI by season and cruise

"Spring" Cruises	Average OC2PI	"Non-spring" Cruises	Average OC2PI
APR98SAB	2.52	SEP97SAB	1.19
APR96FER,BF	1.83	NOV97SAR	1.41
FEBLIT96	3.90	NOV98SAB	0.97
MAY97OB	1.30		
Seasonal average	2.13	Seasonal average	1.08
Total stations	43	Total stations	37

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Chapter 6

Validation of Ocean Color Satellite Data Products in Under Sampled Marine Areas

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6.1 INTRODUCTION

During the period September 1998 to September 1999, we under took two cruises to fulfill our obligations to the SIMBIOS program – Indian Ocean Experiment (INDOEX) and Searcher99. The INDOEX cruise was coordinated with the Scripps Institution of Oceanography group lead by Dr. Flatau. Dr. Flatau has been charged with the responsibility of assembling all the data collected during this field campaign to submit a comprehensive data report to the SIMBIOS Project. The Searcher99 cruise was conducted in July-August 1999 in the Baltic Sea and is described below. We also worked on developing and implementing a global Trichodesmium algorithm described below.

6.2 RESEARCH ACTIVITIES

Field Campaign

The R/V Ronald H. Brown left Mauritius on Leg 1 of the INDOEX cruise on the 22 February 1999 and arrived in Male, Maldives on 1 March 1999.

Leg 2 of the cruise extended from 4 March to 23 March 1999 and Leg 3 from 26 March to 30 March 1999 (Figure 1, Table 1). Stations were occupied almost everyday. Each station consisted of a CTD cast for pigments (fluorometric and HPLC), absorption – particulate and dissolved, primary production measurements; an optics cast for MER measurements of downwelling irradiance, upwelling radiance and irradiance, AC9 measurements of total absorption, Hydroscat measurements of spectral backscatter, FRRF measurements of variable fluorescence; and a SPMR cast for downwelling irradiance and upwelling radiance. Ten liters of water (1 niskin bottle) were filtered for Trichodesmium counts at select stations. On clear days, the SIMBAD and a Spectrix above-water reflectance radiometer was used to measure remote-sensing reflectance. The counts data showed that there was the beginning of a bloom when we headed north (stations 36-39), but we did not find any Trichodesmium after 3 days when we headed south. Unfortunately, there were no clear SeaWiFS images of this region during this time. The SPMR free falling spectroradiometer was used on all stations in legs 2 and 3. Above the surface downwelling irradiance and upwelling radiance 75 cm below the surface was measured using the floating reference SMSR.

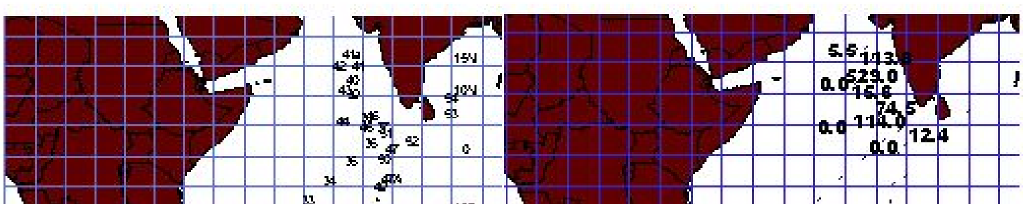

Figure 1. INDOEX Station Locations (Stations 23-30 Leg2 AEROSOLS, 31-36 Leg 1, 37-50 Leg2, 51-54 Leg 3). Surface Trichodesmium colonies/L from select stations.

Water column profiles of downwelling irradiance and upwelling radiance were measured using the free-falling SPMR. The diffuse attenuation coefficient was calculated from the profile data and was then used to propagate the upwelling radiance from 75 cm below the surface to water leaving radiance. This water leaving radiance was then used with the SMSR downwelling irradiance to calculate the normalized water leaving radiance (Figure 2). The second cruise we participated in was in the Baltic Sea with scientists from the Botany Department and the Department of Natural Geography at Stockholm University. On these cruises we made measurements of total and organism specific absorption spectra, absorption due to detrital material, absorption due to CDOM, total suspended material. Surface water samples were also taken for pigment concentrations using HPLC techniques and chlorophyll a using the spectrophotometric method. We measured the above-water remote sensing reflectance using a hyperspectral spectrometer and the aerosol optical thickness using a sunphotometer. We also made *in situ* profiles of the light field at 13 wavelengths using the Satlantic SPMR free-falling spectroradiometer with a floating surface reference. A total of nine stations were occupied between 27 July and 18 August 1999. Eight of the nine days were clear and had good satellite images that showed wide spread blooms in central and southern Baltic proper. We have processed most of the *in situ* data and are in the process of matching them to the satellite-derived data. Initial analyses of the above-water hyperspectral reflectance data suggest that the optical model derived for Trichodesmium is applicable to the Baltic cyanobacterial blooms. The biggest difference we have noticed is that the Nodularia blooms are extremely rich in carotenoids, increasing the absorption around 480 nm. The total absorption spectra in a bloom show a shoulder at spectra (Figure 3). The remote sensing reflectance spectra show that the blooms have a high backscatter.

Development of A Trichodesmium Chlorophyll Specific Algorithm

We have not yet been successful in inverting the Trichodesmium optical model to derive an algorithm for detecting this organism. There are probably many factors that contribute to the problem including difficulties with atmospheric correction in the presence of a highly scattering bloom. While we are still moving forward with attempts to invert our model, we also proceeded on another approach to derive a Trichodesmium classification based on training pixels from Trichodesmium rich waters. We applied this classification on two years of 9 km, 8-day binned Level 3 SeaWiFS data to map Trichodesmium globally. The map thus derived showed Trichodesmium in regions and seasons where they have been historically noted. But we are not quite satisfied with the robustness of this approach and we will continue to improve on our techniques as we acquire more SeaWiFS imagery with concurrent ground truth. We are also working on applying the empirically derived algorithm on daily 1-km resolution HRPT data from north-western Australia and the Gulf of Mexico,

6.3 WORK PLAN

We will participate in the Yellow Trich Road Cruise off northern Australia in October-November 1999. This cruise is scheduled to occur at a time when Trichodesmium blooms are most common in those waters and we look forward to making significant progress on the algorithm with this data. Initial analysis of the Baltic SeaWiFS images has given us a better understanding of patchy surface phenomenon and we intend to return to the Baltic in summer 2000. But we intend to spend majority of the time on refining the Trichodesmium algoritm.

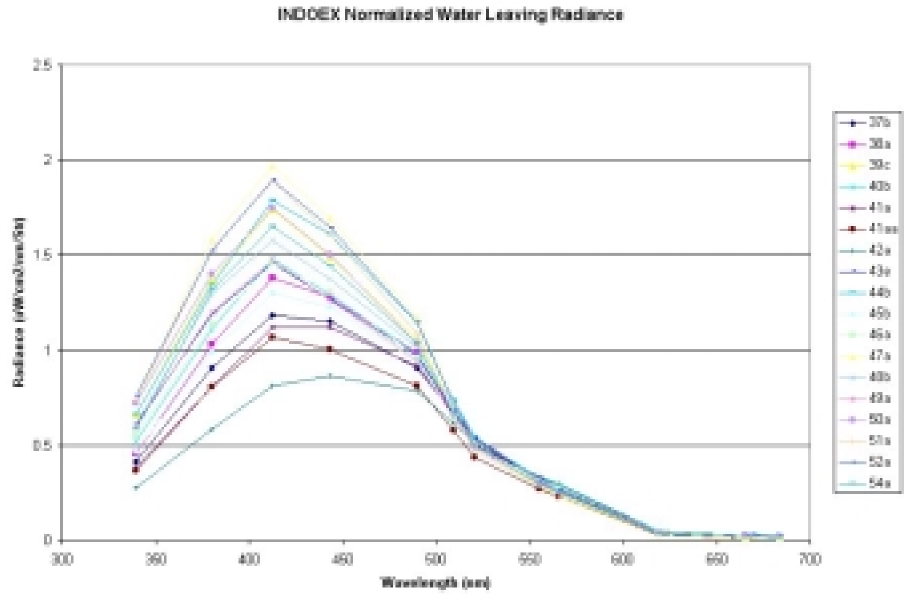

Figure 2. SPMR/SMSR based normalized water leaving radiance measurements for INDOEX legs 2 & 3.

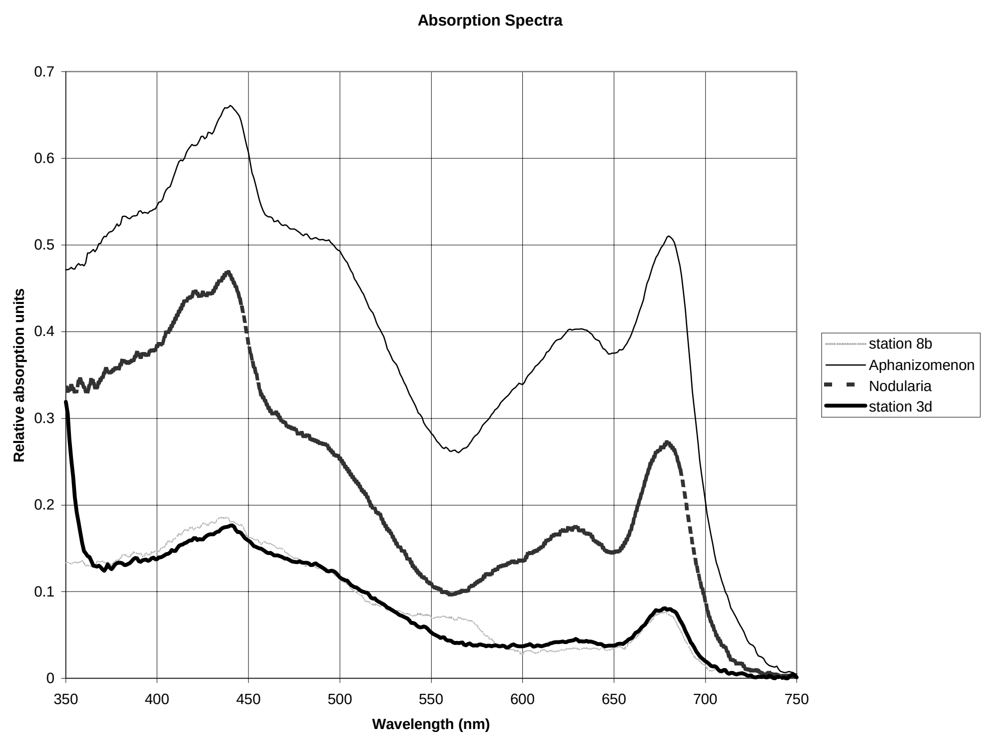

Figure 3. Absorption spectra of cultures of Nodularia and Aphanizomenon compared to total absorption measured at stations 3d and 8b.

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Chapter 7

Stray Light and Atmospheric Adjacency Effects for Large-FOV, Ocean Viewing Space Sensors

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7.1 INTRODUCTION

The radiance of dark targets (e.g. oceans and lakes) when measured by large-field imagers such as MODIS and SeaWiFS can be enhanced by stray light within the sensor and by radiance atmospherically scattered from bright, adjacent targets. One of the goals of this project is evaluation of this stray light and estimation of its effect on derived products of remote color imagery.

7.2 RESEARCH ACTIVITIES

Calibration

In accordance with SeaWiFS protocols, semiannual calibrations at facilities at the University of Arizona (UA) were conducted. The handheld radiometers known as Spectrix (SPX) and the Labsphere reflectance targets are calibrated in the labs of the Remote Sensing Group (RSG) (P. Slater, S. Biggar, and K. Thome). Additional calibrations are conducted at the UA Steward Observatory on nearby Mt. Lemon. RSG provides calibration services and groundtruth for a host of hyperspectral satellite sensors including LANDSAT, SeaWiFS, OCTS, and some European sensors.

Radiometric calibration of the SPX is achieved with a 1m Spherical Integrating Source (SIS) and the RSG portable transfer radiometer (Biggar, 1998). Specific details of the SIS calibration are contained in the calibrations reports for each period. The red-rich tungsten calibration is supplemented with a blue-rich, solar-based calibration on Mt. Lemon. The solar-based radiometric calibration (SBRC) method compares the total downwelling irradiance to the diffuse downwelling irradiance. The difference in the two measurements is the direct solar beam which is assumed to be constant (at the top of the atmosphere) and known from previous work (Thuiller et al., 1998). The Steward Observatory on Mt. Lemon, Arizona is at an elevation of 2791m ASL and experiences light continental aerosol loading. It provides a convenient location to conduct accurate SBRC's. Two Reagan autotracking solar radiometers provide the aerosol optical thicknesses at 10 wavelengths. The calibrations are conducted in the spring and fall to bracket the field work and to coincide with the lowest aerosol concentrations at Mt. Lemon.

Field Experiments

This project collected field data to evaluate the performance of SeaWiFS. Field sites were selected where adjacency artifacts would be likely. One site is a deep ocean canyon surrounded by bright carbonate banks, the Tongue of the Ocean (TOTO); another is Lake Okeechobee, Florida where dark water is surrounded by bright vegetation (in the infra-red, IR). With funding from other sources, additional field experiments were applied to this study and help with evaluation of SeaWiFS performance. These included sampling on Tampa Bay, the West Florida Shelf, Exuma Sound, the San Juan Islands in Puget Sound, and Lake Tahoe.

Modeling efforts

One aspect of the project was a modeling effort simulating different atmospheric adjacency scenarios. Two are included here, one is a hole in the clouds and the other is a dark target surrounded by bright areas (in the visible but not the IR). The cloud hole is a 3-D problem requiring a complex Monte Carlo simulation to generate the atmospheric adjacency effect. Figure 1 demonstrates how clouds affect downwelling irradiance at the sea surface. All calculations use Elterman's (1968) atmosphere with water Fresnel reflectance and about a 2% diffuse reflectance. For a 10 km diameter hole in clouds and a 40^0 solar zenith angle, the Esky_d(550)/F0(550) varies as observer moves away from hole center. Note that Esky_d(550)/F0(550)=0.28 for a "no-cloud" scenario and 0.33 near the hole center. The clouds can increase downwelling irradiance from the sky by 18% even when they are 5 km away.

The second model is for a dark target surrounded by bright reflectivity, similar to a 10 km diameter lake or embayment with a shallow bright banks. The model results shows that proximity to land does not effect Esky_d(550). The dark target scenario is a 2D problem and thus much simpler than the cloud problem. To evaluate stray light problems on satellite sensors, dark targets like lakes or ocean areas surrounded by bright land or shoal regions are much easier to correct for atmospheric adjacency effects than are holes in clouds.

7.3 RESEARCH ACTIVITIES

Tongue of the Ocean

To confirm the results for a dark target surrounded by bright shallow banks, reflectance measurement were made at the Northwest Passage of the Tongue of the Ocean (Bahamas) during SeaWiFS pass on 4 April 1999. The ship results confirm the uniformity of the reflectance right up to the edge of the banks. Atmospherically-corrected remote sensing reflectance measured by SeaWiFS is significantly higher than the actual reflectance. Samples from the northwest passage of the Tongue of the Ocean (25^0 25'N and 78^0 00'W) are shown in Figure 2, demonstrate this effect for a row of SeaWiFS pixels along the centerline of the canyon. The other sites were even closer to the edge of the canyon. Using these reflectances to generate chlorophylls with the Carder global algorithm can lead to a four fold over estimation compared to chlorophylls generated from the field reflectance measurements using the sample pigment algorithm (Figure 3) which are consistent with fluorometrically measured chlorophyll a concentrations.

Algorithm Evaluation

The degradation of SeaWiFS infrared bands, which are used to evaluate the type and amount of aerosol path radiance, caused a perturbation in the type of aerosol correction to be made by the SeaWiFS atmospheric correction scheme. This resulted in over estimation of the blue-richness of the aerosol scattering. Furthermore, high cirrus clouds have a tendency to exaggerate this effect, due to enhanced aerosol absorption in the oxygen band near 762 nm. To obviate the worst effects of both problems, we developed an aerosol-typing algorithm using bands 6 and 8 over clear waters. This approach forced the calibration of band 6 relative to band 8 to provide normalized water-leaving radiance values at band 6 consistent with the Gordon and Clark (1981) for scenes with known aerosol type. For scenes of unknown aerosols, the new 6-8 band combination delivered appropriate aerosol types with SEADAS. This prevented blue exaggeration of the aerosol type and prevented excessive removal of blue radiance from the scene, which otherwise would have resulted in blue-poor water-leaving radiance values. This approach provided atmospherically-corrected scenes that did not go negative at blue wavelengths for gelbstoff-rich (blue-absorbing) areas.. This approach also provided clear water, normalized water-leaving radiance values at 555 nm consistent with Gordon and Clark (1981) using the calibration factors distributed by the SeaWiFS Project on 6 January 1998. Furthermore, it provided a data distribution for clear waters using ratios of bands 1 and 2 versus bands 2 and 5 that are consistent with those found by Carder et al. (1999) using the SeaBASS in situ data set. Using the above calibration scheme, SeaWiFS images of the TOTO, the West Florida Shelf, and regions between were compared to field data using the default NASA chlorophyll algorithm and the Carder et al. (1999), MODIS-like, semianalytic chlorophyll algorithm. For these spring scenes, the pigments were somewhat packaged with little in the way of photoprotective pigments. Both algorithms performed similarly (within 5%) for Case 1 waters. When gelbstoff absorption overwhelmed the pigment absorption, however, the semianalytic algorithm delivered chlorophyll values within 25% of measured values, while the default NASA algorithm over estimated chlorophyll by as much as a factor of 4. These scenes will be re-evaluated with the new calibration-degradation curves of SEADAS 3.2 during the next contract year, but the new results are not expected to deviate significantly from these results using the 6-8 band combination except for turbid waters. In terms of evaluating atmospheric adjacency and stray light effects due to infrared radiance emanating from the bright foliage surrounding Lake Okeechobee or blue-green light reflected from the bright shallow banks surrounding TOTO, our preliminary findings suggest the following:

- Lake Okeechobee has so much horizontal variability in the water-leaving radiance field at infrared wavelengths that it is at times an impractical site at which to evaluate stray infrared light from its surrounds. It does offer, however, so much gelbstoff absorption at 412 nm that we are considering performing atmospheric corrections based upon the blue end of the spectrum.
- Data we collected at the Friday Harbor Laboratory in the San Juan Islands suggest that this site provides a viable alternative to Lake Okeechobee for evaluation of stray infrared light and/or atmospheric adjacency effects. PHILLS aircraft data Curtis Davis (NRL) suggests that one can find a red-edge effect (exaggerated infrared light) in the water near sunlit tree lines in data collected at 10,000 feet and with visibility in excess of 50 km. These data will be evaluated next year along with SeaWiFS data collected at high resolution over Griffin Bay (San Juan Island) which is surrounded by forest land.
- Field chlorophyll values farther than 2 pixels offshore and east from bright, shallow banks of the TOTO were not significantly different than those found farther offshore. Extreme caution must be taken, however, to avoid misinterpreting conditions where gelbstoff- and particle-laden waters from the shallows are transported offshore. The semianalytic model (Carder et al. 1999) provided estimated chlorophyll values from field reflectance spectra within 15% of measured values, however, with values largely unaffected by CDOM effects. Seawifs Rrs data near the banks over estimated by as much as a factor of two, providing chlorophyll over estimates of 3X for a station surrounded on three sides by bright carbonate banks. New AVIRIS data will permit separation of stray

light from atmospheric adjacency effects. Next year an evaluation of the electronic over-shoot, and/or hysteresis on the west sides of bright targets will also be evaluated on the eastern edge of the TOTO. More accurate calibration of the SeaWiFS sensor will help in this effort.

- A recently published paper by Reinersman et al. (1998) on calibration of aircraft and small footprint, spacecraft sensors using cloud shadows was dependent upon the development of a Monte Carlo model of radiance from single spherical clouds. This model is being modified to permit evaluation of atmospheric adjacency effects of clouds on radiance values received by a space sensor when viewing the ocean through an opening (elliptical cylinder) in a cloud bank. Algorithms that are more immune to the adjacency effects of clouds will be sought. Much of the light scattered into the sensor from clouds will be from molecules and stratospheric aerosols and thin cirrus clouds. A strategy using the effect of the oxygen absorption line on band 7 versus results from bands 6 and 8 may provide an indication of the effective height of any aerosol scattering for SeaWiFS, whereas MODIS has a cirrus discriminator built into its data processing scheme

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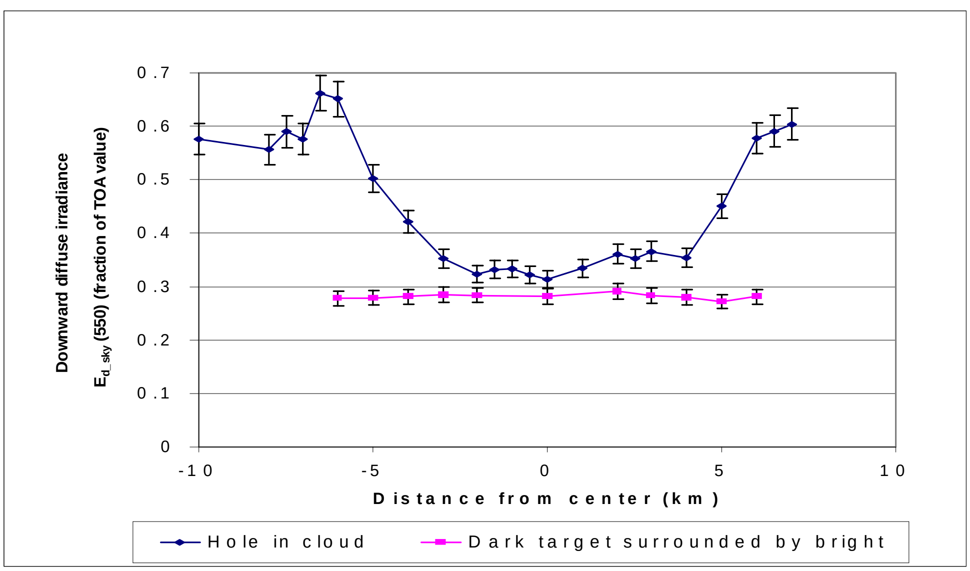

Figure 1. Comparsion of two Monte Carlo models of atmospheric adjacency effects: a 10km hole in the clouds and 10km lake surrounded by bright banks.

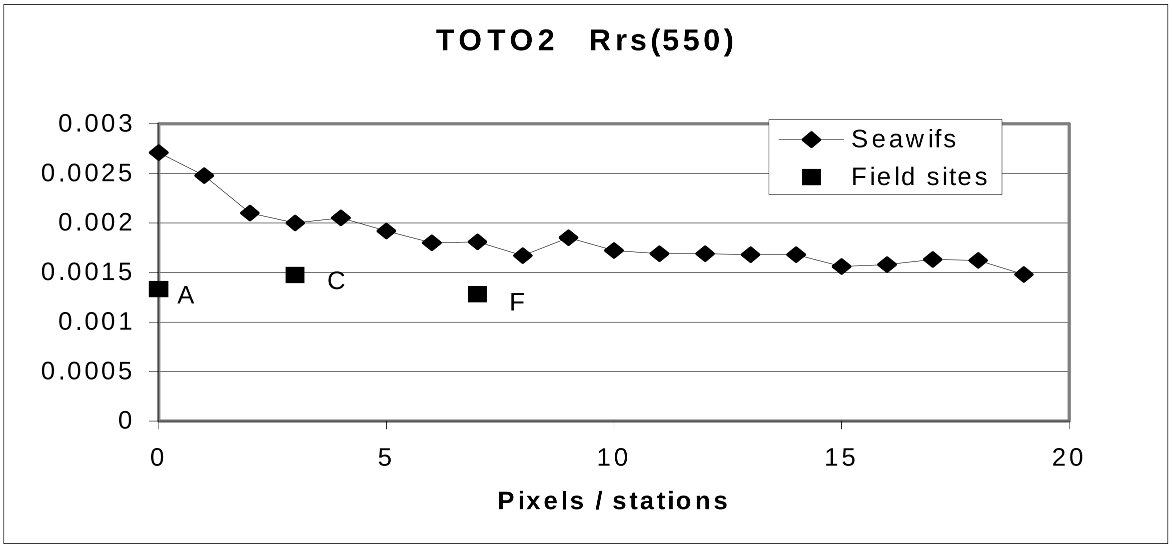

Figure 2. Comparison of remote sensing reflectance from field stations & row of SeaWiFS pixels for 4 April 99.

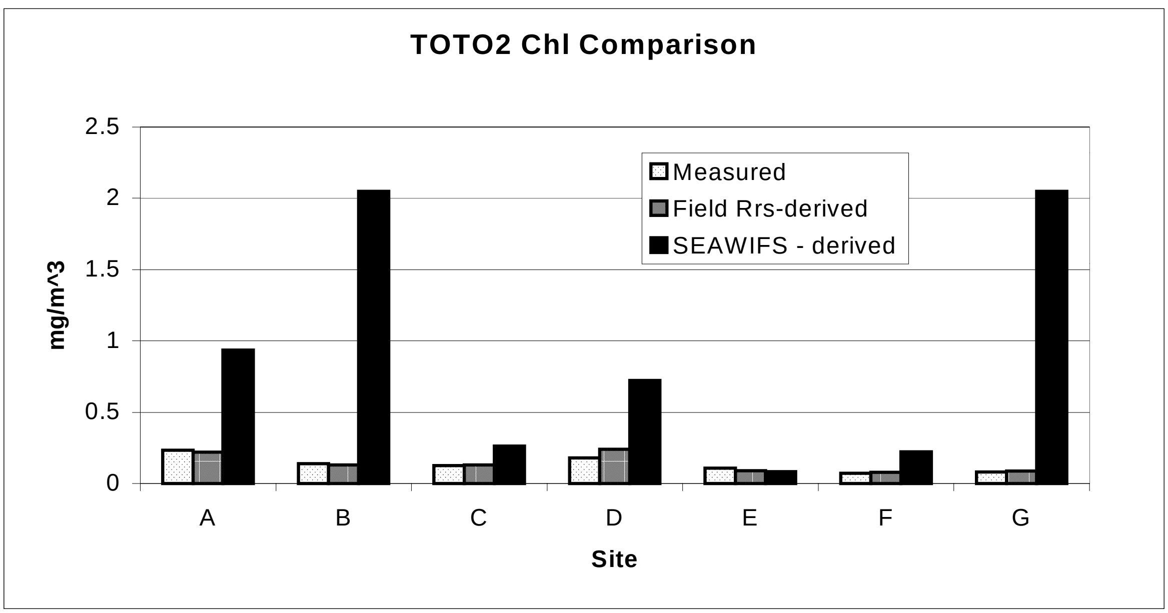

Figure 3. Comparison of fluorometrically measured chlorophyll concentrations to those derived from SeaWiFS and field reflectances for TOTO2 sites.

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Chapter 8

Bio-Optical Measurements at Ocean Boundaries in Support of SIMBIOS

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8.1 INTRODUCTION

The equatorial Pacific is a major component of global biogeochemical cycles, due to upwelling that occurs from the coast of South America to beyond 180°. This upwelling has significant implications for global CO_2 fluxes (Tans et al., 1990; Takahashi et al., 1997; Feely et al., 1999), as well as primary and secondary production (Chavez and Barber, 1987; Chavez and Toggweiler, 1995; Chavez et al., 1996; Dugdale and Wilkerson, 1998; Chavez et al., in press; Strutton and Chavez, submitted). In addition, this region of the world's oceans represents a large oceanic province over which validation data for SeaWiFS are necessary. This project consists of a mooring program and supporting cruise-based measurements aimed at quantifying the spectrum of biological and chemical variability in the equatorial Pacific and obtaining validation data for SeaWiFS. The project has the following general objectives:

- to understand the relationships between physical forcing, primary production, nutrient supply and the exchange of carbon dioxide between ocean and atmosphere in the equatorial Pacific;
- to describe the biological and chemical responses to climate and ocean variability;
- to describe the spatial, seasonal and inter-annual variability in near surface plant pigments, primary production, carbon dioxide and nutrient distributions; and
- to obtain near real-time bio-optical measurements for validation of SeaWiFS and subsequent ocean color sensors.

8.2 RESEARCH ACTIVITIES

Moorings

Chavez et al. (1998; in press) and McClain and Fargion (1999, p.44) describe the configuration of the MBARI bio-optical and chemical instruments deployed at 0°, 155°W and 2°S, 170°W; two of the 70 moorings which form the Tropical Atmosphere Ocean (TAO) array. In addition, MBARI also maintains smaller bio-optical packages at sites in the equatorial Pacific: 2°N, 180°; 2°S, 140°W and 2°N, 110°W. For the time being, the site which was maintained at 2°N, 140°W has been discontinued because of a change in mooring design at that site which precluded deployment of the instruments, and the loss of three of the original ten packages, which has made instrument rotation and timely calibration more difficult.

From 0°, 155°W and 2°S, 170°W, daily local noon (ie approximate time of SeaWiFS overpass) bio-optical and chemical data are transmitted via service ARGOS in near real time to MBARI, and then via automated FTP to the SeaBASS database, after some processing and quality control. Higher frequency, publication-quality data (10 or 15-minute intervals) are recovered at approximately six month intervals, and sent to the SeaBASS database after processing and quality control. Derived products, such as K_λ, OC2V2 chlorophyll, mean chlorophyll over the upper 20m of the water column (Morel, 1988) and water leaving radiance (Lw) are included in these data files for validation efforts. Lw is currently calculated via three different methods:

1. The diffuse attenuation coefficient (K_λ) over the upper 20m of the water column is calculated using Ed3m+ and Ed20m, then using this K_λ , $Lu_{\ 20m}$ is extrapolated back to the surface and multiplied by 0.544 to derive $Lu_{\ 0m+}$. This should be the most reliable method because the 3m+ and 20m instruments are less susceptible to fouling than the OCR-100s moored at ~1.5m.

2. Using the Satlantic OCP and SPMR optical profile data from equatorial Pacific cruises in 1997 and 1998, an empirical relationship between $Lu_{\ 1.5m}$ and $Lu_{\ 0m+}$ was derived. Thus the Satlantic OCR-100 data ($Lu_{\ 1.5m-}$) from the moorings are used to calculate $Lu_{\ 0m+.}$ Attenuation over the upper 1.5m of the water column is likely to have a negligible effect on the derivation of Lw, but this method could be improved to account for such variability. The OCR-100 instruments are protected from bio-fouling by a TBT ring, which is effective for approximately three months. Estimates of Lw using this method are probably inferior to the previous method after this time.

3. Lu_{0m-} can be derived from a simple, two point log-linear extrapolation of Lu $_{20m}$ and Lu $_{1.5m}$ to the surface, then multiplied by 0.544 as above to derive Lu $_{0m+}$. For the same reasons discussed above this method is probably unreliable after approximately three months.

In situ measurements

Table 1 summarizes the cruises undertaken by MBARI thus far in support of SIMBIOS. Essentially, the cruise-based measurements consist of chlorophyll (using the fluorometric method described by Chavez et al., 1995) and nutrient profiles (8 depths, 0-200m) obtained at CTD stations between 8°N and 8°S across the Pacific from 95°W to 165°E. On selected cruises (the 155°W and 170°W meridional transects), primary productivity (14C) measurements and optical profiles, using the Satlantic SeaWiFS Profiling Multispectral Radiometer (SPMR), are also performed. These data are archived at MBARI and the chlorophyll and optical profile measurements provided to the SeaBASS database.

8.3 RESULTS

Biogeochemical cycles

Several publications have been produced under MBARI's SIMBIOS funding. Chavez et al. (1998) used mooring data from 0°, 155°W to describe the biological-physical coupling observed in the central equatorial Pacific during the onset of the 1997-98 El Niño. Chavez et al. (in press) combine the physical, biological and chemical data from moorings, ships and SeaWiFS to provide a comprehensive view of the the ecosystem's response to the extreme physical forcings experienced during the 1997-98 El Niño. Strutton and Chavez (submitted) summarize the *in situ* cruise measurements spanning the period from November 1996 to December 1998, and use these data to describe the perturbations to chlorophyll, nutrients and productivity during the same time period.

SeaWiFS Calibration/Validation

The comparisons between MBARI SPMR-derived Lw and SeaWiFS have revealed very close agreement. Figure 1(a) shows matchups obtained between October 1997 and June 1998. It should be noted that the 1997 matchups (2 of the 5 shown) were made using the SPMR's predecessor, the Ocean Color Profiler (OCP), which was deployed without a surface reference unit. The data indicate that the OCP/SPMR provide excellent validation data, and these measurements will continue. But as with all ship-based matchup data, the percentage of measurements which meet the stringent criteria for matchup inclusion is small, which illustrates the importance of mooring validation data.

During 1998 the SIMBIOS validation team has begun to incorporate the MBARI mooring data into the calibration/validation effort. Figure 1(b) summarizes the best 300 matchups (78% of total) of the initial analysis performed in June 1999.

8.4 WORK PLAN

During 2000 data collection will continue as for 1998 and 1999. The two major mooring installations at 0°, 155°W and 2°S, 170°W are now operating well, as are the smaller bio-optical packages at three additional locations (2°N 110°W, 2°S 140°W, 2°N 180°). The program of cruise-based measurements of chlorophyll, nutrients, primary productivity and bio-optical profiles will continue on up to eight equatorial Pacific cruises during 2000, with scheduled SeaWiFS LAC where applicable, to enhance the probability of obtaining valid matchups.

During 1999 our data processing and data provision capabilities have improved, and the majority of the mooring data can now be downloaded and plotted via the web at: http://quillback.shore.mbari.org/~bog/mooring.html.The major data analysis project for 2000 is to improve the algorithms for derivation of Lw, and to develop a stringent set of quality control routines.

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Table 1. Summary of cruises during which *in situ* data have been obtained by MBARI in support of SIMBIOS. All cruises were undertaken aboard the NOAA ship *Ka'imimoana*, with the exception of GP6-98-RB and GP8-99-RB aboard the NOAA ship *Ronald H. Brown*. Meridional transects indicate the lines occupied by the ship. Along each line, CTD stations were performed approximately every degree of latitude from 8°N to 8°S. Measurements consisted of extracted chlorophyll (Chl) plus nitrate, phosphate and silicate (Nutrients) at 8 depths between 0 and 200m. On selected cruises, primary productivity (PP) measurements were also made using ^{14}C incubation techniques, and daily optical profiles with the Satlantic Profiling Multispectral Radiometer (SPMR) were obtained. During GP7-98-KA, GP3-99-KA and GP7-99-KA, a SIMBAD radiometer was also used, on loan from the SIMBIOS instrument pool.

Cruise ID	Dates	Meridional transects	Measurements
GP6-97-KA	27-Sep-97 to 30-Oct-97	125°W and 140°W	Chl, PP, Nutrients, SPMR
GP7-97-KA	06-Nov-97 to 17-Dec-97	155°W, 170°W and 180°	Chl, PP, Nutrients, SPMR
GP1-98-KA	05-Feb-98 to 13-Mar-98	95°W and 110°W	Chl, Nutrients
GP2-98-KA	18-Apr-98 to 20-May-98	125°W and 140°W	Chl, Nutrients
GP3-98-KA	02-Jun-98 to 03-Jul-98	155°W and 170°W	Chl, PP, Nutrients, SPMR
GP4-98-KA	07-Jul-98 to 03-Aug-98	165°E and 180°	Chl, Nutrients
GP5-98-KA	05-Sep-98 to 09-Oct-98	125°W and 140°W	Chl, Nutrients
GP6-98-RB	11-Oct-98 to 13-Nov-98	95°W and 110°W	Chl, Nutrients
GP7-98-KA	19-Oct-98 to 13-Nov-98	155°W and 170°W	Chl, PP, Nutrients, SPMR
GP8-98-KA	18-Nov-98 to 12-Dec-98	180° and 170°W	Chl, Nutrients
GP1-99-KA	22-Jan-99 to 24-Feb-99	125°W and 140°W	Chl, Nutrients
GP2-99-KA	30-Apr-99 to 04-Jun-99	95°W and 110°W	Chl, Nutrients
GP3-99-KA	30-Jun-99 to 30-Jul-99	155°W and 170°W	Chl, PP, Nutrients, SPMR
GP4-99-KA	04-Aug-99 to 01-Sep-99	165°E and 180°	Chl, Nutrients
GP5-99-KA	09-Sep-99 to 14-Oct-99	125°W and 140°W	Chl, Nutrients
GP7-99-KA	20-Oct-99 to 14-Nov-99	155°W and 170°W	Chl, PP, Nutrients, SPMR
GP8-99-RB	1-Nov-99 to 10-Dec-99	95°W and 110°W	Chl, Nutrients
GP9-99-KA	18-Nov-99 to 12-Dec-99	180° and 170°W	Chl, Nutrients

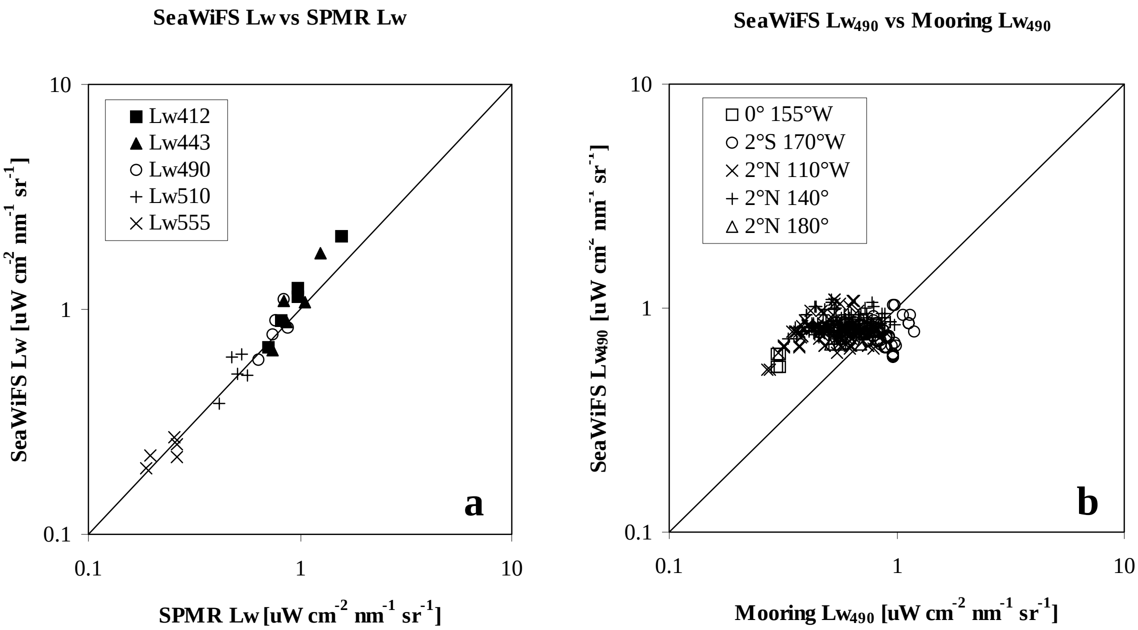

Figure 1. SeaWiFS matchups performed by the SIMBIOS calibration/validation team for *in situ* data obtained from (a) the Satlantic SPMR optical profiler and (b) MBARI moorings in the equatorial Pacific.

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Chapter 9

Remote Sensing of Ocean Color in the Arctic: Algorithm Development and Comparative Validation

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9.1 INTRODUCTION

The purpose of this project is to acquire a large bio-optical database, encompassing most environmental variability in the Arctic ocean, to develop algorithms for phytoplankton biomass and production and other optically active constituents. To that end a large suite of bio-optical and biogeochemical observations are being collected in a variety of high latitude ecosystems at different seasons. The Optical Research Consortium of the Arctic (ORCA) is a collaborative effort between G.F. Cota of Old Dominion University (ODU), T. Platt and W.G. Harrison of the Bedford Institute of Oceanography (BIO), S. Sathyendranath of Dalhousie University and S. Saitoh of Hokkaido University. ORCA has now conducted 10 cruises and collected about 500 in-water optical profiles plus a variety of ancillary data. All quality-assured data have been submitted to NASA's SeaBASS data archive. Observational suites typically include apparent optical properties (AOPs), inherent optical property (IOPs), and a variety of ancillary observations including sunphotometery and biogeochemical profiles. Our algorithm development efforts address most of the potential bio-optical data products for SeaWiFS, MODIS and GLI, and provides validation for a specific areas of concern, i.e. high latitudes and coastal waters.

9.2 RESEARCH ACTIVITIES

Of two scheduled cruises on ships of opportunity neither were completed. The first cruise (CCG Hudson to the Labrador Sea) was decreased in duration and slipped two months. It was cancelled because it conflicted with the second cruise (USCG Polar Star to the Chukchi Sea). The later icebreaker cruise was cancelled the day before departure due to mechanical problems. Consequently, no additional arctic field data were collected this year. Research efforts were focussed on data reprocessing and analysis, match-up analysis, modeling, and synthesis for presentation and publication. Our Labrador Sea data sets have played a central role in NASA's and NASDA's validation efforts for OCTS. Recent effort has been concentrated on synthesizing that part of our database. Satlantic Inc. has recently released new software with improvements and additional capabilities such as batch processing. All early optical data sets have been reprocessed to insure internal consistency and all will be resubmitted to SeaBASS. In most cases the changes in derived products are small (<1-2%), but can be 10-15% in the worst cases. PERL code has been developed to attach SeaBASS style headers for Satlantic (SPMR/SMSR) and WETLabs (AC-9) profiles. This code will be made available to the project. Our Satlantic data from 1994 and 1995 have compromised 412 nm surface irradiance values, but otherwise these data are of high quality. The SeaWiFS and SIMBIOS Projects have been informed of this. The 1998 Labrador Sea (Lab98) data set remains problematic. The downwelling irradiance Ed sensor malfunctioned during Lab98, and the data processing required modifications of Satlantic software. Additional ancillary data are also being submitted as they become available from our lab and collaborators. For example, triplicate chlorophylls were collected concurrently with triplicate optical profiles during our Labrador Sea cruises, and these are being submitted with the reprocessed optical data sets.

Data sets also have been made available to additional investigators. Our current chlorophyll algorithm for the Arctic was supplied to Bernie Walters for his research on detection of surface slicks with SAR. Jay O'Reilly has recently compared his spectral 1324 indices for our entire data set with the OC2V2 data set. The data sets will soon be made widely available on the web. Our web site is being updated and expanded to include optical data, many value-added products, and a variety of ancillary information. Cruise reports, station sheets, photos of sky and sea state, instrument specifications, calibration histories, etc. will be available. Similarly results from on-going analyses and intercomparisons will be highlighted.

9. 3 RESEARCH RESULTS

Regional comparisons have been made between *in situ* observations and bio-optical models tuned with high latitude data. High latitude waters have unique bio-optical properties compared with temperate data and models (e.g. Mitchell 1992, Sathyendranath et al. 1999a,b). There is a large dynamic range for biomass, which must be considered in algorithm development. Diatoms usually dominate phytoplankton assemblages, but prymnesiophyte blooms may alter bio-optical signatures (Sathyendranath et al. 1999a). Relatively large diatom cells in polar waters are highly packaged (~90%) with low chlorophyll-specific attenuation compared with temperate ecosystems. Attenuation due to soluble matter also varies regionally with the highest values in our northernmost study site, the Canadian Arctic Archipelago near Resolute Bay. Discrepancies between the high latitude bio-optical data and operational chlorophyll algorithms for SeaWiFS and OCTS can be marked, especially at bloom concentrations. Chlorophyll retrievals from the Labrador Sea with OC2V1 were over threefold to high at 25 mg Chl m-3, whereas OC2V2 yields values twofold to low (Cota et al. 1999). Similar results are obtained for the Canadian Arctic Archipelago. Better agreement is found in the Bering Sea, but our data set covers a very limited range and is dominated by low values (< 3 mg Chl m-3). Optical models for lower latitude do not describe the high latitude data sets well. Sathyendranath et al. (1999a) employed a diatom-specific absorption spectrum with very low relative chlorophyll-specific absorption to obtain better agreement. Cota et al. (1999) have confirmed that chlorophyll-specific absorption by phytoplankton is low relative to temperate ecosystems, and that soluble absorption by colored dissolved organic matter (CDOM) constitutes 60 – 95% of total particulate absorption in the blue and blue-green algorithm channels. Backscattering must be very low (<0.3%) and an inverse function of chlorophyll to obtain better agreement in simulations with HydroLight (Mobley 1994) tuned with our absorption spectra for various constituents. Several approaches for estimating primary production in the Arctic are being evaluated. Simple empirical band ratio algorithms explain 80% and 50% of the observed variability between surface chlorophyll and integrated net daily production, respectively. Predictions from more complex production models are being compared to observations after being tuned with high latitude data. Yoder's MODIS production algorithm (pers. comm., Howard and Yoder 1997) is a depth-integrated model employing satellite chlorophyll, daily PAR, SST, and climatologies for MLD. When tuned this model underestimated observed production with a slope of 0.74 and explained 42% of the variance. This discrepancy resulted primarily from melting ice, which made the observed MLD 3-10 times shallower than climatological estimates. Their estimated KPAR would also be considerably higher than observed values at higher biomass levels. Another depth-integrated model by Behrenfeld and Falkowski (1997) utilizes similar environmental inputs and a temperature-dependent Popt derived from productivity profiles. Their tuned model also underpredicted production with a slope of 0.55, but explained 56% of the variance. Compound errors in satellite predictions of production from satellite chlorophyll could be two to fourfold underestimates. Reasons for the performance of various models are being explored.

9.4 WORK PLAN

Cruise plans for 2000 include a spring (May) cruise in the Labrador Sea and a summer (June-July) cruise in the Chukchi Sea. As proposed ORCA will conduct 1-3 cruises per year on average. We will contribute critical core observational data as well as a variety of ancillary bio-optical and biogeochemical data. All core observations will continue to be delivered within 90 days (spectroradiometer profiles, fluorometric chlorophyll, and normally particulate and dissolved absorption spectra). Additional observations for which ODU has primary responsibility for will be delivered within 12 months, and contributions from international collaborators will be submitted as they become available. Our goal is to make raw data and derived products generally available via the web but our site is still under construction. Efforts in 2000 will concentrate on collection of comprehensive bio-optical data sets, data analyses, modeling, and publication of results. Emphasis will be placed on above-water vs. in-water comparisons.

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Chapter 10

High Frequency, Long Time Series Measurements from the Bermuda Testbed Mooring in Support of SIMBIOS

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10.1 INTRODUCTION

Few *in situ* data are presently available for groundtruthing and algorithm development for ocean color satellites. However, mooring methodology allows for collection of very high temporal resolution, long-term time-series data. Moored measurements have several important advantages including the ability to obtain high numbers of "match-up" data for comparisons with ocean color satellites such as SeaWiFS. However, the use of moorings for obtaining optical data is a relatively new and quite challenging approach. To date, moored radiometric measurements have been attempted by only a few groups (e.g., Dickey, 1991; Smith et al., 1991; Clark et al., 1997; Chavez et al., 1997; Dickey et al., 1998a). Moored optical observations are more difficult than their ship-based counterparts for several reasons (e.g., less frequent calibration, biofouling, etc.). The Bermuda Testbed Mooring (BTM) has been used as a mooring-of-opportunity in order to provide the SIMBIOS program with high frequency, long-term time-series bio-optical data for use in SeaWiFS satellite calibration and validation activities. The BTM program began in mid-1994 at a site located about 80km southeast of Bermuda (31° 43' N, 64° 10' W) in-waters of about 4530m depth (Dickey et al., 1997, 1998a). A schematic of the BTM mooring array, a geographic map indicating the mooring location, and a depiction of the data telemetry system are shown in Figure 1. Key NASA supported BTM optical measurements have included: surface downwelling spectral irradiance (7 λ's, SeaWiFS matched: λ = 412, 443, 490, 510, 555, 665, and 683nm;10nm bandwidth at half power) and subsurface downwelling spectral irradiance and upwelling spectral radiance (7 λ's for each, SeaWiFS matched). Data are collected at 6Hz for 45sec every hour during daylight and at midnight. Products derived from the measured radiometric quantities include spectral attenuation coefficients, spectral reflectance ratios, and water-leaving radiances. These data provide necessary links to and interpolation of radiometric data for remotely sensed observations of ocean color (e.g., SeaWiFS color imager), which can be used to estimate biomass and primary productivity globally. A recently developed telemetry system provides near real-time BTM radiometric data to the UCSB Ocean Physics Laboratory. We have also developed a software system to make key data available to the SIMBIOS Project on a daily basis. Highly complementary, value-added meteorological, bio-optical, and physical data products are provided through our complementary NSF/ONR/NOPP BTM studies (e.g., Dickey et al., 1998a). Our comprehensive measurements can be used to relate bio-optical signals to inherent optical properties and to biogeochemical measurements and to test interdisciplinary models of phytoplankton productivity and carbon flux. In addition, these data can be used to study key environmental parameters (e.g., wind speed, sea-state, etc.), which affect SeaWiFS determinations of water-leaving radiance.

10.2 RESEARCH ACTIVITIES

The BTM provides very high temporal resolution data as illustrated by the Deployment 11 (April 1, 1999 – July 20, 1999) spectral upwelled radiance time-series (Figure 2). During the first year of the project, the proof-of-concept was demonstrated, particularly by showing that BTM radiometric data and ship profile radiometric data (collected by the Bermuda Bio-optical Project (BBOP; e.g., Siegel et al., 1995) matched quite well when recently calibrated radiometers were available. This is supported by the strong correlations between BTM time-series data and BBOP ship-based profile data, which were available during 15 of the ~130 days of Deployment 11 (Figure 3). The second year of our project has focused on determining ways to best assure consistently high quality data, which can be used for evaluating and groundtruthing SeaWiFS data as a precursor to algorithm development. Two important aspects of this particular phase of the work involve calibration of radiometers and the optimal deployment of radiometers (number of sampling depths and placements). In regard to the first issue, continuous *in situ* calibration is not possible for moored instruments; therefore, BTM radiometric data are processed with pre-deployment and post-deployment factory calibrations. In addition, these data are compared with available concurrent BBOP shipboard profiling measurements and SeaWiFS data. Most recently, we have begun to apply a series of quality control and consistency tests, which were developed by Jay O'Reilly, to the BTM data. In the past, we have generally deployed radiometers at the surface and at two subsurface depths, because of limited numbers of systems. Again, because of the lack of a sufficient number of radiometers, it has not always been possible to calibrate all radiometers prior to deployment. For Deployment 11, we added a radiometer system at the 7m depth to determine if improved estimates of water-leaving radiance would be obtained. Most recently for Deployment 12, we added two more radiometer systems bringing the total to 5 subsurface systems. Deployment 12 is still in the field, but preliminary results from Deployment 11 suggest that use of three subsurface radiometer systems may improve estimates, particularly under high wind and sea-state conditions. One of the key findings of the project thus far is that regular (pre- and post-deployment) calibration of BTM radiometers is critical. An especially striking and important highlight of our analysis of Deployment 11 is that BTM and SeaWiFS determinations of water-leaving radiance are very similar (Figure 4). We are presently exploring the effects of wind speed. Hurricane Gert passed fairly close to the BTM in September 1999 (Deployment 12). Thus, we are hopeful that the high wind and sea-state conditions accompanying Hurricane Gert will enable us to better quantify such effects on SeaWiFS and BTM water-leaving radiance. In summary, we have demonstrated that moorings-of-opportunity, such as the BTM, can provide large volumes of useful radiometric measurements for groundtruthing and algorithm development for ocean color satellite imagers. Further, it appears that BTM data sets will be quite useful for developing satellite correction algorithms for various environmental and undersampling effects.

10.3 WORK PLAN

Future directions include quantifying effects and biases arising from different sampling methodologies (e.g., undersampling by ships and satellites) as well as investigating the wind speed and sea-state effects on SeaWiFS-derived water-leaving radiance. Related studies of ocean eddies and hurricanes, which pass the BTM, are also underway (e.g., McGillicuddy et al., 1998; McNeil et al., 1999; Dickey et al., 1998b).

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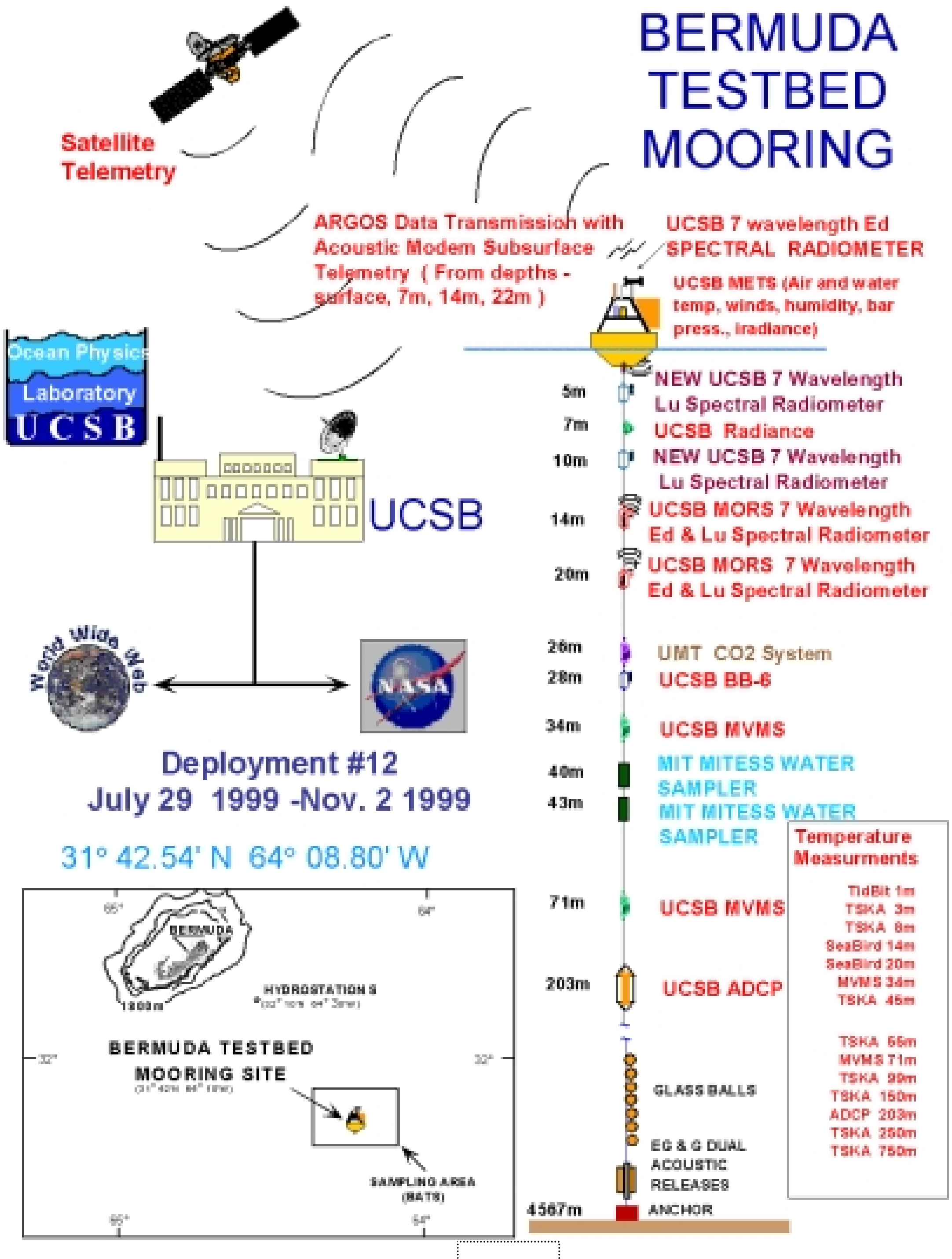

Figure 1. Schematic of the Bermuda Testbed Mooring (BTM) array, geographic map indicating BTM site, and diagram showing data telemetry system and data flow.

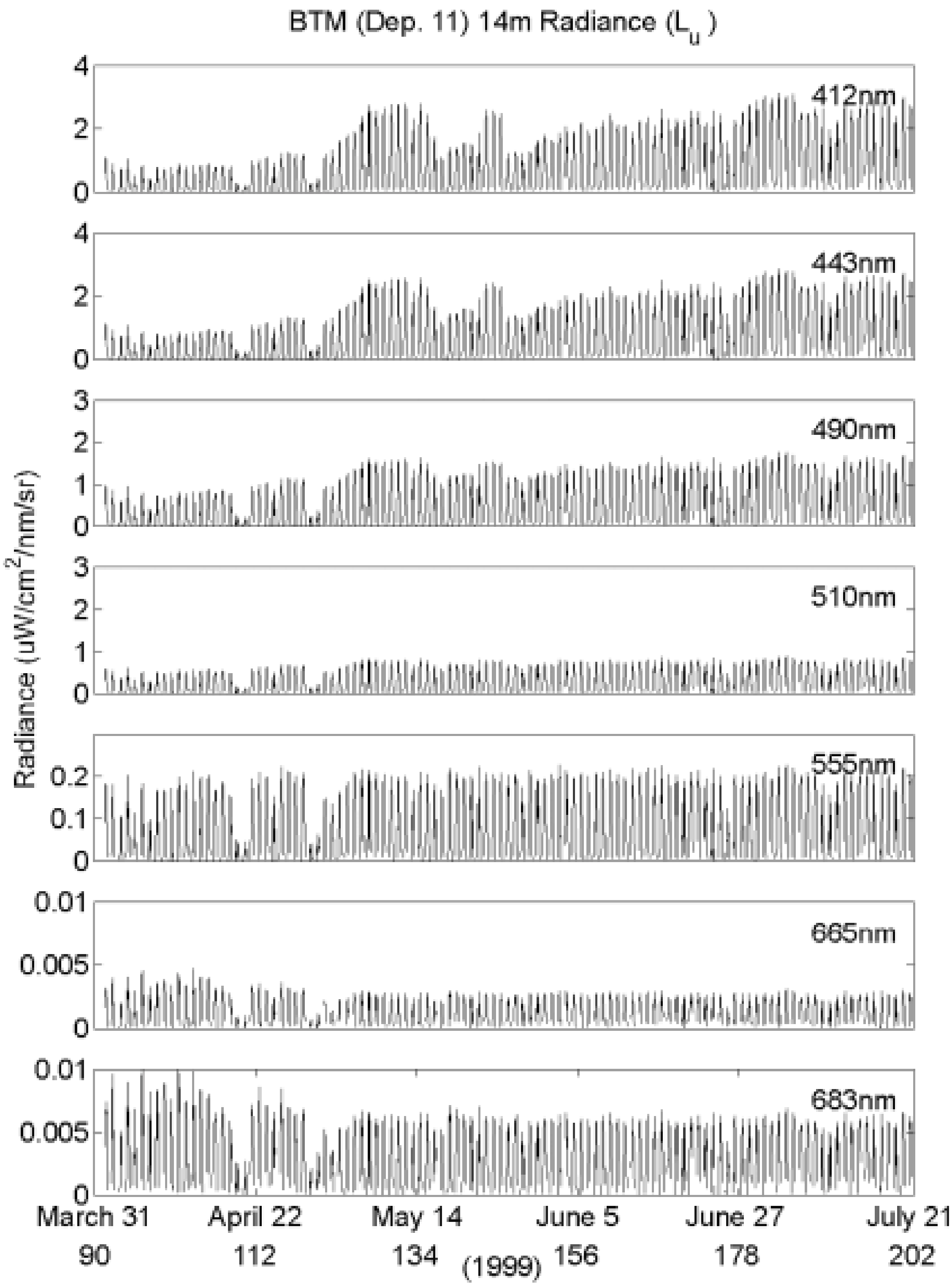

Figure 2. Time-series of BTM 14m upwelling radiance for 7 SeaWiFS wavelengths during BTM Deployment 11.

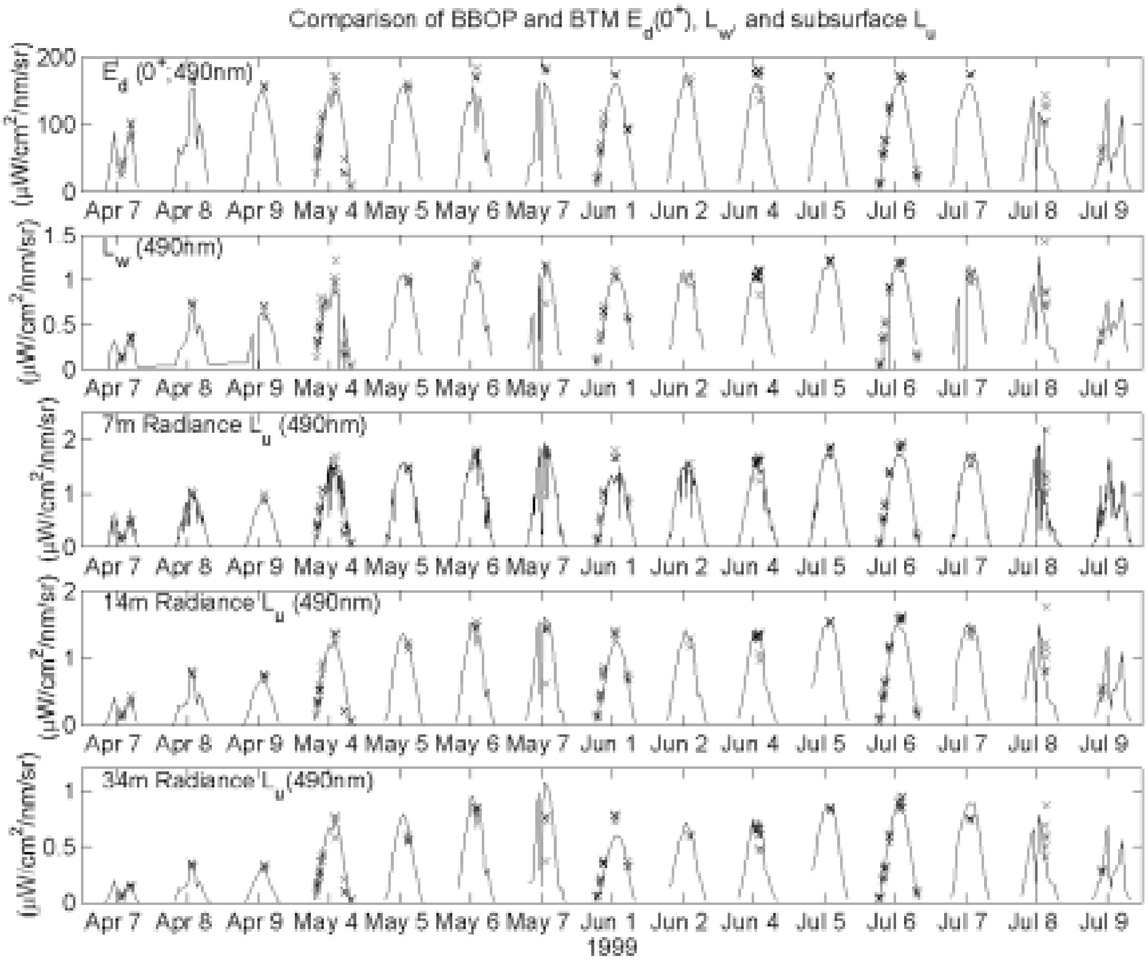

Figure 3. Comparison of BTM and BBOP time-series of surface downwelling irradiance, water-leaving radiance, and upwelling radiance at 7, 14, and 34m. These 15 days were selected because concurrent BBOP data were available. BBOP data are shown as x's. All data are for the 490nm wavelength.

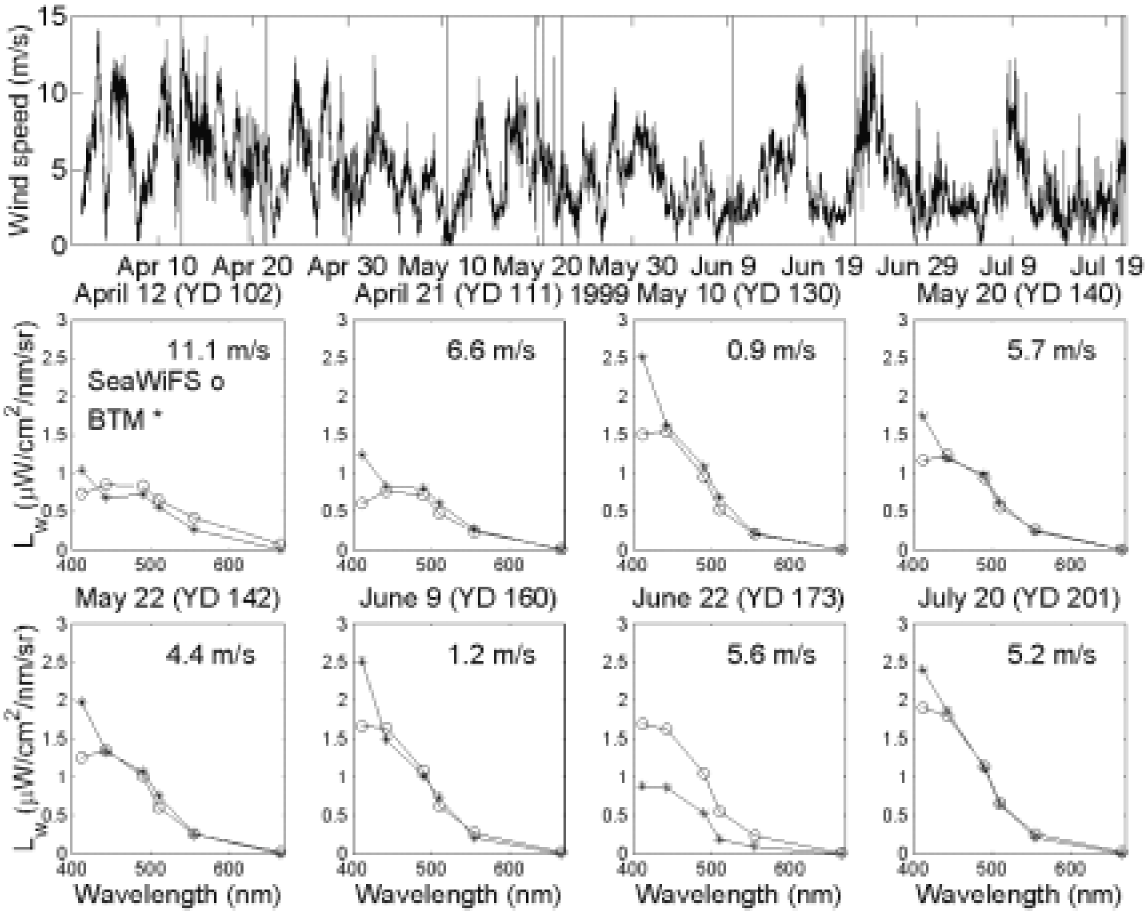

Figure 4. Top panel shows BTM time-series of wind speed. The lower panels show water-leaving radiance as a function of wavelength as determined from the BTM radiometer measurements (asterisks) and SeaWiFS (circles). Wind speed for the individual comparisons are indicated.

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Chapter 11

Satellite Ocean Color Validation Using Merchant Ships

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11.1 INTRODUCTION

A measurement program for satellite ocean color validation based on ships of opportunity and specific instrumentation, the SIMBAD radiometer, was developed to complement dedicated experiments at sea, which are expensive, cannot sample the wide range of oceanic and atmospheric conditions expected to be encountered, and generally provide a few match-ups. The radiometer is portable, easy to operate, and measures the basic ocean-color variables, namely aerosol optical thickness and water-leaving radiance, in typical spectral bands of ocean-color sensors. Importantly, the ship is not required to stop, making it possible to make measurements along regular routes traveled by merchant ships in the world's oceans.

For water-leaving radiance, the radiometer views the ocean surface from the side of the ship lit by the sun, outside the sun glint, at a nadir angle of 45 degrees and a relative azimuth angle of 135 degrees. A vertical polarizer reduces the skylight reflected in the instrument's field of view. For aerosol optical thickness, the radiometer views the sun like a classic sun photometer. The same optics (with a field of view of 2.5. degrees) and detectors are used in both sun- and ocean-viewing modes. The radiometric measurements are made simultaneously in five spectral bands centered at 443, 490, 560, 670, and 870 nm, but the sun and ocean surface are viewed sequentially. Downward solar irradiance at the surface, a variable that must be known to normalize water-leaving radiance, is not measured but calculated, which can be done accurately when the sky is clear or partly cloudy (<30% cloud coverage) with the sun not obscured by clouds. This defines the sky conditions under which the SIMBAD radiometer should be operated. To achieve adequate sampling, a series of ten radiometers was built for use in two complementary networks, one operated by the Scripps Institution of Oceanography (SIO), University of California San Diego, and the other by the Laboratoire d'Optique Atmospherique (LOA), University of Lille. Arrangements have been made with suitable merchant ships, and officers trained to make SIMBAD measurements. Some of the ships, for example M/V Micronesian Navigator (SIO network), and M/V Toucan (LOA network) have been providing data routinely. The SIMBAD datasets include values of aerosol optical thickness, Angstrom coefficient, water-leaving radiance, marine reflectance, downward solar irradiance, and ancillary variables such as fractional cloud coverage and wind speed. They are available at http://genius.ucsd.edu/~frouin/ and http://www.loa.univ-lille1.fr/~poteau/.

11.2 RESEARCH ACTIVITIES

During the second year of the project, collection of SIMBAD data sets during research campaigns and merchant ship voyages of opportunity intensified, bringing to 376 the number of data sets collected by the SIO network under clear or mostly clear skies within a few hours of SeaWiFS overpass. The objectives were to improve the sampling of oceanic and atmospheric conditions, compare marine reflectance measured by SIMBAD and more classic (e.g., MER-type) radiometers, and perform a first evaluation of SeaWiFS-derived marine reflectance. Efforts also focused on developing an operational, PC portable processing code for SIMBAD data.The research cruises and merchant ship voyages accomplished by the SIO network since the launch of SeaWiFS are listed below (Table 1) with general location or route, date, and name of the operator. The exact location of the data sets is displayed in Figure 1. Most of the data sets were acquired at latitudes between -40 and 40 degrees, but the three major oceans were sampled.

Table 1. SIMBAD research and merchant ship voyages.

- CalCOFI 9710, 20 September - 08 October 1997, Southern California Bight (Wieland).
- M/V Asian Challenger, 26 October - 04 November 1997, Valparaiso-Auckland (Cutchin).
- R/V Melville, 02 November 1997 - 07 June 1998, San Diego-Acapulco-Callao-Valparaiso-Easter-

Papeete-Honolulu (Comer).
- M/V Nacre, 20 December 1997 - 03 January 1998, Honolulu-Coronel (Cutchin).
- CalCOFI 9802, 23 January - 10 February 1998, Southern California Bight (Subranamian).
- CalCOFI 9804, 02 April - 24 April 1998, Southern California Bight (Mitchell).
- M/V Chevron Mississipi, 18 May - 23 May 1998, Honolulu-Valdez (Cutchin).
- NAN 9807, 06 July -10 July 1998, Cape Cod (Shieber).
- M/V Mokihana, 20 July - 15 August 1998, Oakland-Guam-Taiwan-Japan-Oakland (Bousseloub).
- CalCOFI 9807, 09 July - 27 July 1998, Southern California Bight (Wieland).
- M/V Micronesian Navigator, 30 August - 14 October 1998, California-Micronesia-Philippines-California (Sumogat).
- M/V Mokihana, 04 September - 21 September 1998, Oakland-Guam-Taiwan-Japan-Oakland (Bousseloub).
- CalCOFI 9809, 13 September - 01 October 1998, Southern California Bight (Frame).
- R/V Ka'imimoana, 19 October - 11 December 1998, Equatorial Pacific (Strutton).
- R/V Cape Hatteras, 21 October - 01 December 1998, Beaufort-Jacksonville (Subranamian).
- M/V Micronesian Navigator, 03 November - 29 December 1998, California-Micronesia-Philippines-California (Sumogat).
- M/V Micronesian Navigator, 01 January - 15 March 1999, California-Micronesia-Philippines-California (Sumogat).
- CalCOFI 9901, 09 January - 29 January 1999, Southern California Bight (Frame).
- R/V Ron Brown, 14 January - 18 February 1999, Charlston-CapeTown-Mauritius (Frouin).
- R/V Ron Brown, 22 February -02 April 1999, INDOEX, Mauritius-Maldives (Flatau).
- R/V Bellows, 12 April - 29 April 1999, Tongue of the Ocean II, Bahamas (Shieber).
- R/V New Horizon, 23 May 1999, Southern California Bight (Chavez).
- R/V Oceania, 20 June - 08 July 1999, Tromso-Longyearbyen (Stramski).
- R/V Revelle, 24 June - 17 July 1999, Sea of Japan (Mitchell).
- R/V Ka'imimoana, 27 June - August 3 1999, Equatorial Pacific (Strutton).
- CalCOFI 9908, 05 August - 27 August 1999, Southern California Bight (Wieland).

11.3. RESEARCH RESULTS

The ability of the SIMBAD radiometer to reduce reflected skylight was justified theoretically and verified experimentally (Appl. Opt., 38, 3844, 1999). Residual skylight is correctable to 10^{-4} in reflectance units, which for most oceanic waters corresponds to 1% of the marine reflectance in the blue and green. Polarization of sunlight by the water body is small for the viewing geometry (scattering angles between 148 and 158 degrees), and one should be able to correct the residual effects to within 5% relative accuracy.

The diffuse marine reflectance measured by the radiometer was compared with that measured by an underwater MER system during various CalCOFI cruises (13 comparison sets) and the Aerosols99 cruise (8 comparison sets). Figure 2 displays the two types of measurements. Agreement is good in the four spectral bands considered (to within 10-15% in the blue and green); there is no apparent bias. Even though the number of points is not sufficient to compute meaningful statistics, the comparison attests to the quality of the SIMBAD marine reflectance.

SeaWiFS-derived normalized water-leaving radiance was evaluated against SIMBAD measurements (Figure 3). Only 15 match-ups were obtained in clear and turbid waters (but not coastal waters) during the period considered, September 1997 through July 1998. The scatter between the two types of water-leaving radiance is large, but the SeaWiFS values are generally higher than the SIMBAD values in the blue and green, suggesting an underestimation by SeaWiFS of the chlorophyll-a concentration in open oceanic waters. This is apparent in the higher SeaWiFS 443/555 and 490/555 reflectance ratios (not shown here).

A code to process SIMBAD data was delivered to the SIMBIOS Project office. It requires as input "sun", "dark", and "sea" data files, calibration coefficients for "sun" and "sea" data, surface pressure, Dobson amount, wind speed, cloud fraction, cloud optical thickness, and name of the output file. Default values are used for wind speed, Dobson amount, and cloud optical thickness when these variables are not known or available. The output file contains sun and viewing geometry, aerosol optical thickness, Angstrom coefficient, downward solar irradiance, raw marine reflectance, corrected marine reflectance, water-leaving radiance, normalized water-leaving radiance, and "remote-sensing" reflectance. The code was adapted (Sean Bailey) for use on PCs; the executable is available from the SIMBIOS Project office.

11.4. WORK PLAN

During the third year of the project, the SIO network will be extended to include additional Micronesian ships, namely M/V Micronesian Heritage and M/V Micronesian Nations. These ships, like M/V Micronesian Navigator, have the bridge forward, making it easy to avoid ship-generated foam. A collaborative effort is envisioned with the ORSTOM Center of Noumea, New Caledonia, which has been using merchant ships to collect physical oceanography data for several decades. Participation in research campaigns during which water-leaving radiance and/or aerosol optical thickness are measured by other instrumentation (e.g., CalCOFI campaigns) will continue, allowing further evaluation of the SIMBAD data. But to increase the number of match-ups, the focus will be shifted toward ships that do not carry out the same type of measurements as the SIMBAD radiometer. An evaluation of the SeaWiFS-derived marine reflectance and aerosol optical thickness will be performed using the SIMBAD data collected by the SIO and LOA networks. The differences between SeaWiFS and SIMBAD water-leaving radiances will be analyzed as a function of aerosol optical thickness, Angstrom coefficient, radiation geometry, and wind speed.

An advanced SIMBAD instrument, SIMBADA, will be designed and built by the University of Lille. It will be lighter and more compact, will operate without any cables, will have improved electronics, reduced noise, a larger internal memory, better batteries with internal charger, easier display of viewing geometry, and will measure in eight spectral bands instead of five. An option being considered is the remote acquisition of downward solar irradiance, allowing the instrument to make quality marine reflectance measurements in clear as well as cloudy, even overcast conditions. A prototype will be tested at the SIO pier and onboard ship during CalCOFI campaigns. The objective is the realization of a series of at least 10 advanced instruments by the end of 2000.

ACKNOWLEDGMENTS

The authors wish to thank all the officers and scientists that have collected SIMBAD data, J. McPherson for developing the SIMBAD processing code, S. Baily for adapting the code to PC, A. Poteau for processing SIMBAD data and helping with the maintenance of SIMBAD radiometers, B. Shieber for providing SeaWiFS match-up data, and C. Pietras for helpful discussions. This work has been carried out with the support of the National Aeronautics and Space Administration under contract NAS-97135, the Scripps Institution of Oceanography, the Centre National d'Etudes Spatiales, and the Centre National de la Recherche Scientifique.

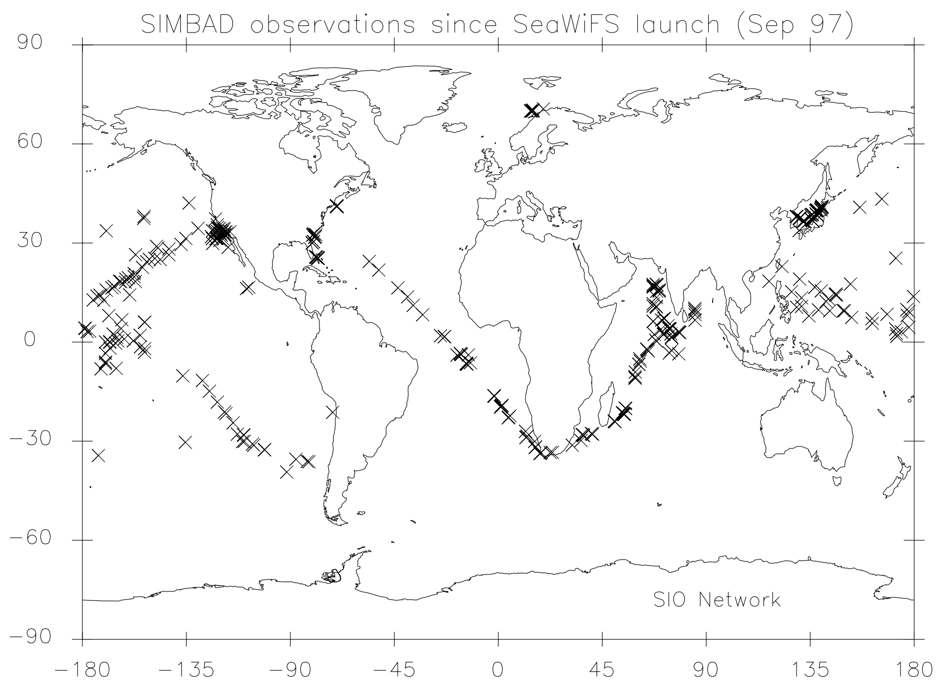

Figure 1. Location of SIMBAD datasets collected since SeaWiFS launch.

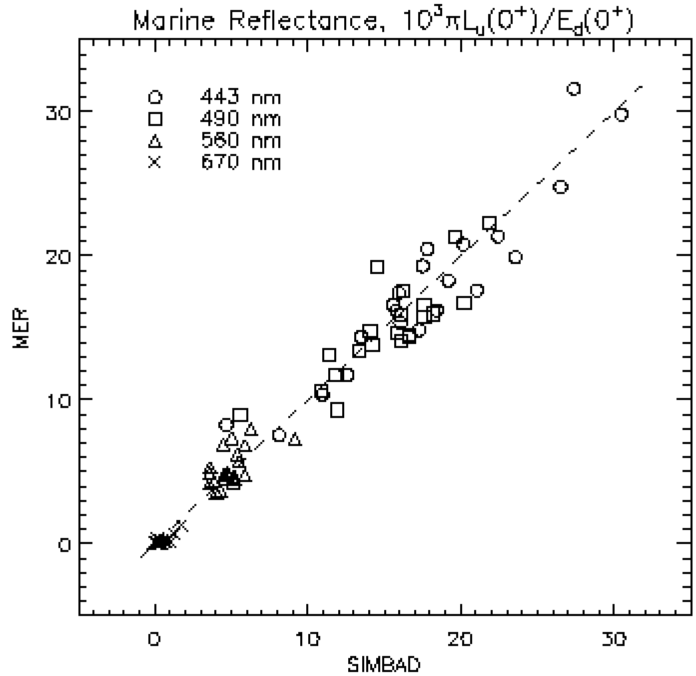

Figure 2. Comparison of marine reflectance just above the surface measured by MER and SIMBAD radiometers

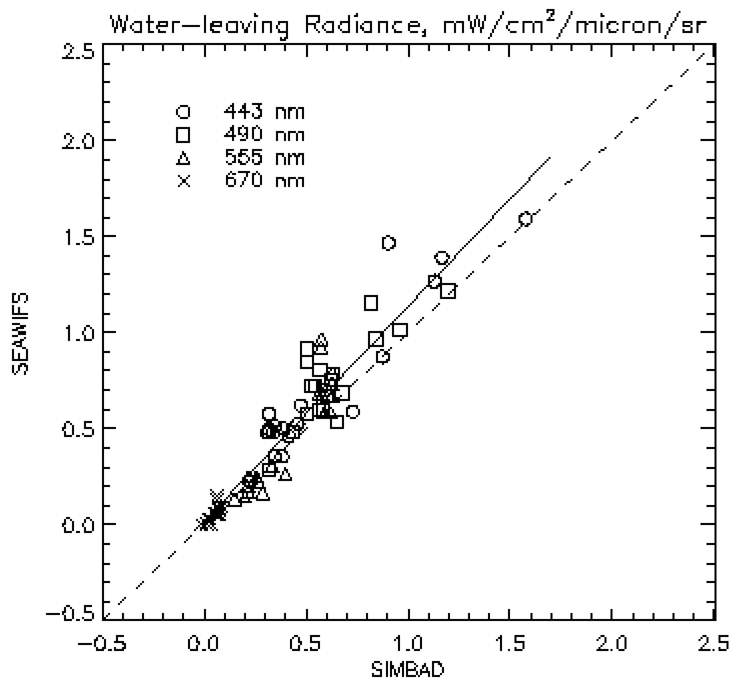

Figure 3. Comparison of SeaWiFS-derived and SIMBAD-measured water-leaving radiance

This research was supported by the

SIMBIOS NASA contract # 97135

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Chapter 12

High Altitude Measurements of Radiance at High Spectral and Spatial Resolution for SIMBIOS Sensor Calibration,Validation, and Intercomparisons

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12.1 INTRODUCTION

The objective of this research is to calibrate and validate the on orbit radiometric characteristics of SeaWIFS with underflights of NASA's calibrated Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). This objective is feasible because AVIRIS measures the same spectral range as SeaWIFS at higher spectral resolution (Figure 1). The AVIRIS sensor flies at 20 km altitude on a NASA ER-2 near the top of the absorbing and scattering portions of the atmosphere. Conversion of AVIRIS data to top-of-the-atmosphere radiance is achieved through the use of the MODTRAN atmospheric modeling package. AVIRIS measures the solar reflected spectrum from 370 nm to 2500 nm through 224 contiguous 10 nm wide spectral channels. Data are acquired as images of 11km width by up to 800 km extent with 20 m spatial resolution. The stability and repeatability of AVIRIS calibration has been and continues to be validated through a series of inflight calibration experiments. With pre- and post-flight calibrations of AVIRIS, coupled with the on-board calibrator, calibration accuracy of better than 2% spectral, 3% radiometric and 3% spatial have been achieved.

The calibration and validation objective of this project is pursued for the following reasons: (1) Calibration is essential for the quantitative use of SeaWIFS and other SIMBIOS sensor data; (2) Calibration in the laboratory of spaceborne sensors is challenging; (3) Satellite sensors are subjected to aging on the ground and to trauma during launch; (4) The Earth orbit environment is significantly different than the laboratory calibration environment; (5) Through years of effort AVIRIS has been demonstrated to be well calibrated; and (6) AVIRIS can match the spectral and spatial observation characteristics near the top of the atmosphere at the time of SeaWIFS measurements.

The approach taken for the SIMBIOS Project has been to: (1) Determine the calibration accuracy of AVIRIS with high confidence in the laboratory, in flight, and on the runway before flight; (2) Underfly the SeaWIFS satellite sensor with AVIRIS matching observation geometry and addressing weather, satellite, aircraft, sensor, and location issues; (3) Correct AVIRIS spectral image data to the top of the atmosphere radiance; (4) Convolve AVIRIS spectral channels to SeaWIFS bands; (5) Determine and extract matching areas with correct observation geometry; (6) Compare and analyze the matchup data and repeat acquisitions for monitoring.

In 1999: (1) AVIRIS data were acquired for SIMBIOS investigators; (2) intercomparisons between AVIRIS and other radiometric calibration standards were made; and (3) AVIRIS underflew the SeaWIFS satellite sensor. The current results of the 1999 year activities are given in this report.

12.2 RESEARCH ACTIVITIES

Laboratory Cross Comparisons

In 1999 three efforts were undertaken for cross comparison of laboratory radiometric standards. An initial effort was made in April to compare the AVIRIS 1999 radiometric standard with a SIMBIOS ocean radiometer. The results were highly variable. Upon further analysis it was concluded that the differences in the apertures and instantaneous fields of view of the AVIRIS and the SIMBIOS ocean radiometer did not support this cross comparison.

In June of 1999, the SIMBIOS Transfer Radiometer (SXR) became available. In this timeframe, an effort was made to use the SXR to cross compare the AVIRIS and SIMBIOS absolute radiometric standards. Initial analysis of these data were promising, however, the SXR did not give good repeatability before and after the measurements in the AVIRIS calibration laboratory. This was the first use of the SXR and future measurements with the AVIRIS calibration standards are expected.

Finally, the Landsat Transfer Radiometer (LXR) was able to view the AVIRIS radiometric calibration standard in the June 1999 timeframe. The LXR is similar, but has a longer heritage than the SXR. Analysis of the cross comparison of the LXR and AVIRIS 1999 radiometric standard was completed with good stability before and after the measurements. Results of this analysis are given. In the 440 nm region the agreement was 1.08%, in the 655 nm region the agreement was 1.45% in the 830 nm region the agreement was 1.35%.

The AVIRIS radiometric standard is a reflectance panel illuminated by a calibration quartz-halogen lamp. This standard provides a smooth and repeatable radiometric output between the measured LXR wavelength regions. These characteristics suggest that the AVIRIS 1999 calibration agreement will be comparable across the spectral range spanned by the LXR measurements. The results with the LXR are consistent with the expected uncertainty of 2% to 3% of the AVIRIS 1999 radiometric calibration standard in the spectral region.

Analysis of 990807 SeaWIFS Underflight

On the 7th of August 1999 AVIRIS successfully underflew the SeaWIFS satellite sensor off the east coast of the United States. To compare SeaWIFS and AVIRIS data, the data sets must be warped into the same geometric space, so that direct comparisons are available between pixels which match in space, time, illumination angle, and observation angle. AVIRIS has a 15° scan angle. In order to match the ~20° view angle of SeaWIFS, the AVIRIS ER-2 platform is flown in a circle, with the plane banked at 20°. AVIRIS is typically flown in two circles during the time of a SeaWIFS overpass. Once the two data sets are projected into the same geometric space, the SeaWIFS region and AVIRIS region with overlapping observation geometry can be selected, and the resulting radiance compared.

Results for the 990807 AVIRIS underflight were calculated for two cases: matching illumination/observation angles to within 2°, and matching geometry to within 5°. Radiometric calibration agreement ranges from 2% to 12% across the eight SeaWiFS bands, with band 6 having the largest discrepancy.

12.3 WORK PLAN

In 1999, under this component of the SIMBIOS effort, AVIRIS data have been acquired for SIMBIOS investigators, three radiometric calibration standard cross comparison experiments have been orchestrated, and one successful underflights of SeaWIFS by AVIRIS was completed. The AVIRIS data acquired for the SIMBIOS investigators has been delivered to them and to the SIMBIOS Project (Table 1). Based on repeatability analysis only one of the cross comparison experiments was deemed successful. The results from this experiment show that the AVIRIS 1999 radiometric calibration standard agrees with the Goddard Space Flight Center Landsat Transfer Radiometer at the 2% level. This is consistent with the level of uncertainty expected and consistent with the calibration and validation objectives of this activity. On the 7th of August 1999 AVIRIS successfully underflew the SeaWIFS satellite sensor. Analysis of these data show radiometric calibration agreement ranging from 2% to 12% across the eight SeaWIFS bands. Analysis is continuing to review this comparison and attempt to tighten the confidence in the result.

A second successful underflight was completed on the 1st of October 1999. Comparison of the 7 August and 1 October 1999 result will provide insight into the repeatability of this on orbit calibration and validation experiment. In November of 1999 a new radiometric calibration standard will be integrated into the AVIRIS sensor laboratory. This 3000 degree cavity blackbody source will give an additional check on the absolute radiometric calibration of AVIRIS. This new standard may also allow tightening of the AVIRIS absolute radiometric calibration to 1% across the full spectral range. Results of these new activities and there impact of this SIMBIOS effort will be reported in the future.

ACKNOWLEDGMENTS

This research was carried out at the Jet Propulsion Laboratory/California Institute of Technology, Pasadena, California, under contract with the National Aeronautics and Space Administration. This research was funded as part of the SIMBIOS Project at the Goddard Space Flight Center of the National Aeronautics and Space Administration.

Table 1. AVIRIS data have been measured for the SIMBIOS Project in 1997, 1998, and 1999. Given below is a summary of this data and the status of delivery at various levels of processing. The following calibrated AVIRIS radiance data were delivered to the SIMBIOS Project in 1999.

Data set	**PI**	**Target**
f970410t01p02_r03	Robert O. Green	CalCOFI Boat Overpass
f970520t01p02_r02	Robert O. Green	OCTS underpass
f971002t01p02_r02	Robert O. Green	CalCOFI Boat Overpass
f971002t01p02_r03	Robert O. Green	SEAWIFS underpass
f980530t01p02_r06	Robert O. Green	SEAWIFS underpass
f981031t01p01_r02	Kendall L. Carder	Lake Okeechobee
f981031t01p01_r03	Kendall L. Carder	Sarasota Bay
f981031t01p01_r04	Kendall L. Carder	Tampa Bay
f981116t01p02_r03	Kendall L. Carder	Tampa Bay
f990521t01p02_r02	Kendall L. Carder	Lake Okeechobee 3
f990521t01p02_r03	Kendall L. Carder	Lake Okeechobee 1
f990521t01p02_r04	Kendall L. Carder	Lake Okeechobee 2
f990524t01p02_r02	Kendall L. Carder	Bahamas 2
f990524t01p03_r01	Kendall L. Carder	Bahamas 2
f990524t01p02_r01	Kendall L. Carder	Bahamas 1
f990807t01p02_r03	Robert O. Green	SEAWIFS underpass
Additional data that have been acquired and will be delivered as calibrated radiance are:		
f991001t01p02_r05	Robert O. Green	SEAWIFS underpass
f991013t01p02_r09	Robert Frouin	4 meter Whitecaps
Data analyzed and generated for this project have been delivered for the following SEAWIFS underpasses:		
f970520t01p02_r02	Robert O. Green	AVIRIS convolved to OCTS bands AVIRIS geocorrected data (circles) OCTS scene subset (geocorrected)
f971002t01p02_r03	Robert O. Green	AVIRIS convolved to SEAWIFS bands AVIRIS geocorrected data (circles) SEAWIFS scene subset (geocorrected)
f990807t01p02_r03	Robert O. Green	AVIRIS convolved to SEAWIFS bands AVIRIS geocorrected data (circles) SEAWIFS scene subset (geocorrected)
Data analyzed and generated for this project will be delivered for the following SEAWIFS underpasses:		
f991001t01p02_r05	Robert O. Green	AVIRIS convolved to SEAWIFS bands AVIRIS geocorrected data (circles) SEAWIFS scene subset (geocorrected)

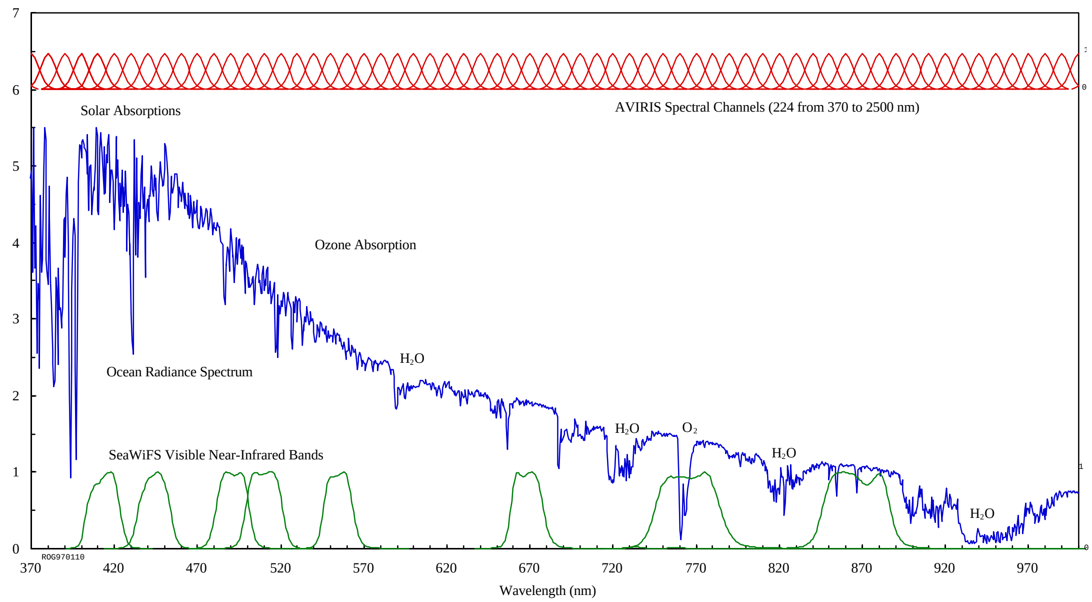

Figure 1. This plot shows the eight SeaWIFS bands and the AVIRIS spectrally contiguous channels in the region from 370 to 1000 nm. A high spectral resolution modeled plot of the typical upwelling spectral radiance for an ocean target is shown in blue.

This research was supported by the

SIMBIOS NASA interagency agreement

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Chapter 13

Merging Ocean Color Data from Multiple Missions

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13.1 INTRODUCTION

Oceanic phytoplankton may play an important role in the cycling of carbon on the Earth, through the uptake of carbon dioxide in the process of photosynthesis. Although they are ubiquitous in the global oceans, their abundances and dynamics are difficult to estimate, primarily due to the vast spatial extent of the oceans and the short time scales over which their abundances can change. Consequently, the effects of oceanic phytoplankton on biogeochemical cycling, climate change, and fisheries are not well known.

In response to the potential importance of phytoplankton in the global carbon cycle and the lack of comprehensive data, the NASA and the international community have established high priority satellite missions designed to acquire and produce high quality ocean color data. Seven of the missions are routine global observational missions: OCTS, POLDER, SeaWiFS, MODIS-AM, MERIS, GLI, and MODIS-PM. In addition, there are several other missions capable of providing ocean color data on smaller scales. Most of these missions contain the spectral band complement considered necessary to derive oceanic pigment concentrations (i.e., phytoplankton abundance) and other related parameters. Many contain additional bands that can provide important ancillary information about the optical and biological state of the oceans.

Any individual ocean color mission is limited in ocean coverage due to sun glint and clouds. For example, one of the first proposed missions, the SeaWiFS, can provide about 45% coverage of the global ocean in four days and only about 15% in one day (Gregg and Patt, 1993).

Objectives

We propose to investigate, develop, and test algorithms for merging ocean color data from multiple missions. We seek general algorithms that are applicable to any retrieved ocean color data products, and that maximize the amount of information available in the combination of data from multiple missions. Most importantly, we will investigate merging methods that produce the most complete coverage in the smallest amount of time, nominally, global daily coverage. We will also assess the ability to produce fuller coverage in larger time increments, including 4-day, 8-day (weekly), monthly, seasonal and annual. We intend to develop methods that are not mission-specific, but take advantage of the unique characteristics of the missions as much as possible.

13.2 RESEARCH ACTIVITIES

Work has focused on 1) defining the problems and opportunities provided by the existence of multiple sensors, 2) analysis of past sensors to provide insights into the characteristics, drawbacks, and advantages of individual sensor responses in the context of merging, and 3) analysis, development, and testing of candidate merger algorithms.

Defining Problems and Opportunities of Multiple Missions

A) First we assessed the global coverage improvements possible by the 6 global missions. These results show that significant scientific advantages can accrue from assembling and merging data from the multiple satellite platforms proposed for ocean color in the next decade. The principal advantages are increased ocean coverage in less time, and new observations of the daily dynamics of phytoplankton abundances, resulting from different observation times of co-located ocean areas. Data from three satellites can increase ocean coverage by 58% for one day, and 45% for four days. Additional satellites produce diminishing returns, however. This latter point is not necessarily an adverse finding, since each mission has a limited life expectancy and in-flight problems are, unfortunately, still not rare in the satellite business. Using observations from pairs of missions, as much as 14 hour time differences at co-located points can be realistically achieved at high latitudes, even considering the distribution of land masses and ice cover. Smaller time differences are observed at lower latitudes, but 5 to 7 hour differences are still available. Furthermore, massive numbers of these co-located pairs are available, suggesting that routine scientific studies of diel phytoplankton variability can be supported. These results were published in the IEEE Transactions on Geoscience and Remote Sensing (Gregg et al., 1998).

B) More detailed analyses emphasized seasonal and regional coverage improvements and was limited to the SeaWiFS/MODIS combination, since these are the two missions planned for launch next. The results showed that the launch of EOS AM-1 provides an opportunity to potentially improve ocean color observations by combining data from the SeaWiFS and MODIS missions. The sensors have different scanning characteristics and are flying on different platforms in different orbits. The results suggested that very large improvements in coverage frequency (daily to four-day) can be obtained by combining data from both sensors: 40-47% increases in global coverage over SeaWiFS alone in one day, and > 100% in areas near the solar declination. Four-day increases are slightly smaller for global coverage, 29-35%, but meridional percent increases are similar to the one-day case. These differences are due to reduced sun glint contamination obtained by tilting (SeaWiFS), and scanning away from the maximum glint region (MODIS), due to its 10:30 AM equator crossing time, and due to the large scan width of MODIS. The results show that SeaWiFS and MODIS are very complementary ocean color missions that can provide more complete observations of ocean processes at high frequency if data are combined. These results were published in the IEEE Transactions on Geoscience and Remote Sensing (Gregg and Woodward, 1998). A more detailed paper with more fully defined results was published as a NASA Technical Memorandum (Woodward and Gregg, 1998).

C) Assessed potential capability for improving ocean color observations by selecting complementary mission orbits. Considering that observations are severely hampered by cloud cover and sun glint, a possibility exists for using multiple missions to improve the coverage of the oceans in shorter time scales. In fact, only about 10-18% of the oceans are observed in a single day, even by so-called global observational missions, due to these two ocean color contaminants. Analysis of a 7-day period of cloud cover from the International Satellite Cloud Climatology Project (ISCCP), show that 12% new surface area is available for viewing each day. This translates to an increase of about 0.5% per hour of separation in viewing times. Thus if the ocean could be viewed by 2 different satellites 4 hours apart, 2% more ocean area could be observed. This represents a coverage increase of about 13%. If 2 satellites were placed in Earth orbit with equator crossing times 4 hours apart, the improvement in coverage by these 2 satellites over a single one is about 60%. Furthermore, by managing the orbits of the 2 satellites, nearly complete sun glint avoidance can be achieved, further improving the ocean coverage. The best improvements can be made by 2 satellites in the same node, whose orbital positions are adjusted to view the sun glint contaminated areas of the other. If scan edges are useful for quantitative ocean color observations (the validity of which is unknown at this time), then only 2 polar-orbiting satellites are necessary. If not, a third satellite is necessary, preferably in a low inclination orbit where losses in coverage in the tropics by the polar orbiters can be best compensated (polar orbiters overlap coverage at high latitudes, and the scan edges are necessary only near the equator). However, the best configuration is 3 geostationary satellites, which provide complete global coverage routinely with a viewing time separation that can maximize cloud and sun glint avoidance, with a single polar orbiter to provide high latitude coverage. This option is considered expensive at the present time, however.

Analysis of Past Sensors

Investigations with OCTS began before the failure of ADEOS, in an effort to characterize its ocean color data for use with a merging activity with SeaWiFS. The loss of data from the sensor precludes its use in merging, but the similarity of some aspects of sensor design with MODIS suggests that significant understanding of the capabilities and deficiencies of MODIS data can be facilitated through a thorough analysis of OCTS data. In fact, we have found this to be true. Initial observations just after failure of OCTS suggested 6 problem areas: band registration, image striping, cloud noise, navigation, calibration, and bright target response (Gregg, 1997). Analysis of the first three led to solutions that improved imagery substantially (Gregg, 1998; Gregg, 1999). Particularly the methods for reducing image striping is a useful method for a problem expected to occur in MODIS imagery. Analysis of geolocation, radiometric stability and accuracy, and bright target responses were characterized (Gregg et al., 1999). The results here also have implications for MODIS.

Analysis of OCTS imagery indicated three areas of impairment for quantitative scientific research applications: 1) band misalignments, 2) image striping, and 3) image noise. These impairments are caused by 1) band offsets in the sensor design, 2) detector radiometric response variability, and 3) cloud contamination (primarily) and the band offset design (partially), respectively. The band offset design has potentially serious implication for ocean color research, given the presence of small scale variability, the requirement of multiple bands to produce ocean color geophysical outputs, and the sensitivity of the algorithms. A nearest neighbor band-to-band co-registration method produces the best results, with the least image noise, best cloud identification potential, and most accurate depiction of the actual full spectral suite at a given location. The offset design, however, still produces inconsistencies in a spectral understanding of each OCTS IFOV, and therefore provides a limitation on the sensor's ultimate capability. We found it effective to handle image striping by linearizing detector responses to the extent possible, and then applying a median filter to a quasi-chlorophyll product to smooth out the individual detector responses. Location of the total radiances used to produce the median filtered quasi-chlorophyll are retained and enable smoothing of the total radiances, after which a straightforward application of atmospheric correction can be performed. The net effect of both band co-registration and image striping reduction is to reduce the actual spatial resolution from < 1 km to about 5 km. A multi-step method for identifying and removing cloud effects was found to be a reasonably effective method.

The OCTS archive collected by NOAA and NASA over the US East Coast and Gulf of Mexico appears to contain a geometric offset of 4 to 5 pixels in the along-track direction. Analyses of scan edges indicate that an adjustment to the tilt produces the most reliable agreement to a high resolution land data file. Analysis using an island matching algorithm confirm that an adjustment to the tilt reduces the along-track bias: from about 5 pixels to 1.5 pixels for the tilted segment of operations Mar. 18, 1997 to end of mission, and from 2.6 to less than 0.3 pixels for the nadir pointing operations for Dec. 15, 1996 to Mar. 18, 1997.

OCTS appears to exhibit near field scatter effects in its imagery. These effects are substantial in magnitude, and have a spectral character, but are limited to approximately the dimensions of the focal plane (30 pixels wide by 10 pixels long). Not all bright targets exhibit these near field effects, nor do the effects always last the width of the focal plane. Most land features in the data set do not appear to produce effects as large as clouds, which is consistent with their relative brightness. Far field scatter effects are difficult to demonstrate conclusively, since haze or sub-saturating clouds cannot be ruled out. However, large cloud features nearly always produce successively decreasing reflectance far from their locations, and extending in all directions. The effects also appear to be non-spectral, which conforms to the effects of far field scatter. However, these effects, if they are in fact sensor-derived, are not large although long lasting, and do not necessarily produce adverse effects on ocean chlorophyll estimates because of the error-correcting nature of the atmospheric correction algorithms. Exceptions may occur in the presence of large amounts of troposheric aerosols, whose scattering properties differ greatly from those of far field scatter and sub-saturating clouds. In any event, similar problems, e.g., sub-saturating clouds and thick haze, are encountered by all ocean color sensors, and probably do not have a large impact on the derivation of ocean properties. However, these effects could impact aerosol analyses over the oceans.

OCTS aerosol bands exhibit substantial short term variability, producing daily differences in aerosol reflectance ratios of 5 to >10%. Determination of longer term trends in the stability of the aerosol bands is inconclusive, because of the apparent long-term signal is much smaller than the short term variability, and because a complete seasonal cycle is not available due to the untimely loss of the mission after 9 months. Atmospheric correction appears to reduce the magnitude of this short term variability when observing normalized water-leaving radiances, which exhibit daily variability of only about 1-5%. Seasonal variability also appears to exist, although observations in other areas of the oceans are necessary to conform that these are not sensor effects. Similarly, long-term trends of the sensitivity of OCTS Bands 1-5 are inconclusive because of these daily and seasonal effects, which exceed the apparent mission lifetime effect. Comparison of calibration adjustment factors derived from 6 *in situ* data sources with those obtained from an independent *in situ* data set (Shimada et al., 1998) show good agreement in the bands used to evaluate the optical state of water (Bands 1-5). Maximum differences in these bands are < 4%, and differences 1% or less are observed in Bands 1 and 2. Aerosol bands differ up to 5% in Bands 6 and 7 and 11% in Band 8, but are attributed to a measurement of Band 8 by an aircraft underflight by Shimada et al. (1998) , while Band 8 is assumed unadjusted from its pre-flight value here, due to our inability to evaluate it by any other means. However, the relative adjustments to Band 7 used here produce λ (765,865) values in open ocean near 1, which are expected under most conditions, as opposed to about 1.15 using the Shimada corrections, which is somewhat higher than expected.

Analysis and Development of Merging Algorithms

Efforts have began on developing merging algorithms. We are investigating four possible approaches:

- simple splicing/averaging, where data from 2 or more satellites are averaged where they coexist at grid points, and use of a single satellite in gaps where only one exists,
- subjective analysis, where specific dependences and deficiencies are identified using knowledge about sensor environmental conditions and co-located observations are merged using different weighting functions for the sensors,
- the Conditional Relaxation Analysis Method (CRAM), where the best data are selected as interior boundary conditions into a merged set using Poisson's equation, and
- optimal interpolation, where merging occurs by weighting individual sensor data to minimize spatial covariance function.

All forms have been implemented in software, and analysis of conceptual strengths and weaknesses has begun. Analysis of SeaWiFS and simulated MODIS can provide insight into operational aspects of the algorithms, but flight data are necessary to refine these conclusions.

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Chapter 14

Validation of Bio-Optical Properties in Coastal Waters: A Joint NASA-Navy Project

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14.1 INTRODUCTION

This project is a joint effort between NASA's Earth System Science Office and the Naval Oceanographic Office (NAVOCEANO) at the John C. Stennis Space Center, MS. The collaboration reflects a partnership developed by NASA and NAVOCEANO over seven years to share resources and expertise in the collection of ocean optics, hydrographic, biological, and remotely sensed data to support each agency's goals in coastal research. NAVOCEANO provides ship time, instrumentation, and operational support during oceanographic surveys while NASA provides expertise in data collection, computer programming and modeling, and data processing and analysis.

This SIMBIOS Project was established to provide data collected in the South China Sea, Gulf of Thailand and adjacent coastal waters. This project is designed to provide NASA with cost-effective access to in-water optics and ancillary data in coastal waters representing diverse turbid environments, and if successful, will help provide an effective mechanism for interagency cooperation and data exchange.

14.2 RESEARCH ACTIVITIES

NAVOCEANO hydrographic surveys 621198 (USNS Bowditch, 11 - 30 September 1998) and 261299 (USNS Silas Bent, 8 - 22 July 1999) were completed in the Gulf of Thailand and South China Sea, respectively. The SIMBIOS Project investigators comprise the optics team of these surveys, one of three primary operations: optics, bioluminescence, and basic hydrography. Vertical profiles were acquired by each operations team following a dense grid of selected stations.

The equipment employed during survey 621198 included a SIMBIOS Project Microtops II Sunphotometer, a GER (Geophysical Environmental Research, Inc.) 1500 hand-held spectroradiometer (300 -100 nm, effective 1 nm bandwidth), a SBE-19 CTD (Sea-Bird Electronics, Inc.), a WetStar flow-through fluorometer (Wet Labs, Inc.), 2 SeaTech transmissometers (490 nm and 532 nm), and a Seapoint turbidity meter. Several optical instruments (e.g., Satlantic SPMR, AC-9) and supporting computer hardware did not arrive at port of departure prior to sailing. Furthermore, weather conditions limited sampling during this survey to about 10 days. Vertical profiles were taken at 80 stations using a single package containing the CTD, WetStar, transmissometers and the turbidity meter. Above-water remote sensing reflectance spectra were taken during the day (11 stations) given appropriate conditions of solar zenith angles (avoidance of sun glint), sea state, and cloud clover. A Spectralon 10% reference placard was used a reflectance standard. Two PC-based programs were written to acquire and analyze GER reflectance spectra and calculate remote sensing reflectance following the methods outlined in Mueller and Austin (1995) and Lee et al. (1997).

The equipment employed during survey 621198 included a SIMBIOS Project Microtops II Sunphotometer, a GER (Geophysical Environmental Research, Inc.) 1500 hand-held spectroradiometer, a SBE-19 CTD (Sea-Bird Electronics, Inc.), 2 AC-9s (Wet Labs, Inc.), a Satlantic SPMR (SeaWiFS Profiling Multispectral Radiometer) and a TRSBII (Satlantic, Inc.) Power and communications to the AC-9s and CTD were provided by MODAPS (Modular Ocean Data and Power System, Wet Labs, Inc.). The CTD and AC-9s were deployed at 76 stations. The inflow tubes of one AC-9 were fitted with a 0.2 μm inline filter to partition the total spectral absorption and beam attenuation into dissolved and particulate fractions. Temperature, salinity and scattering corrections were applied to all AC-9 data. Scattering corrections used either Method 1 of the Zaneveld Method (AC-9 User Guide, Wet Labs, Inc). A branching algorithm was used based on the a715 nm / b715 nm ratio to select which scattering method was applied. Method 1 was used for ratios greater than 0.35. The Zaneveld Method was used for ratio values <= 0.35. The Satlantic SPMR and TRSBII were deployed at 38 stations during the day when the solar zenith angle was less than 60^0 and profiles analyzed using the vendor-supplied PROSOFT analysis program. GER above-water reflectance spectra were obtained at 33 stations and processed as outlined above. Comparison between in-water (Satlantic) and above-water (GER) estimates of remote sensing reflectance is now underway.

Discrete Water Samples: At most stations, discrete water samples were collected at select depths (based on profiling transmissometer and fluorometer data) using Niskin Bottles mounted on a hydrographic CTD rosette. These water samples were filtered for analysis of fluorometric chlorophyll a and phaeopigments, HPLC pigments, CDOM absorption, particle absorption (QFT), and total suspended mater. All samples were collected and processed following the procedures of Mueller and Austin (1995). HPLC pigments determined were chlorophyll a, chlorophyll b, peridinin, fucoxanthin, 19'hex, prasinoxanthin, alloxantin, lutein, zeaxanthin, diadinoxanthin, canthaxantin, and β-carotene. Absorption spectra were determined for total, detrital, and phytoplankton components following the hot-methanol extraction technique (Kishino et al., 1985). Corrections for path-elongation were performed following the method of Mitchell (1990). CDOM absorption spectra were collected using a Perkin-Elmer Lambda 3 spectrophotometer. The number of samples collected for each analysis were (Survey 621198; 261299): HPLC (35; 54), fluorometic chl a (33; 53), total suspended mater (33; 77), CDOM absorption (33; 36), and particle absorption (18; 54).

14.3 RESULTS

The lack of equipment on survey 621198 in the Gulf of Thailand significantly handicapped the full collection of data as proposed, but allowed the development deployment, acquisition, and analysis procedures for the GER reflectance spectra. Hence, a SIMBIOS year 2 "replacement" cruise was planned and conducted as survey 261299 in the South China Sea. This cruise was able to follow the proposed work plan with regards to data collection and processing. In general, instrument calibration and data collection followed the guidelines provided by the proposal. Intermittent problems were again encountered with the MODAPS system restricting the number of deployments The problem was isolated as a grounding-loop problem that will be corrected in future cruises.

A major milestone related to data release was accomplished in late April 1999. Under the command of the CMNMOC NAVOCEANO was formally granted permission to release ocean optics data collected by NAVOCEANO to the SIMBIOS program for algorithm development and digital product generation. From this approval, the project is currently integrating the data collected into a unified dataset for regional algorithm development.

14.4 WORK PLAN

The project is actively processing the data from the three surveys completed as part of this SIMBIOS Project. Given the formal release of the data, the project directed all activities to providing quality control, formatting, and instrument calibration to transmit this large collection of data to the SeaBASS archive. A significant set of these data have been submitted to the SIMBIOS program office.

The project will conduct at least one additional survey in both the Gulf of Thailand and the South China Sea. Data collected during the life of the project will be analyzed as described in the original proposal. A Hydroscat-2 (442 and 589 nm) will be deployed. Regional bio-optical algorithms will be developed. A comparison between in-water, above-water, and SeaWiFS remote sensing reflectance will be made.

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Chapter 15

Bio-Optical Measurement and Modeling of the California Current and Polar Oceans

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15.1 INTRODUCTION

This SIMBIOS Project contract supports *in situ* oceanic optical observations in the California Current and Southern Ocean. The principal objectives of this research are to validate standard or experimental products through detailed bio-optical and biogeochemical measurements, and to combine ocean optical observations with advanced radiative transfer modeling to contribute to satellite vicarious radiometric calibration and algorithm development.

In collaboration with the California Cooperative Oceanic Fisheries Investigation (CalCOFI) and US Joint Global Ocean Flux Study (JGOFS) programs, our sampling efforts have been focused primarily on the California Current and Antarctic waters, with the purpose of generating a high-quality, methodologically consistent data set encompassing a wide-range of oceanic conditions. In the past year we have collaborated with other SIMBIOS PIs to collect data in the Atlantic and Indian Oceans and we are merging our Office of Naval Research (ONR) sponsored Sea of Japan data set to the SIMBIOS database. The combined data base we have assembled includes stations which cover the clearest oligotrophic waters to highly eutrophic blooms and red-tides, and provides a coherent set of observations to validate bio-optical algorithms for pigments, inherent optical properties and primary production. This unique and comprehensive data is utilized for development of experimental algorithms (e.g. high-low latitude pigment transition, phytoplankton absorption, photosynthesis, and cDOM).

15.2 RESEARCH ACTIVITIES

Field methods and data

The Southern California Bight region, from San Diego to just north of Point Conception, has one of the longest, most comprehensive time-series of marine observations; the CalCOFI. This region experiences a large dynamic range of coastal and open ocean trophic structure, and has been extensively studied with respect to its regional optical properties in an effort to develop regional ocean color algorithms (e.g. Smith and Baker 1978, Mitchell and Kiefer 1988, Sosik and Mitchell 1995). During the second year of our contract, we participated in 3 CalCOFI cruises in the California Current region as part of the CalCOFI program.

The Southern Ocean is a large, remote region, which plays a major role in global biogeochemical cycling. Despite evidence that bio-optical relationships in these waters can diverge significantly from lower-latitude waters (e.g. Mitchell and Holm-Hansen 1991), Antarctic waters have been under-represented in the databases (e.g. SeaBAM) used to formulate and test modern ocean color algorithms. During the past year, we have analyzed detailed observations collected in year 1 of our SIMBIOS Project and have published novel algorithms for retrieval of particulate organic carbon (Stramski et al., 1999) and have submitted a detailed optical model for Southern Ocean waters (Reynolds et al., submitted).

On all cruises, an integrated underwater profiling system was used to collect optical data and to characterize the water column. The system included an underwater radiometer (Biospherical Instruments MER-2040 or MER-2048) measuring depth, downwelling spectral irradiance (Ed) and upwelling radiance (Lu) in 13 spectral bands. A MER-2041 deck-mounted reference radiometer (Biospherical Instruments Inc) provided simultaneous measurements of above-surface downwelling irradiance. Details of the profiling procedure, characterization and calibration of the radiometers, data processing and quality control are described in Mitchell and Kahru (1998). The underwater radiometer was also interfaced with 25 cm transmissometers (SeaTech or WetLabs), a fluorometer, and SeaBird conductivity and temperature probes. When available, additional instrumentation integrated onto the profiling package included AC9 absorption and attenuation meters (WetLabs Inc.), and a Hydroscat-6 backscattering meter (HobiLabs).

In conjunction with *in situ* optical measurements, discrete water samples were collected from a CTD-Rosette immediately before or after each profile for additional optical and biogeochemical analyses. Pigment concentrations were determined fluorometrically and with HPLC. Spectral absorption coefficients (300-800 nm) of particulate material were estimated by scanning particles concentrated onto Whatman GF/F (Mitchell, 1990) in a dual-beam spectrophotometer (Varian Cary 1). Absorption of soluble material was measured in 10 cm cuvettes after filtering seawater samples through 0.2 um pore size polycarbonate filters. We have also been collecting detailed measurements of other optical and phytoplankton properties including phycoerythrin pigment, size distribution using a Coulter Multisizer, photosynthesis, and particulate organic matter (carbon and nitrogen).

15.3 RESEARCH RESULTS

a) Chlorophyll algorithms

CalCOFI data represents approximately 30% of the data used by O'Reilly et al. (1998) for development of the operational SeaWiFS Ocean Color 2 version 2 algorithm (OC2v2). We have evaluated this algorithm compared to a CalCOFI-specific regional algorithm (CAL-P6) using match-ups collected during CalCOFI cruises (Kahru and Mitchell, in press). At this time the atmospheric correction or calibration errors in the retrieval of LWN create larger errors in chl-a retrieval than differences between OC2v2 and CAL-P6. For the Southern Ocean, however, there is a significant bias in the OC2v2 algorithm, which warrants a focused effort – at low chlorophyll a OC2v2 underestimates chlorophyll a, and it overestimates at high chl-a. Figure 1 illustrates the LWN (490)/ LWN(555) ratio plotted against chl-a for our combined RACER and JGOFS Southern Ocean data sets. This region has been shown to have bio-optical algorithms that are different than low latitude regions such as CalCOFI (Mitchell and Holm-Hansen, 1991; Mitchell, 1992; Arrigo et al., 1998). Our results underscore the eventual need for specific regional algorithms to obtain more accurate estimates of chlorophyll a and primary production from ocean color remote sensing. Regional algorithms will require procedures to allow transition from low latitude to high latitude without introducing errors at the lower latitudes. Unfortunately, there is relatively little data in the polar front region; we have less than 20 observations from JGOFS, and there are no reports of other data in this region. Also lacking in the polar Southern Ocean data sets are combined pigment and optical observations in the extremely low chlorophyll regions that can be observed in the SeaWiFS imager for the southern Pacific Ocean sector west of the Drake Passage, and the southern Indian Ocean sector west of Kerguelan Island. These two regions represent very low satellite-derived chlorophyll which never exceed values of 0.2 mg chlorophyll a m^{-3}.

b) LWN match-ups: in situ instrument intercomparison

During INDOEX, we deployed our Biospherical Instruments MER-2048 and the SIMBIOS pool Satlantic SPMR radiometer at the same stations. The MER-2048 was deployed from the ship's stern A-frame, with potential contamination by ship's shadow, and the SPMR was deployed in free-fall mode, which would have no ship shadow artifacts. Figure 2A is a scatter plot for SeaWiFS channels of LWN derived from the two systems. Overall, the correspondence is excellent with no bias relative to the 1:1 relationship. Figure 2B is a plot of MER-2048 and SPMR derived spectral LWN compared to SeaWiFS derived LWN for a clear sky match-up. The issues of poor LWN retrieval reviewed by Kahru and Mitchell (in press) and Mitchell and Flatau, 1998 are evident.

Evaluation of atmospheric correction schemes

The SIMBIOS Project has defined a need to evaluate the atmospheric correction algorithms for SeaWiFS, and convened a workshop which led to the proposal of 6 separate atmospheric correction schemes. We evaluated all 6 schemes with our match-up data (25 match-ups, 17 of which are from CalCOFI). Evaluation of satellite-retrieved normalized water-leaving radiances (LWN) was done by comparing SeaWiFS HRPT images with *in situ* data collected concurrently (± 4 hours). HRPT data were processed to LWN using SeaDAS 3.3 software (Fu et al. 1998; update 004 released 9/1/99). The level 2 generation atmospheric correction module of this version of SeaDAS was modified by the SIMBIOS Project with 6 candidate codes to be evaluated. Satellite values were derived as averages over 3 x 3 pixel areas centered at the *in situ* measurement. In summary, these comparisons reveal under-estimation of the SeaWiFS-retrieved LWN using the "baseline" algorithm compared to *in situ* measurements; the discrepancies were larger for pooled data greater than 1 mg chl m^{-3}. An example of the SeaWiFS retrieved problem is illustrated in Figure 2B. The differences were generally smallest in the 555 nm band, and largest at shorter wavelengths. Some of the proposed atmospheric correction revisions improved the underestimation, but none of the candidate algorithms was capable of retrieving accurate LWN for SeaWiFS bands 1 and 2. Part of the problem at short wavelengths may be attributed to calibration errors rather than issues related to the zero water leaving radiance assumptions or aerosol models of the base line processing.

15.4 WORK PLAN

Our participation in the quarterly CalCOFI cruises in the California Current will continue throughout the next period. We also hope to carry out at least 1 cruise to the Southern Ocean as well as additional cruises in Korean waters. We will continue data processing from previous cruises, including CalCOFI, JGOFS, INDOEX and Japan/East Sea. Specific attention will be placed on developing routine processing schemes for our AC9 and Hydroscat data. We will continue our modeling efforts to improve our understanding of regional bio-optical properties and their relationship to biogeochemical parameters (e.g. Reynolds et al, submitted). Our goal is to develop appropriate regional parameterizations for semi-analytical inversion models for the retrieval of inherent optical properties as well as biogeochemical properties besides chlorophyll a from satellite ocean color data.

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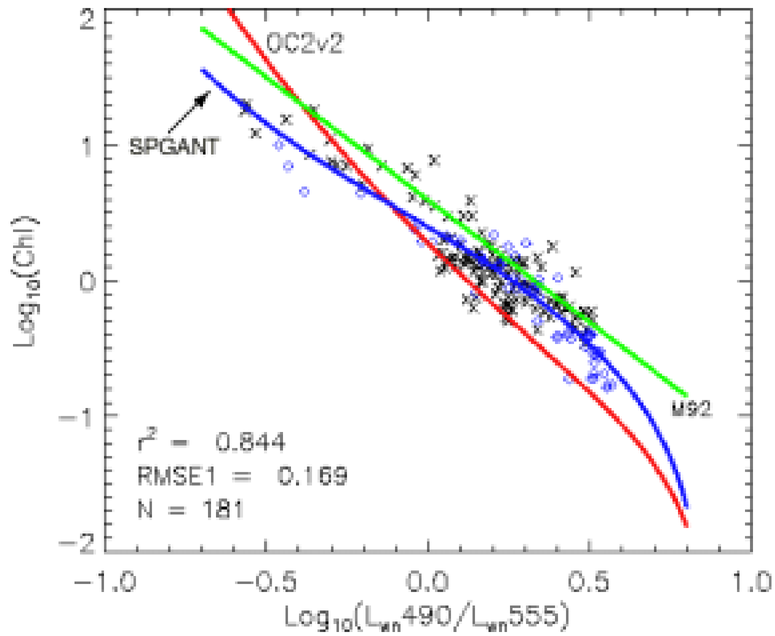

Figure 1. The relationship between log transformed values of LWN(490)/LWN(555) versus chlorophyll a for Southern Ocean data. Curves represent the SeaWiFS OC2v2, Mitchell 1992, and our latest Southern Ocean algorithm SPGANT.

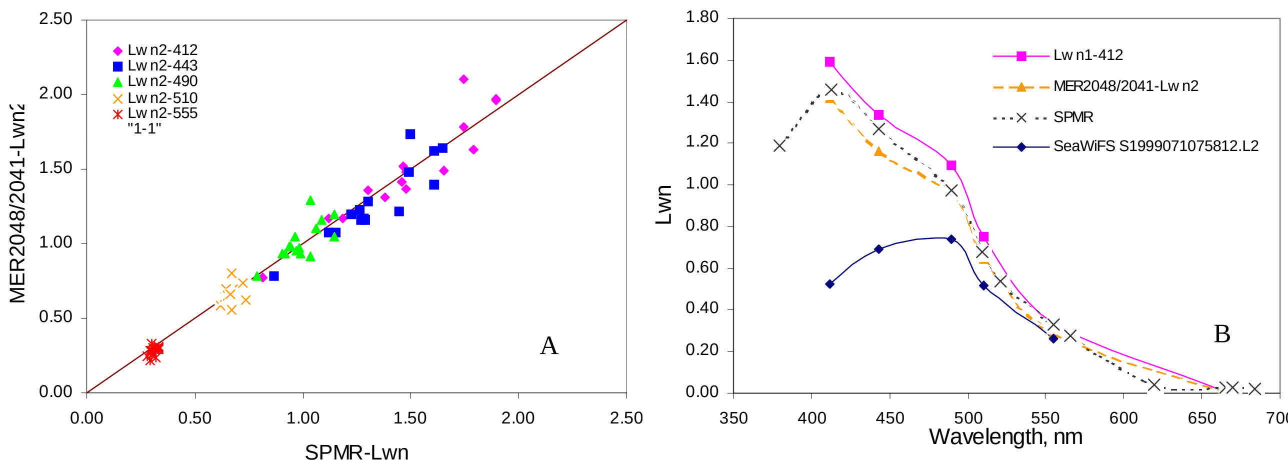

Figure 2. A. Scatter plot of LWN estimates for several stations during INDOEX derived from data using our Biospherical Instruments MER 2048 and the SIMBIOS pool Satlantic SPMR.
B. Spectral plot of LWN derived from SeaWiFS and from two different in-water profilers.

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Chapter 16

SIMBIOS Normalized Water-Leaving Radiance Calibration and Validation: Sensor Response, Atmospheric Corrections, Stray Light and Sun Glint

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16.1 INTRODUCTION

This SIMBIOS contract supports acquisition of match up radiometric and bio-optical data to validate SeaWiFS and other ocean color satellites, and experiments to evaluate uncertainty budgets and protocols for *in situ* measurements of normalized water leaving radiance.

16.2 RESEARCH ACTIVITIES

Two cruises (GoCAL98B in Nov-Dec 1998 and GoCAL99A in April 1999) were completed in the Gulf of California during the second year of the contract. These cruises were carried out aboard a Mexican research vessel in collaboration with Drs. H. Maske, R. Lara-Lara, and S. Alvarez-Borrego at the Centro de Investigacion Cientificay de Educacion Superior de Ensenada (CICESE) in Ensenada, Mexico, and with Drs. R. Zaneveld and S. Pegau of Oregon State University (OSU), Corvallis (SIMBIOS Contract NAS5-97129). Radiometric profiles, HPLC and fluorometric chlorophyll a samples, and inherent optical properties (OSU) were measured at 32 and 37 station locations during GoCAL98B and GoCAL99A, respectively. Station distributions during each cruise covered the entire Gulf, in a pattern similar to that illustrated in Fig. 1 for previous years. Due to persistent cloud cover over the Gulf of California in November-December 1998, we obtained no match-ups with SeaWiFS coverage during GoCAL98B. Better weather conditions resulted in 5 match-ups with SeaWiFS coverage during GoCAL99A. All radiometers used in GoCAL cruises were calibrated at CHORS.

Data from GoCAL97 and GoCAL98A were submitted to the SeaBASS archives. Analyses of data from GoCAL98B and GoCAL99A are in progress (a delivery schedule waiver was requested and approved). A significant engineering effort has been devoted to the development of a unique instrument system to support the proposed protocol experiments, and to outfitting a small research boat to provide an appropriate platform from which to conduct the experiments. The in-water profiling component of the system includes sensors to measure hyperspectral downwelling irradiance, upwelling radiance, absorption and beam attenuation, as well as conductivity, temperature, depth, and chlorophyll a fluorescence. The package is deployed on an umbilical tether, and its vertical motion is effected by buoyancy adjustment. Installed aboard the boat are hyperspectral radiometers to measure incident irradiance, radiance leaving the water surface, and sky radiance, and ancillary instruments including an ultrasonic anemometer, a Class A digital barometer, a shielded air temperature and relative humidity sensor, a magnetic heading, roll and pitch unit, a GPS receiver, and a fathometer. Data acquisition and control of the separate instruments are integrated using a network of microcontrollers linked to a central PC. Water samples for pigment and absorption analysis are obtained using bottles deployed from a davit. All the components of this system are in hand, and integration is proceeding at CHORS. Financial costs for the radiometric and IOP system, and for the boat, are shared between this contract, other CHORS contracts and grants, and SDSU Foundation cost-sharing funds.

16.3 RESEARCH RESULTS

Using data from GoCAL95 (pre-SIMBIOS), GoCAL97 and GoCAL98A (Figure 1), we determined that the SeaWiFS algorithms for chlorophyll a and K(490) are not significantly different from regression fits to the data in this region (Trees, Mueller and Maske 1999). We also showed that the correlations between fluorometric and HPLC determinations of chlorophyll a concentration were high for each cruise, but the slopes of the relationships varied strongly between cruises (Trees, Mueller and Maske 1999). In collaboration with colleagues at OSU and CICESE, data from the GoCAL series of cruises were used for match-up comparisons between *in situ* and SeaWiFS determinations of normalized water leaving radiance (Barnard et al. 1998) and to characterize the distribution of bio-optical properties in the Gulf of California (Pegau et al. 1998).

The K(490,z) and Kpar(z) profile data from the station locations illustrated in Fig. 1 were analyzed to derive families of regression models using the remote sensing optical depth K(490)-1, which corresponds to the 37% light level, to predict penetration to the 0.3% light level at 490 nm. Through a process of trial and error, the Gulf was divided into three separate bio-optical provinces: the central island region, the basin N. of the islands, and the southern remainder of the Gulf. Separate relationships were determined relating K(490)-1 to the 490 nm 10%, 3%, 1% and 0.3% light levels in each province. A similar analysis for each province was used to predict the depth of the euphotic zone, assumed to correspond to the 1% level for Epar(z), in the N. Gulf basin (Fig. 2) and in the other provinces. A manuscript base on these results has been submitted, and is in review, for publication in a special issue of Ciencias Marinas (a bilingual Spanish/English journal published in Mexico).

16.3 WORK PLAN

We will complete the integration and software development for the profiler and above-water radiometric system, and associated boat equipment, and begin engineering field tests in the near future. Once the system and boat are fully operational, we will use them to carry out the proposed protocol experiments. In the near future, we will also begin using the boat and instrument system to obtain match-up validation data during SeaWiFS, and hopefully MODIS, overpasses.

We will continue to support the GoCAL99B, and subsequent cruises in the Gulf of Mexico, albeit not necessarily by participating in the cruises per se. We will provide logistic support to the cruises, calibration services for the CICESE PRR and OSU Satlantic radiometers, and analyses and SeaBASS archival of the PRR profiles, fluorometric chlorophyll a concentrations, and HPLC pigment concentrations.

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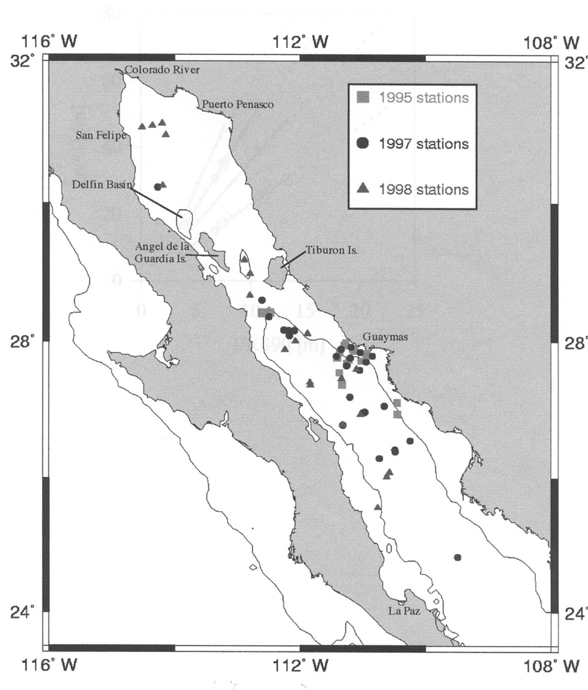

Figure 1. Station locations for cruises GoCAL95, CoCAL97 and GoCAL98A

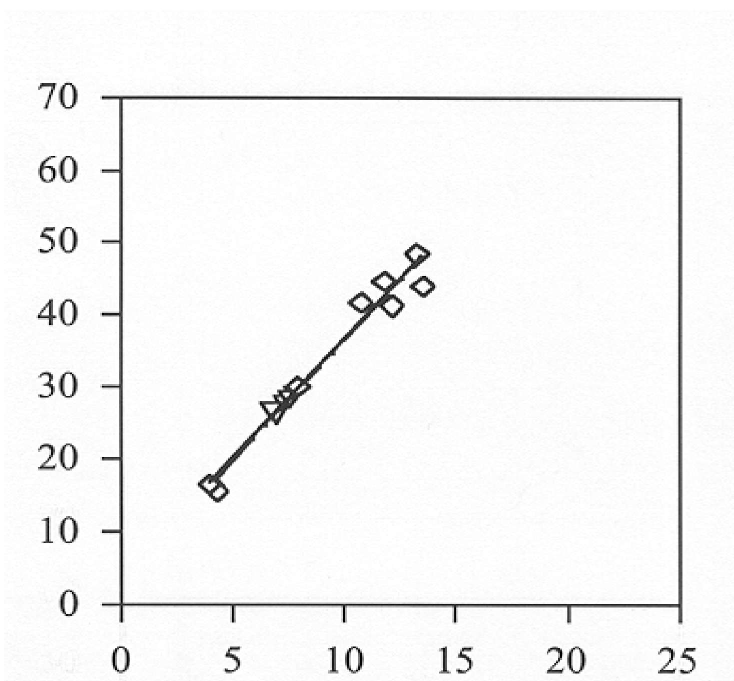

Figure 2. Depth of the euphotic zone (1% depth for E_{par}) in meters versus remote sensing depth $K(490)^{-1}$ (m) for stations N. of the Mid-Gulf Islands in 1997 and 1998.

Chapter 17

Validation of Carbon Flux and Related Products for SIMBIOS: the CARIACO Continental Margin Time Series and the Orinoco River Plume

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17.1 INTRODUCTION

This SIMBIOS investigation focuses on validating ocean color satellite products using monthly observations from the Cariaco Basin (a coastal upwelling site), and seasonal extreme measurements within the plume of the Orinoco River. During 1998-1999, this SIMBIOS Project focused on three major areas:

- monthly bio-optical data collections at 10.5 N, 64.67 W (the multidisciplinary CArbon Retention In A Colored Ocean / CARIACO station),
- bio-optical sampling of seasonal extremes of the Orinoco River plume,
- radiometric and atmospheric correction of SeaWiFS data.

Our main objective was to augment the SeaWiFS match-up database and a database of observations in Case-II waters. We also participated in other SIMBIOS activities, including the SIMBIOS PI meeting in Annapolis and cal/val activities under Ken Carder's SIMBIOS program. We have actively pursued the characterization of the calibration of SeaWiFS satellite data, contributed to the improvement of SeaWiFS data processing software, particularly the SeaDAS package, and developed a scheme for atmospheric correction over turbid waters. Our second-year activities are summarized below.

17.2 RESEARCH ACTIVITIES

The core of this SIMBIOS Project continues to be the CARIACO oceanographic time series station described in the SIMBIOS Project 1998 Annual Report. The series station is located at 10.50 N, 64.66 W, and our observations consist of:

- 1 to 3 monthly cruises with a fully-equipped, modern oceanographic vessel;
- mooring with 4 sediment traps (200, 400, 800, 1200 m; capturing bi-weekly sample integrations);
- varved (laminated) sediment core analyses.

The monthly oceanographic cruises provide information on:

- composition, levels, and light absorption properties of organic particulate and dissolved matter;
- pigments, HPLC, taxonomy of phytoplankton and general classification of bacteria;
- biological productivity (phytoplankton and bacteria);
- the physical/chemical characteristics of the water, including nutrient and oxygen levels;
- carbonate system; and
- meteorological and tide gauge observations.

Prior to October 1998, we conducted subsurface radiance/irradiance profiles using a Biospherical Instruments MER2048 in conjunction with a MER2041 Deck Cell. Since October 1998, we have used a split-level PRR-600. Both MER and PRR-600 casts were performed in October to help cross-reference the observations made with these instruments. The PRR-600 is more appropriate for measurements in some of the high-chlorophyll waters sampled. The PRR-600 bands are:

- 7 bands Ed, Es (412, 443, 490, 532, 555, 665, 683 nm)
- 7 bands Lu (412, 443, 490, 532, 555, 665, 683).

Above-water measurements are made with a Photo Research Hyperspectral Colorimeter Model PR650, which is a calibrated, hand-held radiometer (8 nm resolution). Derived products include Lw (Water-Leaving Radiance), Rrs (Remote-sensed reflectance) and K (attenuation coefficient). In addition, a full suite of measurements is made which includes: particulate material and pigment absorption, HPLC, fluorometric determinations of Chl concentration, pH, Alkalinity, Primary Productivity, POC, DOC absorption and concentration, nutrients, sun photometry, oxygen, and salinity.

Cruise reports for each cruise, detailing station location and observations collected, have been submitted to the SIMBIOS Project.

Our emphasis to date in data analysis has been to characterize the relationship between vertical flux and primary productivity, as a necessary step prior to examining the connection between bio-optical properties and various flux parameters. Primary production followed a seasonal cycle, with significantly higher production observed starting in January and lasting through May each year. Average depth-integrated production between January and April 1996 was 1,784 mg C m^{-2} d^{-1} but reached 2,674 mg C m^{-2} d^{-1} in 1997. May 1996 showed an extreme production value of 6,860 mg C m^{-2} d^{-1}, while May 1997 was about 2,500 mg C m^{-2} d^{-1}, or close to the seasonal average for that year.

We are now starting to examine the values for 1998, which yield a total of about 1,360 mg C m^{-2} d^{-1} between January and April 1998. Clearly, 1998 was strongly affected by El Niño. The upwelling cycle of 1997 showed higher seasonal production primarily as a result of the more frequent ventilation events. In contrast, productivity during June-December was 1,051 mg C m^{-2} d^{-1} and 865 mg C m^{-2} d^{-1} in 1996 and 1997, respectively. Annual integrated production was 686 gC m^{-2} y^{-1} and 536 gC m^{-2} y^{-1} in 1996 and 1997, respectively. Vertical flux of carbon was a minimum in January, with about 0.03 mgC m^{-2} d^{-1} at 275 m, and 0.006 gC m^{-2} d^{-1} at 1,225 m. By March flux had increased to 0.17 gC m^{-2} d^{-1} at 275 m and 0.06 gC m^{-2} d^{-1} at 1,225 m. Over the course of the sampling period, settling carbon flux was 5.6% of integrated primary production at 275 m and about 1.7% at 1,225 m. There was no seasonality in the proportion of vertical flux to primary production, in contrast with the prevailing view of the relationship between new production and total production.

The Orinoco River Plume

Three cruises to the Orinoco River delta and plume have been conducted to date, namely between 23-29 June 1998 (Figure 1), 25 and 30 October 1998 (Figure 1), and 23 and 26 February 1999. We seek to build a set of robust Case-II observations to assess the validity of the SeaWiFS retrievals in the plume. These data will be important for proper interpretation of the global ocean color satellite data since river plumes cover significant areas near continental margins.
We used the same instrumentation described above (MER, PRR-600) for underwater light profiles and above-water spectral remote-sensing reflectance observations. Observations were conducted both away from the coast and very close to the coast, including some of the delta tributaries. The latter observations were conducted from a small boat using only the PRR-600 and above-water, hand-held instrumentation.

The Orinoco Plume data span a very broad range of remote sensing reflectance values. Figure 2 shows a progression in hyperspectral reflectance curves going from offshore plume station 4 (Figure 1) to station 16, located within about 2 km of the mouth of Caño Macareo, the largest active tributary to the Orinoco delta. The river plume data are also being used by Joe Salisbury and Charles Vorosmarty at the University of New Hampshire for automated modeling of river water impact off the continent of South America, in a model linked to terrestrial hydrology. Cruise reports, detailing station locations and observations collected, have been submitted to the SIMBIOS Project.

Radiometric and atmospheric correction of SeaWiFS data: Under leadership of Dr. Chuanmin Hu, a postdoctoral research associate, we have continued to study the performance of the SeaWiFS Gain and Calibration Tables. Dr. Hu also developed an alternative atmopsheric correction scheme of turbid coastal waters, in which the epsilon, aerosol model number, t(765) and t(865) are optimized for “turbid” pixels. Specifically, the atmospheric correction parameters are determined through nearest-neighbor searches of adjacent Case-I water pixels, and these parameters are then applied over the respective turbid pixels.

This method yields significant improvement in estimates of chlorophyll relative to concurrent field observations, and minimizes the number of negative water-leaving radiance retrievals. The method also shows promise for applications over shallow-water regions. Dr. Hu has also implemented a band 6 / band 8 atmospheric correction algorithm in SeaDAS and is preparing a manuscript on results of comparisons with the products derived using the band 7 / band 8 algorithm. We have implemented an extensive SeaWiFS batch processing system for use with IDL and SeaDAS. We also implemented a series of convenient SeaWiFS data analysis tools based on IDL and IDL On the Net (ION), to allow analyses over the world wide web. In an effort to assess MODIS algorithms, we have continued with the implementation of Ken Carder's algorithms in SeaDAS.

Instrumentation

We acquired a split-level PRR-660 instrument from Biospherical Instruments and a hyperspectral hand-held fiber-optic sensor from Analytical Spectral Devices. The latter will help obtain observations between 340 and 1,200 nm. Our older PR-650 instrument only provided observations between 380 and 780 nm, which is inadequate to study the near-infrared reflectance of highly turbid waters. We continue to test the ac-9, which has to date been used on 4 cruises to the Gulf of Mexico and the West Florida Shelf. We have had problems with noise in the instrument and therefore have not sent it to Venezuela on the Orinoco cruises.

The MICROTOPS unit from the SIMBIOS Project Office is used routinely at the time of bio-optical observations during each cruise. Bio-chemical and pigment samples are being analyzed at various locations, while data archival is centralized at our Remote Sensing Lab at the University of South Florida.

17.3 WORK PLAN

We will continue to occupy the CARIACO station on a monthly basis. In addition, we plan to conduct three cruises to the Orinoco River plume, specifically in October 1999 and in February and October 2000. Analysis of data and samples will continue. We are currently advancing several manuscripts that describe the seasonal cycle in bio-optical properties at the CARIACO station, the atmopsheric correction for turbid waters, and digitization sensitivity of the SeaWiFS data.

ACKNOWLEDGEMENTS

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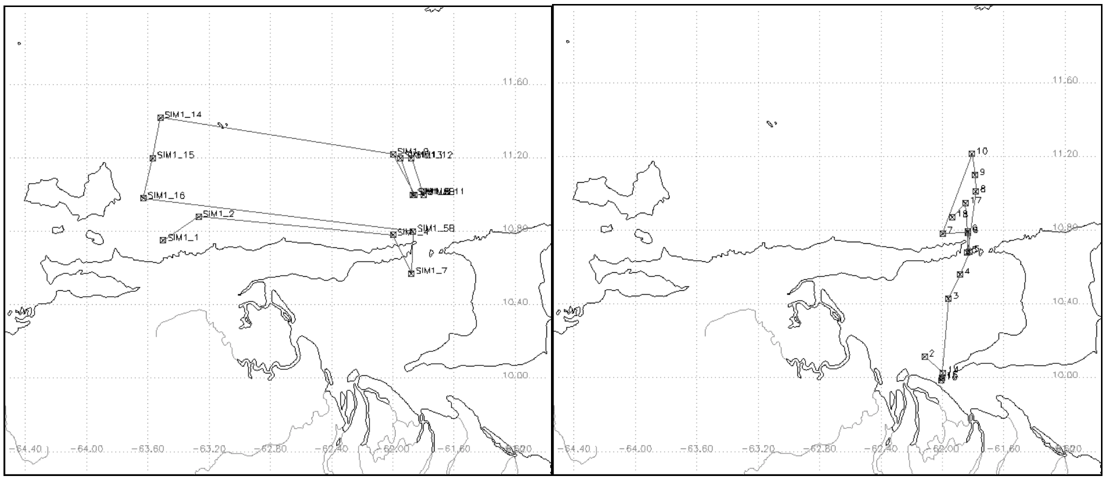

Figure 1. Cruise track for Orinoco Plume cruise SIMBIOS 1, conducted 23-29 June, 1998 (left). Cruise track for Orinoco Plume cruise SIMBIOS 2, conducted 27-30 October, 1998 (right).

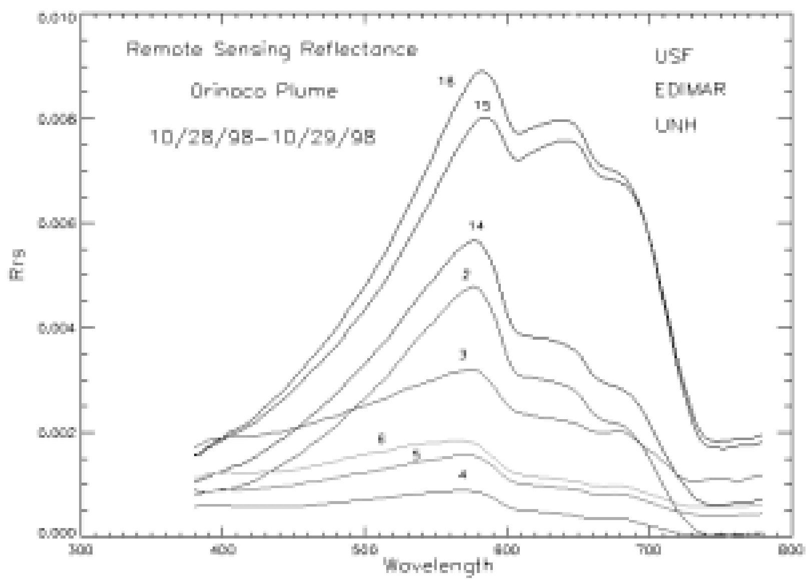

Figure 2. Remote sensing reflectance data obtained with the hand-held Spectrascan PR-650 instrument.

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Chapter 18

The Bermuda Bio-Optics Program (BBOP)

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18.1 INTRODUCTION

The Bermuda BioOptics Project (BBOP) is a collaborative effort between the Institute for Computational Earth System Science (ICESS) at the University of California at Santa Barbara (UCSB) and the Bermuda Biological Station for Research (BBSR, D. A. Siegel [UCSB] and N. B. Nelson [BBSR] P.I.'s). This research program is designed to characterize light availability and utilization in the Sargasso Sea and provide an optical link by which biogeochemical observations may be used to evaluate bio-optical models for pigment concentration, primary production, and sinking particle fluxes from satellite-based ocean color sensors.

18.2 RESEARCH ACTIVITIES

The Bermuda Bio-Optics Program (BBOP) collects detailed profiles of AOPs and IOPs in conjunction with the US JGOFS Bermuda Atlantic Time-series Study (BATS) in the mesotrophic waters of the Sargasso Sea. Cruises are conducted monthly with additional cruises during the spring bloom period, January through May. Continuous profiles of apparent optical properties (AOPs) are collected in the upper 200m. Radiometer deployments are planned to optimize match-ups with the BATS primary production incubations and with SeaWiFS overpasses. The primary optical measurements are downwelling vector irradiance and upwelling radiance, $E_d(z,t,\lambda)$ and $L_u(z,t, \lambda)$, respectively. Our derived products include profiles of remote sensing reflectance (Rrs(z, λ) and down- and upwelled attenuation coefficients ($K_d(z, \lambda)$, $K_u(z, \lambda)$, and are reported in near-real time with ~98% reliability. The sampling package also includes a second mast-mounted radiometer with wavebands similar to those on the underwater instrument for measuring incident downwelling vector irradiance, $E_d(0+,t, \lambda)$. and calculating daily incident solar radiation during primary production incubations. In addition to radiometer data, samples for fluorometric chlorophyll-a are collected daily near noon (local time) and results are delivered to the SIMBIOS Project with the AOP data. Table 1 contains a list of data products collected by BBOP and/or BATS, which are relevant to SIMBIOS.

We are collecting data on both above- and in-water inherent optical properties (IOPs). Discrete samples for determining the absorption spectra of particulates, $a_{ph}(z, \lambda)$ and $a_d(z, \lambda)$, and CDOM ($a_g(z, \lambda)$) are collected according to Nelson et al (1998). Particulate absorption spectra are determined using the quantitative filter technique (Mitchell, 1990) and CDOM absorption according to Nelson et al (1998). We have continued the collection of above-water R+rs(l) spectra using the Analytical Spectral Devices FieldSpec spectrometer (ASD, Boulder CO). Spectral beam absorption measurements (a(z, λ) and c(z, λ), WET Labs AC-9) have been discontinued because the baseline absorption of Sargasso Sea water is nearly the same as that of the deionized water used for the calibration making it difficult to discern a signal (Brody et al, in prep).

18.3 RESEARCH RESULTS

We have continued our work on the local dynamics of non-chlorophyll light attenuation, providing an explanation for the patterns observed in the Sargasso Sea. The significant seasonal cycle in the ratio of Kd(412) to Kd(443) (Siegel and Michaels 1996) was found to be the result of seasonal changes in the concentration of CDOM, which, on average, comprises more than one-half of the total non-water absorption coefficient at 440nm. The distribution of CDOM was found to be influenced by mixing, photo-bleaching and microbial production, with turnover times of 90 - 110 days (Nelson et al. 1998, Nelson and Carlson, in prep). This work implies, for the first time in the blue ocean, a link between microbial community activity and CDOM dynamics (Figure 1).

The Sargasso Sea near Bermuda is mesotrophic, characterized by both eutrophic and oligotrophic conditions during different times of the year. Although low chlorophyll a stocks and primary production rates prevail for the most of the year, there is a short spring bloom characterized by somewhat higher concentrations and rates, traditionally assumed to be controlled by winter mixing and the resultant nutrient influx. However, these accepted mechanisms of nutrient supply have accounted for less than half of the annual nutrient flux required by new production estimates. Using evidence from BATS-CTD surveys, moored instruments, satellite altimetry and eddy-resolving model simulations, Siegel, et al (1999a) and McGillicuddy et al (1998) illustrated the importance of mesoscale eddies to new production in the Sargasso Sea (Figure 2). This work has demonstrated that eddy pumping (the process by which mesoscale eddies induce isopychnal displacements that lift nutrient-replete waters into the euphotic zone) and entrainment into the mixed layer during wintertime convection are the two dominant mechanisms transporting new nutrients into the euphotic zone at this site. Smaller contributions are made by mixing in the thermocline and wind-driven transport. The sum of all physical new nutrient supplies effectively balances geochemical estimates of annual new production. These calculations do not include biological sources of new nutrients (e.g. nitrogen fixation), and the inclusion of these may result in an overestimate of total nutrient supply.

Using a 6-year time series of BBOP and BATS data with site-specific and previously published global models, Sorensen and Siegel, (1999) and Siegel et al. (1999b) illustrated the problems associated with modeling both integrated primary production (∫PP) and effective quantum yield (ϕc, mol C Ein-1) in the Sargasso Sea. Siegel et al (1999b) found that all models of primary production performed poorly, accounting for less than 40% of the variance in ∫PP. Part of the failure of global primary production models to encapsulate the variance is due to the small range of values in ∫PP observations and the small variance to be explained. Additionally, nearly one-half of ∫PP occurs under light saturated conditions. More importantly, the assumptions of steady state and balanced growth required by production models are not met by the "snapshot" nature of optical or satellite measurements and boundaries must be placed on how empirical models for ∫PP are developed, validated and applied to satellite ocean color data sets. Sorensen and Siegel (1999) showed that although the time series showed ϕc values to be highly variable, few parameters correlated consistently and rationally with ϕc. The low predictive capability of published models using a variety of parameters demonstrates that we have yet to develop a predictive understanding of the important photophysiological, ecological and methodological processes controlling primary production.

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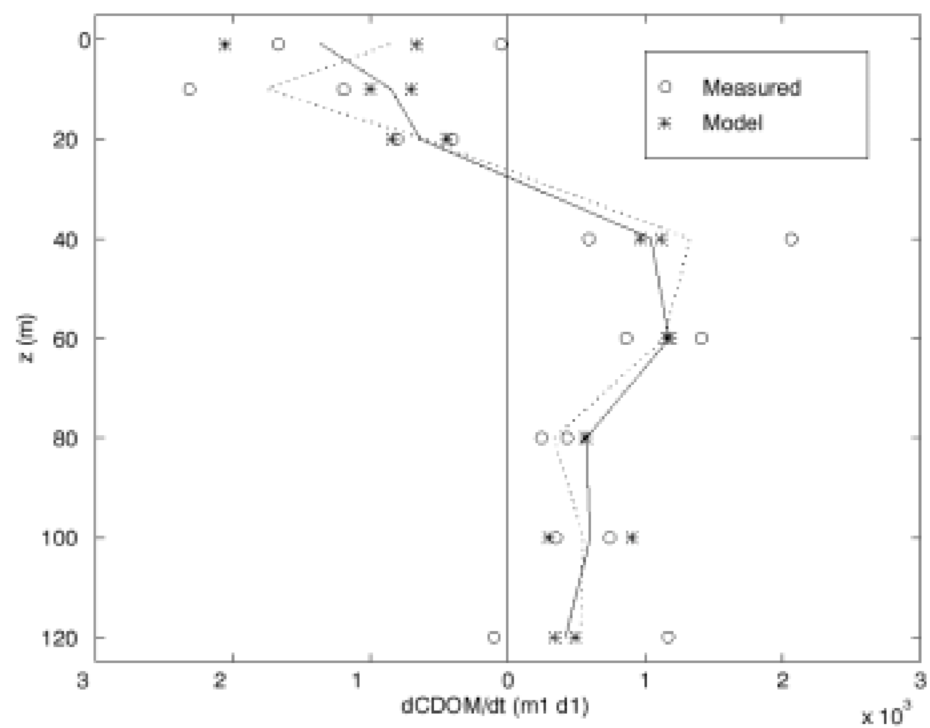

Figure 1. Mean profile of CDOM absorption dynamics (dCDOM/dt, m-1 d-1) for pooled summertime 1994 and 1995 data from the BATS site (from Nelson, et al 1998). Solid and dashed lines are the fitted model using 1994 and 1995 bacterial production estimates, respectively. The linear correlation coefficient (r2) between the pooled data and the model predictions is 0.83.

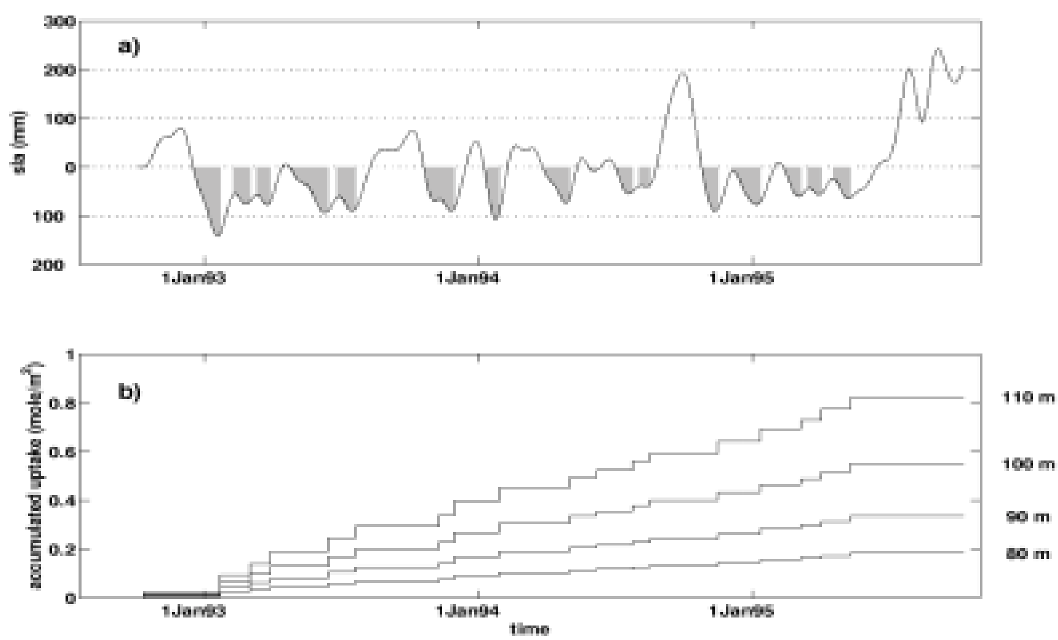

Figure 2. An example of the eddy pumping calculation using sea level anomalies (SLA) at the BATS site from 1993-1995 (from Siegel, et al 1999a). a) time-filtered SLA time series, gray regions denote upwelling events, b) cumulative uptake for 4 euphotic zone depths in units of moles N m-2. The uptake rate is equal to the cumulative uptake divided by the total time (here, 1101 days).

TABLE 1: A partial list of measurements made by BBOP & BATS

BBOP

Direct Measurements:

$E_d(z,\lambda)$	Downwelling vector irradiance (410,441,465,488,510,520,555,565,589,625,665 & 683 nm)
$E_d(0^+,\lambda)$	Incident irradiance (340,390,410,441,465,488,520,545,565,589,625,665 & 683 & 350-1050 nm)
$L_u(z,\lambda)$	Upwelling radiance (410,441,465,488,510,520,555,565,589,625,665 & 683 nm)
$a_{tp}(\lambda)$	Particulate absorption spectrum by QFT
$a_d(\lambda)$	Detrital particle absorption spectrum by MeOH extraction
$a_{ys}(\lambda)$	Colored dissolved absorption spectrum
$E_o(z,\lambda)$	Scalar irradiance at 441 and 488 nm
$F_f(z)$	Natural chlorophyll fluorescence using a broadband upwelled radiance sensor
chl-fl(z)	Chlorophyll fluorescence with a SeaTech fluorometer
c(z,660)	Beam attenuation coefficient at 660 nm with SeaTech 25 cm transmissometer
T(z) & S(z)	Temperature and conductivity with SeaBird probes
chl-a(z)	Discrete chlorophyll *a* determinations via Turner fluorometry (for next day delivery)

Primary Derived Products:

$L_{wN}(\lambda)$	Normalized water leaving radiance (410,441,465,488,510,520,555,565,589,625,665 & 683 nm)
$R_{RS}(0^-,\lambda)$	In-water remote sensing reflectance (410,441,465,488,510,520,555,565,589,625,665 & 683nm)
$R_{RS}(0^+,\lambda)$	Above-water remote sensing reflectance (350 to 1050 nm)
$a_{ph}(\lambda)$	Phytoplankton absorption spectrum (= $a_p(\lambda)$ - $a_{det}(\lambda)$)
$K_d(z,\lambda)$	Attenuation coefficient for $E_d(z,\lambda)$ (410,441,465,488,510,520,555,565,589,625,665 & 683 nm)
$K_L(z,\lambda)$	Attenuation coefficient for $L_u(z,\lambda)$ (410,441,465,488,510,520,555,565,589,625,665 & 683 nm)
<PAR(z)>	Daily mean photosynthetically available radiation at depths of the *in situ* C^{14} incubations
$b(z,\lambda)$	Spectral scattering coefficient (= $c(z,\lambda)$ - $a(z,\lambda)$)

U.S. JGOFS BATS (NSF) and Related Biogeochemistry Sampling Programs

- Primary Production (*in situ* ^{14}C incubation)
- Phytoplankton pigments (fluorometric & HPLC)
- CO_2 system (alkalinity, TCO_2 and pCO_2)
- Dissolved oxygen (continuous & discrete)
- POC & PON (POP infrequently)
- Full water column, WOCE-standard CTD profile
- Phytoplankton abundance by flow cytometry
- Validation spatial cruises (5 days, 4cruises/year)
- Sinking flux (sediment trap array)
- Nutrients (NO_3+NO_2, SiO_4, PO_4)
- Continuous atmosphere & surface pCO_2
- Zooplankton biomass & grazing
- DOC & DON (DOP infrequently)
- Bacterial abundance and rates
- Coccolithophore abundance
- Deep ocean sediment sinking rates

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Chapter 19

Spectral Data Assimilation for Merging Satellite Ocean Color Imagery

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19.1 INTRODUCTION

The Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) project was initiated "to develop a methodology and operational capability to combine data products from these various ocean color missions in a manner that ensures the best possible global coverage and best exploits the complementary missions of the sensors" (GSFC ocean color group, 1995). The objective of our program is to develop and validate an ocean color data merging capability based on the use of (normalized) water-leaving radiances through a semi-analytical model.

The rationale for merging data at the normalized water-leaving radiance level is that such approach potentially allows a good consistency in an extended suite of final products (as opposed to Chl-a only). Another important aspect of this approach is that redundancies in the spectral bands from the various sources of data can be used for consistency checks while the different wavebands result in increased spectral information used by the model.

The core of the procedure is thus termed "Spectral Data Assimilation" as the spectral water-leaving radiances from various ocean color data sources are merged through the use of a model. The complete SDA procedure includes various steps which can be summarized as:

- Matchup process (space and time windows where data from different sources are available);
- Atmospheric correction;
- BRDF correction;
- Surface effects and normalization;
- Semi-analytical Bio-optical model.

Our currently funded activities in SIMBIOS are mainly oriented toward step 5 however we are conducting several analysis related to steps 2 to 4.

19.2 RESEARCH ACTIVITIES

Atmospheric correction of SeaWIFS

In the initial workplan, we were not supposed to deal with the atmospheric correction procedure. However because of the occurrence of highly underestimated water-leaving radiances in SeaWiFS data we have worked in that area as good water-leaving radiances from SeaWiFS are essential for our work. In collaboration with M. Wang and W. Robinson from the SIMBIOS Project, we assessed the role of the near-infrared (NIR) "Black-pixel" assumption in the SeaWiFS data processing scheme and proposed a method to correct for its effects. We used bio-optical models to generate normalized water-leaving reflectances in the NIR which are then incorporated in the SeaWiFS atmospheric processing scheme. This approach showed significant improvements in the SeaWiFS radiometric data and Chl-a retrievals in highly productive waters. A paper is submitted to Applied Optics (Siegel et al., submitted).

Matchup data sets

We also worked with the SIMBIOS and MOBY matchup data sets we received from the SIMBIOS Project. Regular interactions with members of the SIMBIOS Project (B. Schieber, S. Bailey, G. Eplee) helped getting familiar with the data. The SeaWiFS data and the *in situ* measurements contained in the SIMBIOS and MOBY data sets are the data which we will use for the development and testing of the "Data Merger".

The Garver/Siegel model

The Garver/Siegel model code (Garver and Siegel, 1997) was originally written in FORTRAN. An IDL version of it has been developed and tested (for consistency) against the FORTRAN version. The IDL code is used for development and testing of the procedure. It has been adapted so it can handle multiple data sets which is a requirement of the merging procedure. The first tests of SeaWiFS and *in situ* data merging were successfully conducted in September 1999.

Model tuning

The other important aspect we have been working on is the parameterization of the Garver/Siegel model and the implications of that parameterization at varying scales. Our approach on this is twofold: we are testing the model when implemented with parameterizations available in the literature and we are using a global optimization technique (Simulated annealing).

We applied simulated annealing to synthetic and real ocean data sets of remote sensing reflectance (Rrs) for three parameters: chlorophyll concentration (Chl), non-algal absorption coefficient (acdm) and particulate backscattering coefficient (bbp). The real ocean data set is an extended version of the SeaBAM data.

The optimization procedure accurately retrieves model parameter values but the quality of retrievals is sensitive to the noise in the data. This stresses the need for high quality data sets that include the parameters involved in the semi-analytical formulations. Parameterization resulting from the simulated annealing procedure on real data has been tested on SeaWiFS imagery.

19.3 WORK PLAN

Next year we will concentrate on aspects associated with the propagation of uncertainties throughout the system and the derivation of uncertainty estimates for the final merged products. The benefits of increased spectral information resulting from data sources with different characteristics will be assessed. Consistency checks using band redundancies will also be investigated. A test merging SeaWiFS, MOS and *in situ* data will be considered. A paper about the “tuning” of the Garver/Siegel semi-analytical model using both the literature-based and the simulated annealing procedure will be submitted sometime during the year. We are also planning on hiring someone to help building a “complete” Ocean Color data set (AOPs + IOPs) for development and validation of semi-analytical models.

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Chapter 20

SIMBIOS Data Product and Algorithm Validation with Emphasis on the Biogeochemical and Inherent Optical Properties

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20.1 INTRODUCTION

The purpose of our funded component of the SIMBIOS program is to address and quantify the relative accuracy of the various ocean color remote sensing products by means of product and algorithm validation. In order to accomplish these goals, we have been collaborating in an international research program in the Gulf of California designed to examine the spatial and temporal bio-optical variability in this region. In addition, we also participate in various cruises of opportunity to supplement our validation data set.

Our long-term objectives are to; a) collect optical and biochemical data in oceanic and coastal regions of interest, b) provide collected data to the SeaBASS database, SIMBIOS Project office, and other interested users, c) maintain and update instrumentation and data archiving and dissemination systems, and d) determine spatial and temporal error fields for the biological and geophysical data products from the various ocean color missions.

20.2 RESEARCH ACTIVITIES

During the past contract period, we have participated in 5 field campaigns, collecting an extensive amount of radiometric, inherent optical property, aerosol optical thickness, and physical data (Table 1). The five field campaigns included a cruise offshore of Oregon, two Gulf of California cruises, a cruise with Dr. Francisco Chavez (MBARI), and a cruise of opportunity with Drs. Vivian Montecino (University of Chile) and Giovanni Daneri (University of Vaparaiso).

We have maintained and utilized the optical absorption/attenuation profiling system for use in the SIMBIOS instrument pool. We also maintain 3 water filtration systems as a part of the SIMBIOS equipment pool. Recently, we have developed a self-recording small inherent optical property, CTD and radiometer profiling system for small boat operations. In the past year we have worked extensively on building an inline optical sampling system to be deployed on a commercial ferry in the Gulf of California.

Currently, we are receiving all of the SeaWiFS HRPT Level 1A (HMBR) data for the West Coast of North America including the Gulf of California from the DAAC. This data is being processed to various levels for use in the validation of ocean color products and to build an extensive time series of SeaWiFS imagery for the Gulf of California. We have also been involved in a collaborative effort with Drs. Knut Stamnes and Bingquan Chen at the Stevens Institute of Technology investigating atmospheric correction of SeaWiFS imagery.

20.3. RESEARCH RESULTS

A detailed analysis of the spectral characteristics of the absorption, attenuation, and scattering data collected in the Gulf of California over the past 5 years has been completed (Pegau, et al., 1998; 1999). *In situ* data collected in the Gulf of California during two separate research cruises, were used in an investigation into the validation of SeaWiFS satellite measurements (Barnard, et al., 1998). Radiometric data collected during a recent cruise in the Gulf of California were used to validate the normalized water leaving radiance estimated by the SeaWiFS satellite. The results of this work show that the blue wavelengths are greatly underestimated by the SeaWiFS sensor due to inaccurate atmospheric correction (Figure 1).

In order to correctly invert the remotely sensed reflectance to obtain the optical properties, we developed a method for the appropriate depth averaging of remotely sensed optical parameters (Zaneveld, et al., 1998). This method was used to investigate the influence of vertical structure on the remotely sensed signal. The results of this work were presented at the ASLO Aquatic Sciences meeting in Santa Fe, (Barnard, et al, 1999).

Based on the consistent relationships resolved by an earlier study (Barnard, et al, 1998), we developed a method to obtain closure between the inherent optical properties and remotely sensed reflectance measurements (Barnard, et al., 1999). The results of this model showed that inversion of the remotely sensed reflectance to obtain the absorption coefficient is possible if the spectral relationships of the absorption coefficient are known.

We are continuing to work on developing this model to include determination of the absorption coefficient due to CDOM and particulate materials. A recent model that spawned as a result of this research was the determination of photosynthetically available radiation light levels using profiles of the absorption coefficient (Barnard, et al.,1999).

20.4. WORK PLAN

In the upcoming SIMBIOS contract period, we have 3 research cruises planned. We will be participating in the NASA sponsored MODIS initialization cruise (MODE-5) the R/V Melville offshore of Baja California and within the Gulf of California from October 1 to October 21. We also have 2 cruises planned for the Gulf of California, one following the MOCE-5 cruise, and a spring cruise with the dates still to be announced.

We are also currently negotiating with Dr. Carlos Garcia (University of Rio Grande) for ship time on cruises he has planned in early 2000 off Brazil. We anticipate participating in other cruises in the next year, as the opportunity arises. We will also be working on the installation of an in-line fluorometer on the trans-Gulf ferry to provide a monthly transect of chlorophyll fluorescence data in the Gulf of California.

We plan to continue to investigations on the inherent and apparent optical properties of the Gulf of California, as well as continuing our work with ocean color algorithm validation and development. We are continuing to work with Drs. Stamnes and Chen to investigate new methods of atmospheric correction of SeaWiFS data in the Gulf of California.

We will be continuing to process SeaWiFS level 1A (HMBR) data in order to investigate the various temporal and spatial scales of absorption and chlorophyll variability in the Gulf of California. We will also be incorporating AVHRR SST Pathfinder satellite data produced by Dr. Strub (OSU) into this analysis.

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Table 1. Summary of cruises and *in situ* data collected

Cruise Name	IOP Profiles	Radiometric Profiles	Sunphotometer AOT	Surface Chlorophyll samples	Sky/sea-state photos
Offshore Oregon	150	0	14 days	56	
Gulf of California 1998	31	11	6 days	0	X
Gulf of California 1999	36	19	11 days	0	X
Coastal California	6	0	0	0	
Coastal Chile	22	22	0	0	X
Total	245	52	31 days	56	

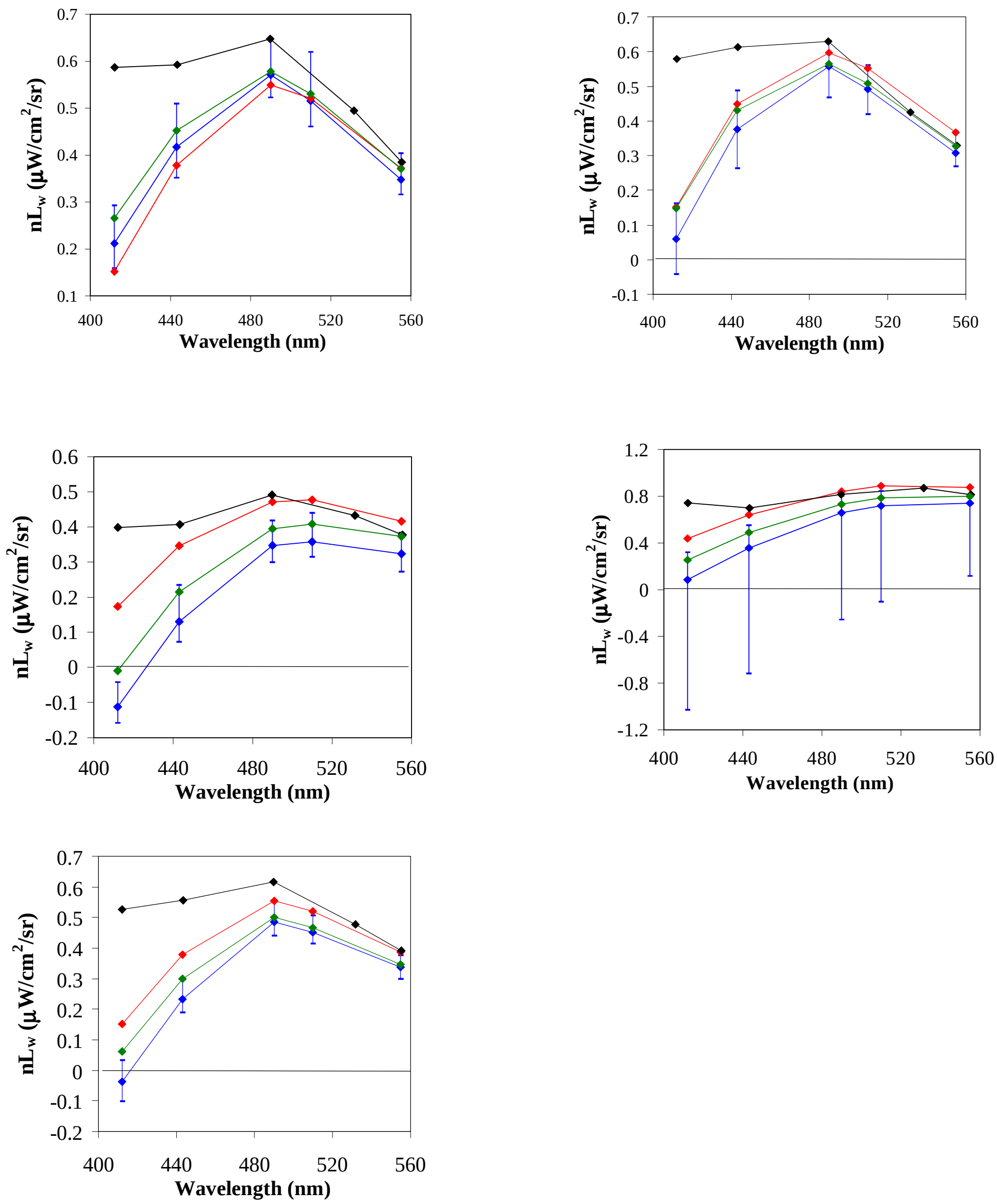

Figure 1. Spectral comparison of the normalized water leaving radiance measured *in situ* (black) and as determined by SeaWiFS using the Gordon and Wang (blue), Siegel (green) and Stumpf (red) atmospheric correction algorithms for 5 days of match-up data in the Gulf of California (April 21, 24, 26, 28, and 30, 1999).

This research was supported by the

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Chapter 21

Atmospheric Correction Algorithms for ocean Color Remote Sensing

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21.1 INTRODUCTION

During the past 15 months the international group of about 15 scientists (Table 1) have been involved in preparation and execution of comprehensive ocean optics and atmospheric radiation studies during the Indian Ocean Experiment (INDOEX). Seven members of this Ocean Color and Aerosol Characterization group participated between February and April of 1999 in scientific cruise on the *R/V* Ronald H. Brown. Our main purpose was to:

- Collect comprehensive, simultaneous, in-water and above-water data for the atmospheric correction process studies.
- Characterize state of the atmosphere during the INDOEX including aerosol optical thickness (AOT), vertical distribution of aerosols and clouds microphysics as well as inherent optical properties of aerosols and phytoplankton.
- Intercompare AOT and remote sensing reflectance (Rrs) measurements obtained with different radiometers and develop algorithms for state-of-the-art above the water instrumentation.
- Develop atmospheric science applications of the ocean color data by interacting with the INDOEX community.

Table 1. INDOEX PI's
K. Aoki
Piotr Flatau
Howard Gordon
Mati Kahru
Krzysztof Markowicz
Mark Miller
Greg Mitchell
T. Nakajima
Jessica Nolan
Mike Reynolds
Ajit Subramaniam
Ken Voss
Judd Welton
John Wieland

The uniqueness of this project is based on the fact that (a) we performed comprehensive above the water and in-water measurements and that (b) we were part of the large atmospheric science aerosol project (INDOEX).

The results up to date, including technical reports, were collected in the INDOEX Ocean and Aerosol Characterization Group CD-ROM available upon request at http://atol.ucsd.edu/~pflatau .

21.2 RESEARCH ACTIVITIES

1. Vertical measurements of aerosols and clouds were made using a micro-pulse lidar system (MPL). The MPL Lidar is part of the SIMBIOS instrumentation pool. The MPL system used during INDOEX was operated at the full laser power supply setting of 1 W. The data are stored in 1 hour binary files with each record containing a header followed by the signal in ph/sec at successive 75 m increments up to a preset range (30 km). The MPL was operated successfully from February 22 to March 15, 1999. The original MPL system was removed and a new MPL was installed on March 15. The MPL ran non-stop with the exception of several hours during mid-day when the system was turned off to avoid direct sunlight from entering the MPL, which would damage the detector. The SRAB(r) data acquired during the cruise is available at the following NASA web-site: http://virl.gsfc.nasa.gov/mplnet/indoex_ ship/mainpage.htm

2. During the INDOEX cruise on R/V Ronald Brown, an integrated underwater profiling system was used to collect optical data and to characterize the water column. The system included an underwater MER-2048 radiometer (Biospherical Instruments Inc., S/N 8772) measuring depth, downwelling spectral irradiance (Ed), upwelling spectral irradiance (Eu) and upwelling radiance (Lu) at 12 spectral bands from 340-665 nm and a MER-2041 deck-mounted reference radiometer (Biospherical Instruments Inc., S/N 8739) measured downwelling irradiance over the same range. The MER-2048 was also interfaced

to a 25 cm transmissometer (SeaTech Inc.), a fluorometer (Wetlabs Inc.), and conductivity and temperature probes (Sea-Bird Electronics Inc.).

3. Aerosol optical thickness (AOT) measurements during the INDOEX were performed between February 26, 1999 (Julian Day 57) and March 30, 1999 (Julian Day 89. The AOT was studied using 4 instruments SIMBAD, Microtops handheld sunphotometer, PREDE sunphotometer, and shadowband instrument. Separate reports provide information about these different instruments.

4. Interaction with research groups who collected extensive atmospheric aerosol characterization data including mass spectrometry, single scattering albedo, aircraft, and numerical modeling datasets on R/V Ronald H. Brown and in the region of tropical Indian Ocean and Arabian Sea.

21.3 RESULTS

Remote sensing reflectance

In general, the INDOEX relationships between LWN and chlorophyll a are similar to the respective relationships for the CalCOFI dataset (Figure 1). The INDOEX chl a values are mostly low, with just one station over 1 mg m^{-3}. The minimum chl concentration in the CalCOFI dataset is 0.05 while INDOEX has values as low as 0.03 mg m^{-3}.

The inherent scatter is due to, among others, variable light field, surface conditions, variations in the absorption and scattering characteristics (e.g. Gordon et al., 1988). In the log-log space the relationship can be fitted with a cubic polynomial. The non-linearity (curvature) of this relationship is more evident at shorter wavelengths (e.g. 412 nm and even more so in the UV region). LWN can be calculated from the relationship $\log(LWN) = a_0 + a_1 * C + a_2 * C^2 + a^3 * C^3$. The coefficients of the polynomial (a_0 to a_3) are given in Figure 1.

At 412 nm the INDOEX LWN values are generally higher compared to CalCOFI values at similar chl values. This is an indication of reduced concentration of the colored dissolved or detrital organic matter (CDOM). A conspicuous feature is a cluster of high LWN (665) values. High reflectance at 665 nm is probably caused by chl fluorescence. The causes of the increased chl fluorescence need to be studied.

Vertical aerosol distribution

Preliminary scanning of the entire data set has identified four groups of similar data. These groups are largely defined by latitude, and are listed below: (a) Southern Latitudes, (b) Mid-Latitudes, (c) Northern Latitudes, (d) Northern Arabian Sea (Northern-most point of cruise). Figure 2 display daily plots of SRAB(r) for Southern Latitude displays an example of lidar data taken in the relatively clean Southern Indian Ocean (mid-day coordinates ~11.19^o S, ~59.25^o E). The plot shows a well defined MBL to about 1 km, with some weak aerosol returns up to about 2 km. The AOD measured in this region (< 0.1) was lower than AOD measured in the other regions. This region was relatively free of upper level cirrus, but did contain occasional packets of cumulous in the MBL and up to ~10 km. This was the cleanest region encountered during the INDOEX cruise. NOTE: Starting just after 20:00 UTC, a cirrus layer from 15 to 16 km can be seen.

Aerosol optical thickness and size distribution derived from PREDE sunphotometer as a function of latitude. Between JD55 and 57 the optical thickness was less than 0.1 in all channels. During the ITCZ crossing (days 58-59) the optical thickness increased to 0.2 at 500nm. In that time the ITCZ was localized between 2-4S. The reason for this increase is that in proximity of the Equator the westerlies limit transport of pollution from Northern to Southern Hemisphere. After the ITCZ crossing the optical thickness increased even further. The Angstrom coefficient shows similar behavior. It is 0.3 in proximity of 10S and 1.4 in vicinity of 4N. This indicates that concentration of small particles is increasing towards North. However, during February 27, 1999 (JD57) we observed sudden drop in the Angstrom coefficient value, which is related to sub-visual cirrus in vicinity of the ITCZ. At the beginning of Leg 2 the AOT was initially high (0.4 at 500nm) but its value decreased fast and was 0.1 in the middle of the Arabian Sea. At the same time Angstrom coefficient was decreasing. At 15N it was 0.5 which indicates that the antycyclonic circulation in this region was responsible for the mineral dust transport from the Somali Desert region.

21.4 WORK PLAN

Our short term goals are threefold:

- intercompare AOT measurements and compare them with the SeaWiFS atmospheric correction;
- intercompare nLw and Rrs and compare them with the SeaWiFS water leaving radiance and remote sensing reflectance;

- characterize large scale aerosol distribution using the MATCH model, NCAR/NCEP reanalysis, and AVHRR data and intercompare them with the SeaWiFS derived AOTs.

These tasks have been already initiated. Our long term goals are to:

- develop improved atmospheric correction algorithms for the regional basins; and

- to develop atmospheric science applications of the ocean color data by interacting with the INDOEX community modeling and data assimilation efforts.

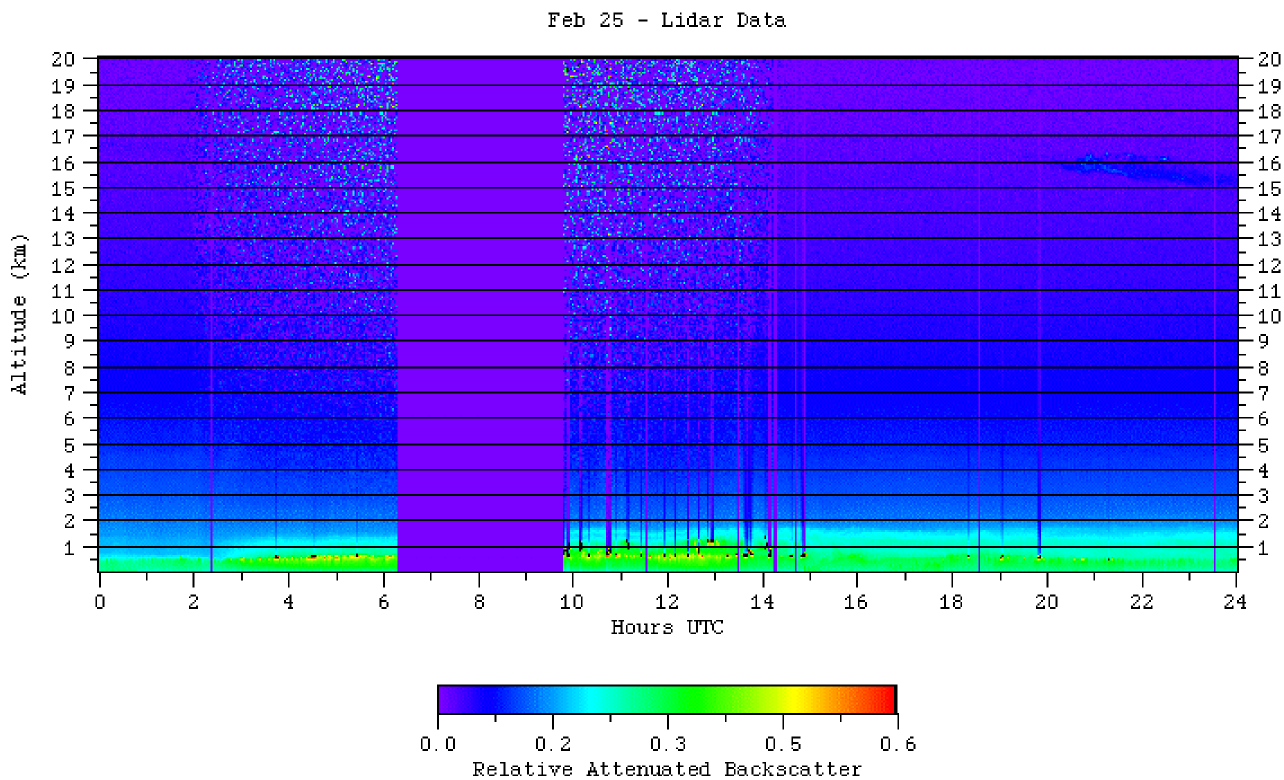

Figure 2. Lidar data taken in the relatively clean Southern Indian Ocean ~11.19° S, ~59.25° E.

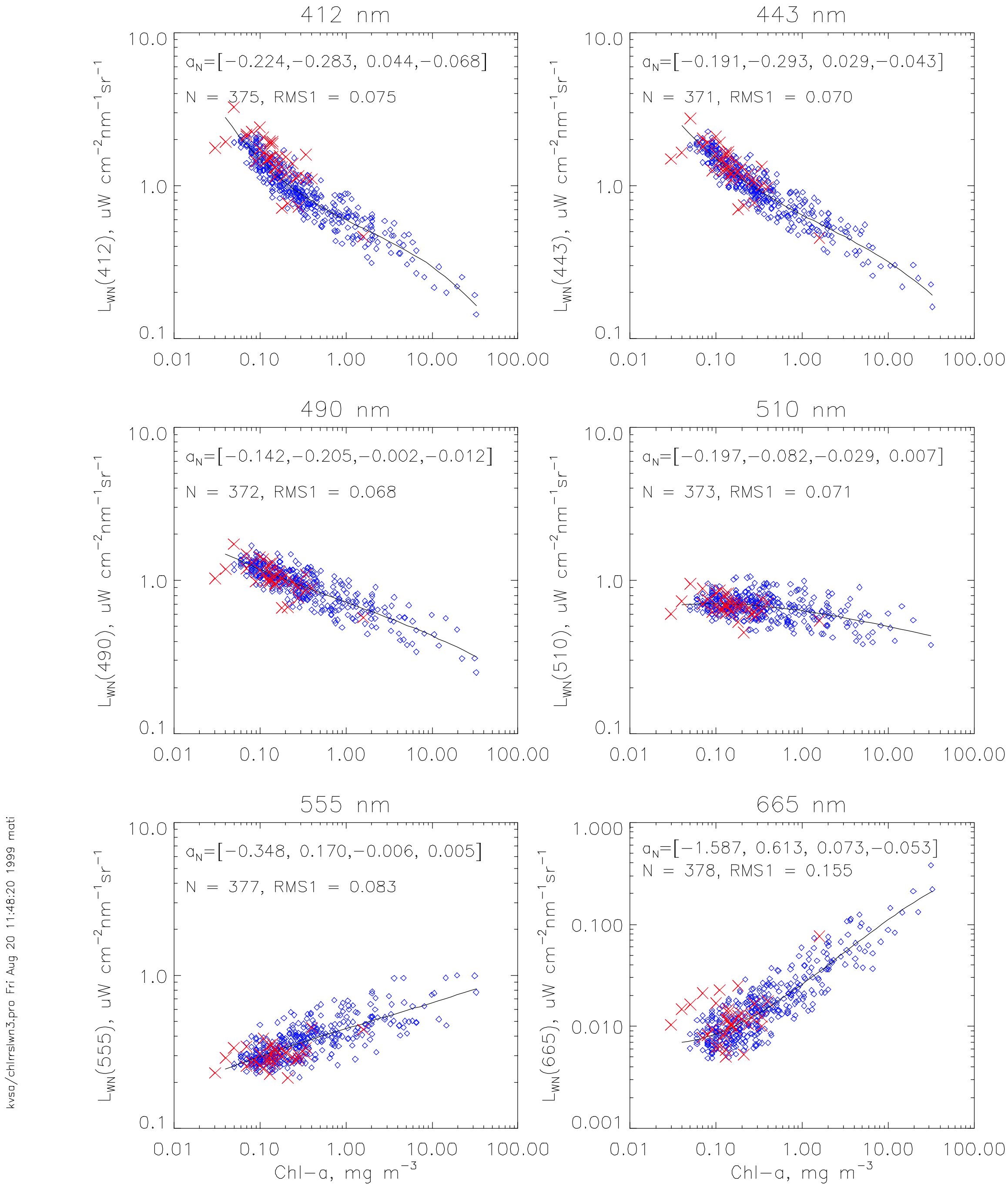

Figure 1. INDOEX relationships between L_{wN} and Chlorophyll a

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Chapter 22

Validation of the SeaWiFS Atmospheric Correction Scheme Using Measurements of Aerosol Optical Properties

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22.1 INTRODUCTION

The goal of the research described below is to validate the assumptions about aerosol scattering properties that are required to compute water-leaving radiance from ocean color satellite radiance measurements. Satellite-to-surface measurement comparisons can be made in the 765-870 nm wavelength band, while modeled aerosol optical properties used in the satellite water-leaving radiance retrievals must be compared with the surface measurements at shorter wavelengths. Because the modeled aerosol properties at wavelengths less than 765 nm are based on the optical properties in the 765-870 nm wavelength band, the first order validation problem is the credibility of the satellite aerosol measurements in those bands. At shorter wavelengths, the validity of the assumed aerosol model is the key issue.

The research outlined below is an effort to measure the aerosol optical properties from 870-380 nm over the world's oceans and coastal zones. These measurements can then be compared with satellite measurements of aerosol optical properties in the 765-870 nm wavelength band and with the models used in satellite water-leaving radiance retrievals at shorter wavelengths. Measuring the aerosol optical properties from ships at sea is done with sun photometry of varying sophistication, while aerosol optical properties in coastal zones are continuously monitored by the Aerosol Robotic Network (AERONET). These measurement systems are used as ground truth to evaluate atmospheric correction algorithms used in satellite ocean color retrievals.

There are two primary types of sun photometer used to measure the aerosol optical depth: narrow field-of-view radiometers aimed at the solar disk and rotating shadow-band radiometers. The latter are wide-field-of-view radiometers that employ an occulting apparatus to add directional capabilities. Just as narrow-field-of-view radiometers must be accurately aimed, a pitfall for measurements on ships at sea, conventional shadow-band radiometers also require exact orientation. Development of the Fast-Rotating Shadow-band spectral Radiometer (FRSR), a hybrid form of the original shadow-band radiometer design, has removed the orientation requirement, whereupon shipboard use of shadow-band radiometers has been encouraged. As compared to land-based units, shipboard fast-rotating shadow-band radiometers require much faster rotation of the occulting arm, faster-response silicon detectors, higher data sampling rates, and more sophisticated data analysis. As part of a multi-agency effort between NASA SIMBIOS and the Department of Energy's Atmospheric Radiation Measurement (ARM) program, the Brookhaven National Laboratory has developed a shipboard FRSR. It measures spectral global and spectral diffuse irradiance with 2-minute resolution, which are used to calculate the 2-minute spectral direct-normal irradiance as a function of solar zenith angle. From these data, the aerosol optical thickness can be computed during clear periods using the Langley regression technique, or continuously if high quality extraterrestrial calibration coefficients are known. In addition, the diffuse irradiance measured by the FRSR can be used to evaluate fractional cloudiness, thereby providing a means to test cloud filtering algorithms used in satellite ocean color retrievals.

22.2 RESEARCH ACTIVITIES

The BNL shipboard FRSR has progressed from a prototype to an operational instrument during the past year. The original FRSR instrument plus three new units constructed for ARM and the University of Miami were deployed aboard 4 different ships along with a variety of other aerosol-oriented instrumentation including hand-held sun photometers. Data coverage exceeded 46 weeks and parts of all three oceans were sampled (Table 1). The field experiments conducted during this period were AEROSOLS99, INDOEX, JASMINE, and NAURU99 and at the conclusion of these cruises, all of the FRSR and hand-held units used to collect data were moved to Hawaii and calibrated at Mauna Loa over a 20-day period. In parallel with the shipboard aerosol measurements, an analysis of satellite and surface-based optical properties continues using SeaWiFS and AERONET data. Results of an analysis of match-up data are presented in last year's report and progress has been made in producing a more reliable match-up dataset during the past year. A key finding of last year's analysis was that the match-up algorithm did not effectively filter clouds as indicated by aerosol optical thickness pixel-to-pixel variability that was not physically realistic. To address this problem, a new cloud filter package was implemented in the SeaWiFS/AERONET match-up code (Sean Bailey, personal communication). The result was a much more stringent set of quality checks that resulted in a vastly improved match-up analysis. An unfortunate trade-off was that the size of the revised match-up dataset was considerably smaller, thereby severely restricting the statistical significance of the match-up analysis in coastal zones. Within the next few months, a more significant dataset should accumulate and a second analysis will be performed, so this aspect of our research is not discussed in this report.

22.3 RESEARCH RESULTS

Extensive deployment of the FRSR and hand-help sun photometers along with a thorough Mauna Loa calibration provide a foundation for the research results discussed here. The Langley calibrations performed on Mauna Loa with the FRSR were in excellent agreement with Langley calibrations at intermediate locations during the three-ocean cruise. This calibration test shows that the FRSR is able to hold its calibration for long periods (i.e. months) even when operated continuously at sea. Moreover, the experiments increase confidence in the aerosol optical thickness (AOT) computed continuously from the cruise data.

A 5-day comparison between the FRSR and three hand-held sun photometers was made during the AEROSOLS99 experiment on-route between Norfolk, VA and Cape Town, South Africa. The hand-held sun photometers were operated in close proximity to the FRSR with different operators simultaneously making AOT measurements at discrete times during each day. As aforementioned, all the instruments used in these comparisons were post-calibrated at Mauna Loa and the same processing algorithm was used to compute AOTs from the raw signal values. Results showed that the FRSR AOTs agree with the AOTs from hand-held sun photometers. Two of the three well-calibrated hand-held sun photometers were in excellent agreement with the FRSR, while the third generally registered higher values of AOT despite its accurate calibration. This discrepancy suggests that there was some problem with the routine operation of this third hand-held sun photometer, perhaps low-batteries or movement of the device into and out of the air-conditioned laboratory between measurements. These comparisons suggest that multiple sun photometer measurements may be the most efficient means of evaluating data quality and identifying suspect measurements.

The AEROSOLS99 cruise lasted approximately 2-weeks and traversed at least three important aerosol regimes: Northern Hemisphere maritime aerosol, a plume of continental aerosol off Africa, and Southern Hemisphere aerosol. The FRSR and hand-held sun photometers detected the increase in AOT into the African dust/biomass-burning plume from an AOT of 0.1 0.5 AOT at 870 nm (Figure 1). Changes in the aerosol characteristics were also indicated by changes in the Angstrom exponent, which suggested that the aerosol in the African plume was considerably smaller in average size than the background sea-salt aerosol. The INDOEX and NAURU99 cruises provided additional data that is currently being analyzed. Preliminary results indicate that the FRSR functioned well in the variety of aerosol and sea conditions that were encountered.

In summary, we have collected a 46-week data set covering portions of three oceans that includes AOTs, global irradiance, and diffuse irradiance in a variety of conditions. Characteristics from various regimes are being quantified and results-to-date suggest that this data set provides information that can be directly applied to SeaWiFS atmospheric correction validation studies. Of particular importance is the size of the database. An autonomous instrument such as the FRSR that operates continuously can be deployed for long periods on ships of opportunity, thereby substantially increasing the odds of a ocean color satellite match-ups.

22.4 WORK PLAN

During the coming year, in addition to expanding our measurement database through field deployments of the FRSR, we will analyze the database collected during the past year and construct SeaWiFS/FRSR/AERONET match-ups for the purpose of evaluating atmospheric correction algorithms. Seminal to this effort is a comparison between the AOTs measured with the FRSR during AEROSOLS99 and INDOEX and those measured with hand-held sun photometers, lidars, PREDE, and SIMBAD. These efforts are being organized under the umbrella of special issues of the Journal of Geophysical Research and scientific coordinators for these projects have been selected.

In addition, we are currently engaged in an analysis of the data collected during all previous field deployments with the following questions are being addressed:

- What are the observable differences between sea-salt aerosol, bio-mass burning by-products, Saharan dust, and other marine aerosols, and are these differences accurately detected by SeaWiFS?

- What is the climatology of clear-sky diffuse irradiance over the world's oceans and is it possible to develop models to compute diffuse irradiance if only the global irradiance is known?

- In partly cloudy conditions, is there a distinct signature that discriminates optically thin clouds and optically thick aerosol thereby allowing the two to be identified from space and/or the surface?

- Are there observable differences in the diffuse irradiance in partly cloudy conditions that are a function of climatological regime or cloud type?

Table 1: Cruise summaries for FY99 deployments of the 4 FRSR's (1 NASA/DOE, 2 DOE, and 1 University of Miami) built by Brookhaven National Laboratory.

Platform	Experiment	Location	Other AOT data	Duration
R/V Ron Brown	Aerosols99	Atlantic Ocean	Microtops, SIMBAD, lidar	1 month
	INDOEX	Indian Ocean	Microtops, SIMBAD, PREDE, lidar	1 months
	JASMINE	Indian Ocean, TWP		1 month
	Nauru99	TWP	Microtops, lidar	1 months
R/V Mirai	Nauru99	TWP	Microtops	1.5 months
Island of Nauru	Nauru	TWP	Full complement	2 months
CC Polar Sea	U. Miami	TWP-N. Pacific	Microtops	2.5 months
Pierre Raddisson	U. Miami	Greenland Sea		2 months
R/V Mellville	SIMBIOS	Gulf of California	Full complement	1 month

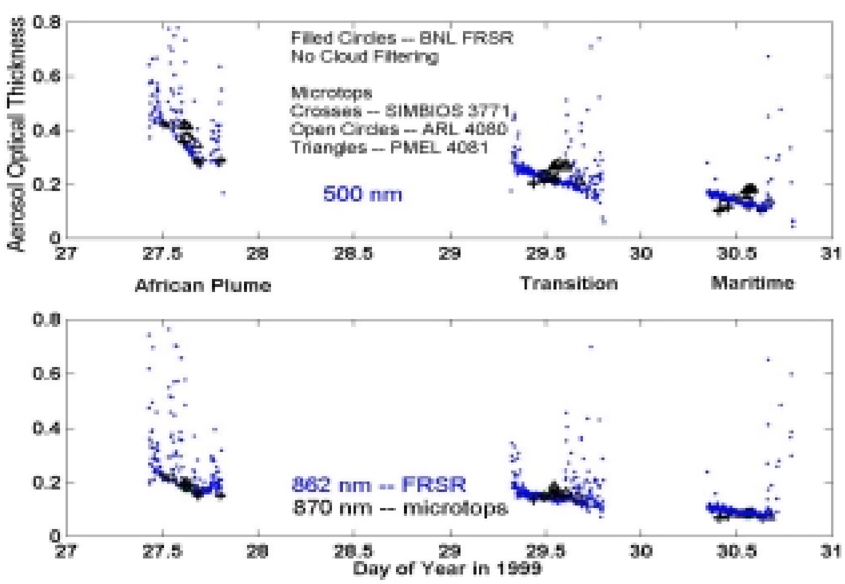

Figure 1. Aerosol optical thickness for three days during the AEROSOLS99 cruise

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PEER REVIEWED PUBLICATION

Porter, J.N., M.A. Miller, C. Motell, and C.Pietras, 1999: Use of hand-held sun photometers for measurements of aerosol optical thickness at sea. Submitted to *J. Atmos. Ocean. Tech.*.

Reynolds, R.M., M.A. Miller, and M.J. Bartholomew, 1999: Design, operation, and calibration of a shipboard fast-rotating shadowband spectral radiometer. Submitted to *J. Atmos. Ocean. Tech.*.

PRESENTATIONS

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Reynolds, R.M. and M.A. Miller, 1999: Instrument demonstration at the 9th Annual ARM Science Team Meeting, 1999, San Antonio, Texas.

Chapter 23

Measurements of Aerosol, Ocean and Sky Properties at the HOT Site in the Central Pacific.

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23.1 INTRODUCTION

Monthly cruises have been made to the Hawaii Ocean Time (HOT) series site (~100 km north of Oahu) since October 1988. The goal of these cruises is to make hydrography, chemistry, and biology observations (PI: Dave Karl and Roger Lucas). Measurements are typically made at a near coastal station (Kahe) on the first day to test the equipment and to obtain coastal shallow water (~1500m) observations. The second and third days are spent at the HOT site. On the morning of the fourth day, measurements are made at the HOT site and noon time measurements are made at the Hale-ALOHA station near the mooring before returning to port by early the next morning. The locations of the three stations are:

- Kahe (21.34^o N, 158.27^o W)
- HOT (22.75^o N, 158.0^{o}W)
- Hale-ALOHA buoy (22.43^{o}N, 158.0^{o}W).

The routine HOT measurements are available during the summer following the year of the observations. The 1998 measurements will therefore become available during the summer of 1999. The data sets can be obtained at the National Oceanographic Data Center (NODC) or from the HOT web site http://kahana.soest.hawaii.edu/hot/hot_jgofs.html.

23.2 RESARCH ACTIVITIES

Microtops Sun Photometer Measurements

Beginning with the HOT89 cruise, aerosol optical depth measurements were made with two Microtops sun photometers. A time series of aerosol optical depths is shown in Figure 1a for 440 and 1020 nm. The other wavelengths were consistent with these in that the annual cycle is clear for the shorter wavelengths but is not so evident at the longer wavelengths. This suggest the spring time Asian transport during 1998 brought significant accumulation mode aerosol to the Central Pacific which is most likely due to anthropogenic aerosol. A similar feature is seen in the SeaWifs images processed for the HOT region. This is shown in Figure 1b which shows the ratio of aerosol scattered light at two wavelengths (780 and 860 nm) (eps_78). Larger ratio values correspond to smaller aerosol and smaller values to larger aerosol. Similar to the aerosol optical depth measurements, the eps_78 suggest a seasonal cycle of smaller aerosol over the HOT site during the spring time. Aerosol optical depth measurements were made at 380, 440, 500, 675, 870 and 1020 nm, column integrated water vapor and ozone concentrations were also derived.

These measurements have been submitted to the SeaBASS archive. Comparisons between ship and satellite optical depths are shown in Figure 2. The best comparisons are shown as blocks and the x values are cases where ship and satellite were close. but not the same. In general the agreement is within 0.03 but several outliers are present. These outliers usually occur with a flat spectral shape which may be dust.

Marine Shadowband Radiometer

During the past two years we have been working on a marine shadowband radiometer which will save aerosol optical depths and downwelling irradiance at ~20 wavelengths. This system uses a gimbaled cosine response detector and a rotating shadowband arm which shadows the detector. A temperature controlled CVI Laser spectrometer is used to collect the light which is saved on a PC104 computer. The system has been tested on several cruises and the gimbal works well. We are planning to take the rebuilt version on the October 1999 HOT cruise.

Radiometric Calibration Facility

Radiometric calibration is being maintained by comparisons with the MOBY calibration facility (thanks to Dennis Clarke) and through Optronics calibration. This includes an integrating sphere and an irradiance lamp. We are also hoping to take part in the upcoming SIRREX calibration effort in Hawaii.

In-Water Optics Measurements

As part of this SIMBIOS effort, routine optical measurements have been made at each of the HOT stations.

Measurements are made simultaneously with a Profiling Reflectance Radiometer (PRR) and a Tethered Spectral Radiometer Buoy (TSRB). These instruments provide measurements in the visible wavelength range of downwelling irradiance and upwelling radiance at the sea surface and at depth. These measurements have been made since the HOT89 cruise (January 1998) by Karl et al. and are processed by R. Letelier and J. Bartlett. Deployment and calibration procedures follow the recommended protocols for SeaWiFS calibration and validation. Immediately following each monthly HOT cruise, the PRR data are processed and submitted to SeaBASS. The processed PRR and TSRB data are also available online for use by the scientific community (http://picasso.oce.orst.edu/ORSOO).

This web site also provides details of the measurement locations, instrumentation, and deployment procedures. The optical data resulting from this ongoing effort will aid in the interpretation of the temporal and spatial variability of the constituents of Hawaiian waters.

23.3 WORK PLAN

Microtops Calibration and Processing

Christophe Pietras has maintained calibration of the SIMBIOS pool of Microtops hand held sun photometers by performing cross calibration with the Cimel sun photometer network. We have separately maintained a calibration effort by making Langley plot calibration efforts at the Mauna Loa observatory. Pending approval by the SIMBIOS Project, we hope to make a coordinated effort by performing Langley plot calibration and comparisons with the set of Cimel sun photometers at the Mauna Loa observatory.

Sean Bailey has recently implemented protocols to process Microtops ship based sun photometer measurements (technical memorandum, Porter, Miller, Pietras, Motell, 1999). As this process is somewhat subjective, we would like to coordinate with Sean to compare his and our techniques.

Sky and Surface Radiometer

We are developing a radiometer to measure sky and ocean surface radiance on ship platforms. The system uses a wide-angle camera and a tilt meter to determine the viewing geometry and a spectrometer to measure the sky or the aureole. The scattering angle is derived from the position of the sun in the camera image and a tilt meter. The system has been constructed but requires very careful angular calibration which we hope to get to in the near future.

Measurements of the Aerosol Scattering and Absorbing Coefficients and the Aerosol Phase Function

During 1998 a prototype polar nephelometer was built to measure the aerosol phase function (Porter et al., Hilo Ocean Optics meeting in 1998). We are now building an improved version with three wavelengths (1064, 532, 355 nm) which will measure the aerosol scattering coefficient and aerosol phase function from ~3 to 177 degrees. A ground based version is near completion and will be used on the HOT cruises. A particle absorption photometer has also been ordered and will be used to measure the aerosol absorption coefficient. The spectral dependence of aerosol absorption will also be determined in post processing. We are also looking into collaborative efforts with Dr. Barry Huebert and Dr. Luann Becker to characterize the in-organic and organic species on the filter. These aerosol filter measurements will be made on all HOT cruises.

Modeling Efforts

We have several topics we would like to address using modeling efforts. These include algorithms to derive information on the aerosol type from sun photometer measurements, studies of the surface reflection problem, and satellite retrievals of aerosol type and the wavelength dependence of aerosol radiance. These modeling studies will be based on the aerosol models used in the SeaWiFS Data Analysis System (SeaDAS) algorithm as well as the more realistic aerosol models currently available.

In order to study these effects we have been working on an atmospheric Monte Carlo model. Due to time constraints, this has taken several years but is now complete. The model has been compared successfully with the Nakajima RTRN algorithm for a Lambertian surface. A Cox and Munk model modified for whitecaps will be used for the final calculations.

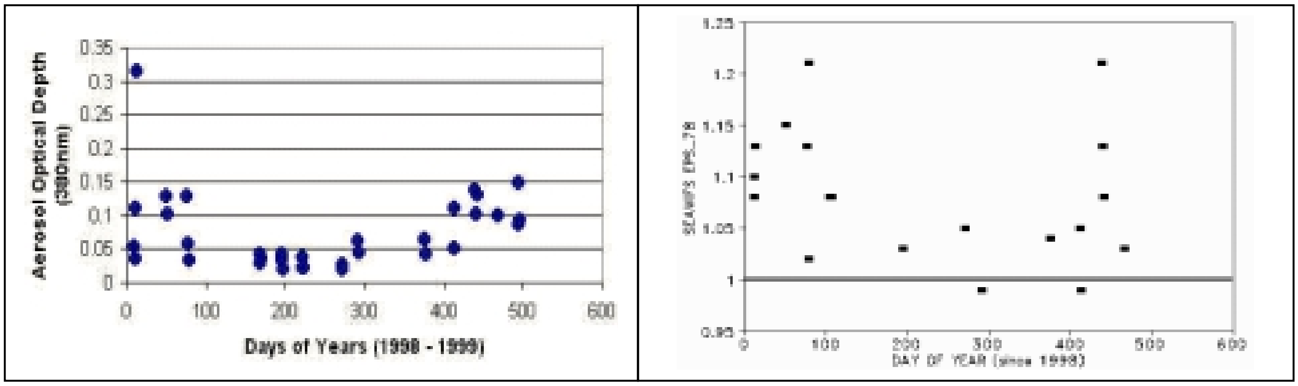

Figure 1. Left panel shows time series of aerosol optical depth (380 nm) at the HOT site. Right panel shows eps_78 derived from SeaWifs for the HOT site.

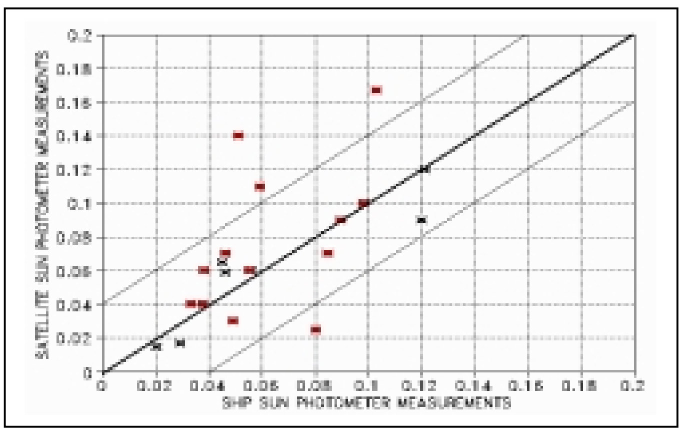

Figure 2. Comparison between Seawifs and ship derived aerosol optical depths (870 nm).

This research was supported by the

SIMBIOS NASA interagency agreement # 97136

PEER REVIEWED PUBLICATION

Porter, John N., Tom F. Cooney and Craig Motell, 1998: Coastal aerosol phase function measurements with a custom polar nephelometer. *Ocean Optics XIV* Conference, Kona, Hawaii.

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Chapter 24

Assessment of the Contribution of the Atmosphere to Uncertainties in Normalized Water-Leaving Radiance: A Combined Modeling and Data Analysis Approach.

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24.1 INTRODUCTION

Our research for the SIMBIOS program has been focussed on modeling and simulation studies aimed at developing an improved atmospheric correction algorithm. Based on our original proposal and discussions at the SIMBIOS team meetings and workshops, the objectives of our research can be summarized as follows:

(a) Use our radiative transfer model for the coupled atmosphere-ocean system to simulate the radiation field at any desired level and in any desired direction in the atmosphere and ocean so as to provide a firm connection between the signal received by the satellite sensor and by a sensor looking down into the water column just above the surface and just below it.

(b) Use the simulations to quantify the influence of atmospheric aerosols on the top-of-the-atmosphere (TOA) radiance, and to quantify the error in the retrieved water-leaving radiance as a function of uncertainties in the aerosol optical properties, mass loading and vertical extent.

(c) Use the model simulations in conjunction with validation measurements taken by other SIMBIOS investigators (for satellite overpasses) to assess our understanding of the radiative transfer process in the coupled atmosphere-ocean column, and to examine the extent to which the model provides a realistic prediction of simultaneously measured *in situ* water-leaving radiance and the radiance received by the satellite sensor.

(d) Modify and improve an existing atmospheric correction algorithm, based on the work above, as needed by constructing new look-up tables that take into account scattering by ocean particles.

(e) Develop an atmospheric correction algorithm for ocean color imagery that will work also in the presence of strongly absorbing aerosols.

24.2 RESEARCH ACTIVITIES

I. We have mainly been working on numerical radiative transfer modeling experiments using a comprehensive radiative transfer model for the coupled atmosphere-ocean system to (a) simulate the radiation transfer process in the coupled atmosphere-ocean system so as to provide a firm connection between the signal received by the satellite sensor and by a sensor looking down into the water column just above the surface and just below it; (b) assess the effects of scattering ocean particles on the water-leaving radiance (Lw) at NIR wavelengths, especially for high latitudes where large solar zenith angles are common; and (c) examine the validity and consequence of the basic assumption commonly used in atmospheric correction of ocean color imagery, namely, that the water-leaving radiance at NIR wavelengths is negligible, using a comprehensive radiative transfer model for the coupled atmosphere-ocean system with an existing bio-optical model of the open ocean and common aerosol models.

II. We have carried out preliminary work on algorithm development for atmospheric correction to (a) examine the existing algorithm developed by Gordon and co-workers for atmospheric correction of ocean color imagery; (b) use a state-of-the-art radiative transfer model for the coupled atmosphere-ocean system to simulate the process of atmospheric correction; (c) study possible new approaches to atmospheric correction; and (d) construct lookup tables for a new and efficient algorithm.

III. We have begun processing of satellite data as well as field-data.

IV. Collaborations with other PIs in the SIMBIOS program and collaborations with other investigators in ocean optics and atmospheric correction: (a) We have had close collaborations with Dr. Mueller's group and Dr. Zaneveld's group. We have had a few mini-workshops among our groups. (b) We have been collaborating with Drs. J.J. Stamnes and O. Frette at the University of Bergen, Norway on the problems of atmospheric correction as well as bio-optical models appropriate for use in open ocean and coastal waters.

24.3 RESEARCH RESULTS

I. Numerical radiative transfer modeling

We have found that the relative contribution of the water-leaving radiance to the total TOA radiance at NIR wavelengths depends on (a) the scattering characteristics of particles in the near-surface ocean water, described by their shape, size, and refractive-index distributions, which in turn determine the scattering phase function; (b) the aerosol optical depth; (c) the ocean particle concentration; and (d) the sun-satellite geometry.

Our simulations show that for common aerosol loadings over the open ocean (aerosol optical depths in the range 0.08-0.11) the water-leaving radiance at NIR wavelengths (e.g., 865 nm) is usually not negligible. This is particularly important when the aerosol loading is low because then the contribution from the water-leaving radiance to the total radiance received by the satellite sensor is relatively larger, and will if ignored introduce significant errors in atmospheric correction. Under pristine atmospheric conditions with low aerosol loading the assumption that the water-leaving radiance at NIR wavelengths can be ignored becomes questionable when the ocean chlorophyll concentration is high because the NIR water-leaving radiance may then contribute significantly to the TOA radiance. Under such circumstances neglect of the NIR water-leaving radiance may result in a significant overestimation of the aerosol loading.

This implies that the aerosol model picked for the atmospheric correction will be wrong. When this erroneous aerosol model is used to estimate the aerosol contribution in the visible and to subtract it from the measured TOA radiance in order to infer the water-leaving radiance, substantial errors are possible that in extreme cases could lead to negative water-leaving radiances. The assumption that the water-leaving radiance is zero at NIR wavelengths is generally questionable for some case I waters. In case II waters this assumption is even less valid due to significant scattering in the NIR spectral region from inorganic particles. Therefore the aerosol optical depth predicted by existing methods/algorithms will be overestimated in both case I and case II waters. This deficiency can be overcome by using a radiative transfer model for the coupled atmosphere-ocean system to retrieve the correct aerosol optical properties at NIR wavelengths.

II. Atmospheric correction

We have obtained preliminary results of an atmospheric correction algorithm for ocean color imagery for weakly as well as strongly absorbing aerosols. Implementation is underway, and papers are being prepared. Compared to Gordon’s atmospheric correction algorithm, our algorithm has the following improvements: (a) It includes multiple scattering in a rigorous one-step manner. (b) It uses a combination of NIR and visible bands to choose correct aerosol model and vertical structure so as to provide proper atmospheric correction for both weakly and strongly absorbing aerosols. (c) It provides aerosol optical depth and vertical structure, as well as diffuse atmospheric transmittance, water-leaving radiance, and chlorophyll concentration in a self-consistent manner.

24.4 WORK PLAN

- We will continue algorithm development and testing using simulated data.

- We will implement the algorithm within the “MSL12” software to allow us to test it off-line against match-up data. This work will be done in collaboration with Dr. Jim Muller and the OSU group (Drs. Zaneweld, Pegau, and Bernard).

- We will implement the algorithm within SeaDAS and apply it to SeaWiFS data for further testing and evaluation. This work will be carried out in collaboration with the SIMBIOS office.

- We will make algorithm available to other SIMBIOS PIs for additional evaluation and testing.

This research was supported by the

SIMBIOS NASA contract # 97138

PEER REVIEWED PUBLICATIONS

Chen, Bingquan, Knut Stamnes, et al., 1999: Water-leaving radiance in the NIR spectral region and its effects on atmospheric correction of ocean color imagery. In press *Journal of Advanced Marine Science and Technology Society*

PRESENTATIONS

Yan, Banghua, Knut Stamnes, and Bingquan Chen, 1999: A Generalized Algorithm for Atmospheric Correction of the Ocean Color Imagery: Feasibility Simulation. AGU 1999 Spring Meeting in Boston.

Chapter 25

Validation of the Water-Leaving Radiance Data Product

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25.1 INTRODUCTION

The objective of this research is to assess an accuracy of data products derived from satellite ocean color data. Specific goals include an assessment of accuracy of the atmospheric correction algorithms for variety of meteorological and oceanological conditions and of the bio-optical algorithms for different water cases. Along with the operational SeaWiFS chl-a algorithm, the semianalytic algorithm developed by our group was validated. Such kind of bio-optical algorithms could solve the problem of Case II waters but they place much more severe requirements to atmospheric correction than the SeaWiFS operational algorithm.

The latter only uses the Lwn values at 490 and 555 nm whereas the semianalytic algorithm needs the correct Lwn values at all SeaWiFS spectral bands including 412 nm. That is the reason why a close attention should be paid to the atmospheric correction algorithm for solving the Case II problem.

25.2 RESEARCH ACTIVITIES

In 1999 we did not carry out any validation cruise and worked on analysis of data obtained during our previous cruises in the Black and Aegean Seas in October 1997 and in the Barents Sea in August-September 1998. Validation of the atmospheric correction and bio-optical algorithms was performed by direct comparison between values of the water-leaving radiance Lwn(λi), i=1-5, aerosol optical thickness τ_a (865), and chlorophyll concentration measured and derived with different algorithms. Also SeaWiFS Level 2 data for the Black, Mediterranean, and Barents Seas have been collected since September 1997 to use them for monitoring these regions as well as to analyze them for revealing defects of different origin.

25.3 RESEARCH RESULTS

Negative Lwn values.

We found negative *Lwn412* values not only in highly productive waters where they are due to the effect of non-zero NIR reflectance, but also in not so productive waters of the Black Sea and even in oligotrophic waters of the Eastern Mediterranean. In Figure 1 the negative Lwn values at 412 nm are seen as dark areas in the averaged monthly distribution in the Eastern Mediterranean in April 1998. One of such areas is located near the Nile run-off and its existence can be explained by the effect of non-zero NIR reflectance, but the other, north of Crete, is with rather clear waters. The negative Lwn values are most frequent at 412 nm but they are also observed at 443 nm and even at 555 nm. Sometimes Lwn is positive at 412 nm but negative at greater wavelength for one and the same pixel. The most probable reason of that is a wrong choice of the aerosol optical model in the SeaWiFS atmospheric correction procedure. Dependence of results of the atmospheric correction on the scan angle. Our analysis shows that results of the atmospheric correction depend on the scan angle. Figure 2 presents results of comparison between the Lwn values derived at small (less than 20^o) and large (greater than 30^o) scan angles for different spectral bands and averaged over the half-degree square south-west of Crete. The spatially averaged Lwn values are calculated for 9 days with the small scan angle (triangles) and 8 days with large scan angle (squares), and it is seen that the Lwn values calculated at the small scan angle are higher than the ones at the large scan angle. The minimum difference in values is observed at 490 nm, the most pronounced is at 412 and 555 nm. As well as in the case of negative Lwn values, the observed difference can be explained by a wrong choice of the aerosol optical model which probability is higher when observation is made at the large scan angle.

Comparison between SeaDAS 3.2 and SeaDAS 3.1 versions of the atmospheric correction.

We suspect that SeaDAS 3.2 atmospheric correction can be worse than SeaDAS 3.1 version. As it is seen from Table 1 where the results with two versions are compared for two stations in the Black and Aegean Seas, SeaDAS 3.2 reduces errors in retrieval of the τ_a 865 values comparing with SeaDAS 3.1, but SeaDAS 3.2 also changes a spectral dependence of Lwn reducing Lwn412 by 13-28% and magnifying the other Lwn values by 3-21%; the errors on the chlorophyll values are increased by 16-71%.

The strange maxima in the Lwn distribution.

The rather strange maxima in the Lwn distribution were found when we tried to use the SeaWiFS Level 2 data for study of mesoscale variability in the Eastern Mediterranean. An example of such maxima west of Crete is shown in Figure 3. Such kind of maxima appear while data are mapped using an isoline technique; they look quite real in amplitude and measure up to tens of kilometers in dimensions but show suspiciously short life time and may form chain or “multicell” structures. They can result in errors in estimate of the mean values and show unrealistically complicated the Lwn distribution in homogeneous ocean regions. The visual analysis of initial data showed that the occurrence of such maxima could be connected with inefficiency of elimination of cloud effects. It can be related to “Stray light and atmospheric adjacency effects” studied by K.Carder and resulted from the scattering by edges of clouds or stray light within the SeaWiFS sensor or from high cirrus clouds. Such kind of effects should be kept in mind while studying ocean mesoscale variability with satellite ocean color data.

Validation of the bio-optical algorithms.

Table 2 presents results of comparison between chlorophyll-a concentrations ($mg.m^{-3}$) measured and retrieved by different bio-optical algorithms at several stations in the Black Sea (Stations 1-3), the Aegean Sea (Stations 4, 5), and the Barents Sea (St. 1088-1281). Because of the poor quality of atmospheric correction in the Barents Sea, the *in situ* measured Lwn values were taken as the initial data for the Chlorophyll retrieval with the bio-optical algorithms; the SeaWiFS algorithm was the OC2 operational algorithm. The author’s algorithm was the semianalytic algorithm based on the low-parametric model for seawater absorption and backscattering and the analytic formula for ocean radiance reflectance; it can be used for deriving chlorophyll, seawater absorption and backscattering coefficients (Burenkov et al., 1999; Kopelevich et al., 1998).

The extreme right column in Table 2 shows values of the ratio between the absorption coefficients of gelbstoff and phytoplankton pigments at 440 nm. The β value is an important parameter which can be used as an indicator of failure of the SeaWiFS empirical algorithm; our analysis showed that the critical value is about 2. As it is seen from Table 2, in the Black and Aegean Seas where the β values are 2.6-5.9 the SeaWiFS algorithm overestimates the chlorophyll concentration about twice; the similar situation in the Barents Sea with the exception of the Pechora Basin (Stations 1090-1157). In the Pechora Basin, which is under strong influence of the Pechora-river discharge and the βvalues are more than 12 and even exceed a hundred; the SeaWiFS algorithm overestimates the chlorophyll concentration by a factor of 4.4 - 22.6. The semianalytic algorithm provides much better agreement between the calculated and measured chlorophyll concentration: the mean error is equal to 15% for stations in the Black and Aegean Seas, 48% for stations in the Pechora Basin, and 27% for other stations in the Barents Sea.

25.3 WORK PLAN

- In 2000 we plan to make a comparative validation of the SeaWiFS atmospheric correction algorithm and the new algorithm to be developed by our group.
- Our cruise plans for 2000 are not yet finalized.

ACKNOWLEDGMENTS

This research was carried out by the group from P.P.Shirshov Institute of Oceanology including Drs. V. Burenkov, G. Karabashev, S. Sheberstov, S. Ershova, M. Evdoshenko.

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Kopelevich, O.V., D. B. Rogozkin, and S. V. Sheberstov, 1998: Results of application of the new atmospheric correction method to the Pacific Ocean color simulated data set. *Proc. PORSEC’98, Vol. 1*, M-X. He and G. Chen, Eds., Secretariat, Qingdao, China, 54-58

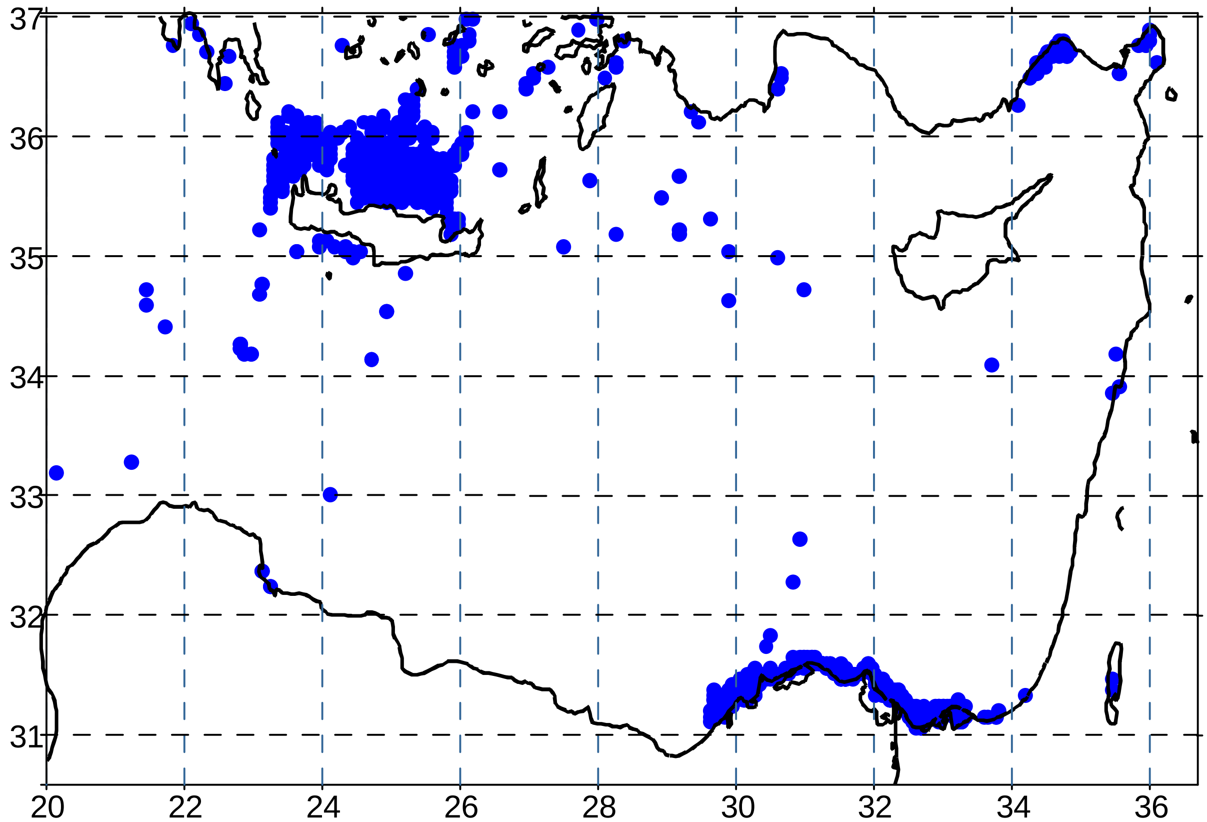

Figure 1. The negative monthly values of Lwn412 (dark) observed in the Eastern Mediterranean (April 1998)

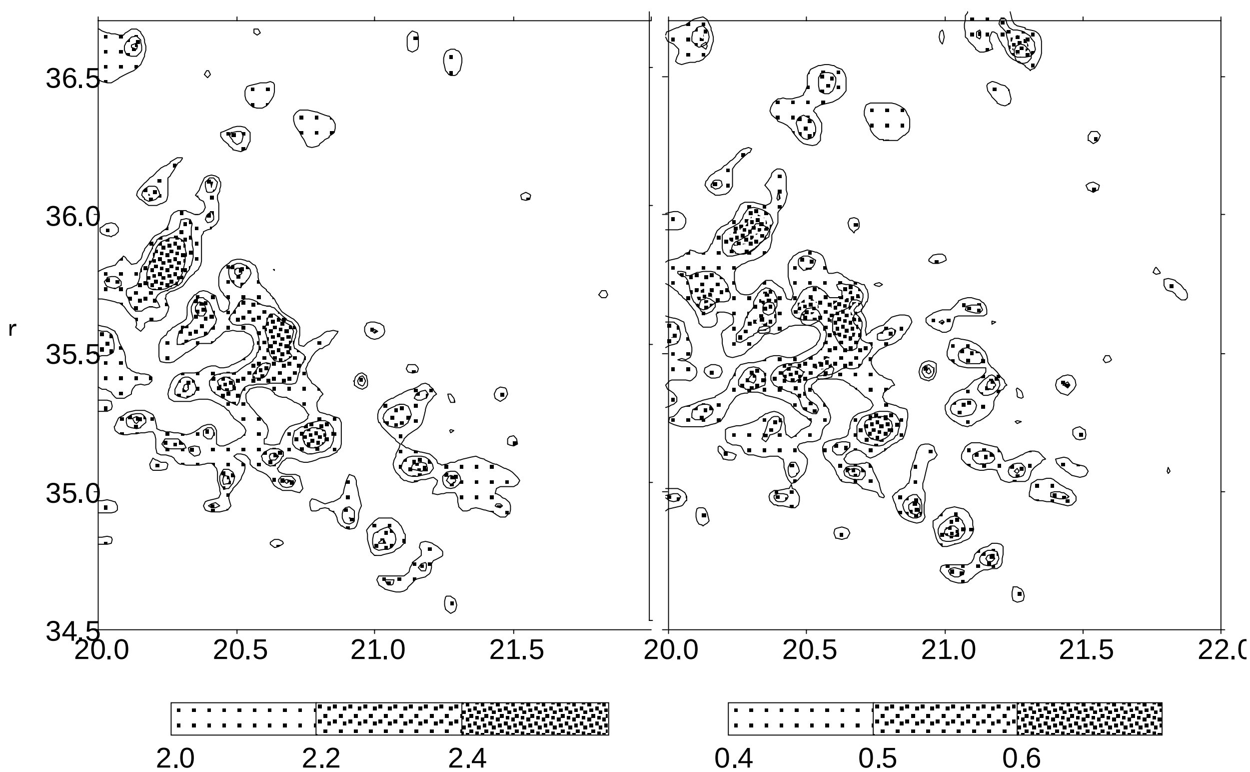

Figure 3. False maxima in distribution of *Lwn412* (left image) and *Lwn555* (right image) observed west of Crete while data are mapped with an isoline technique (08/08/98).

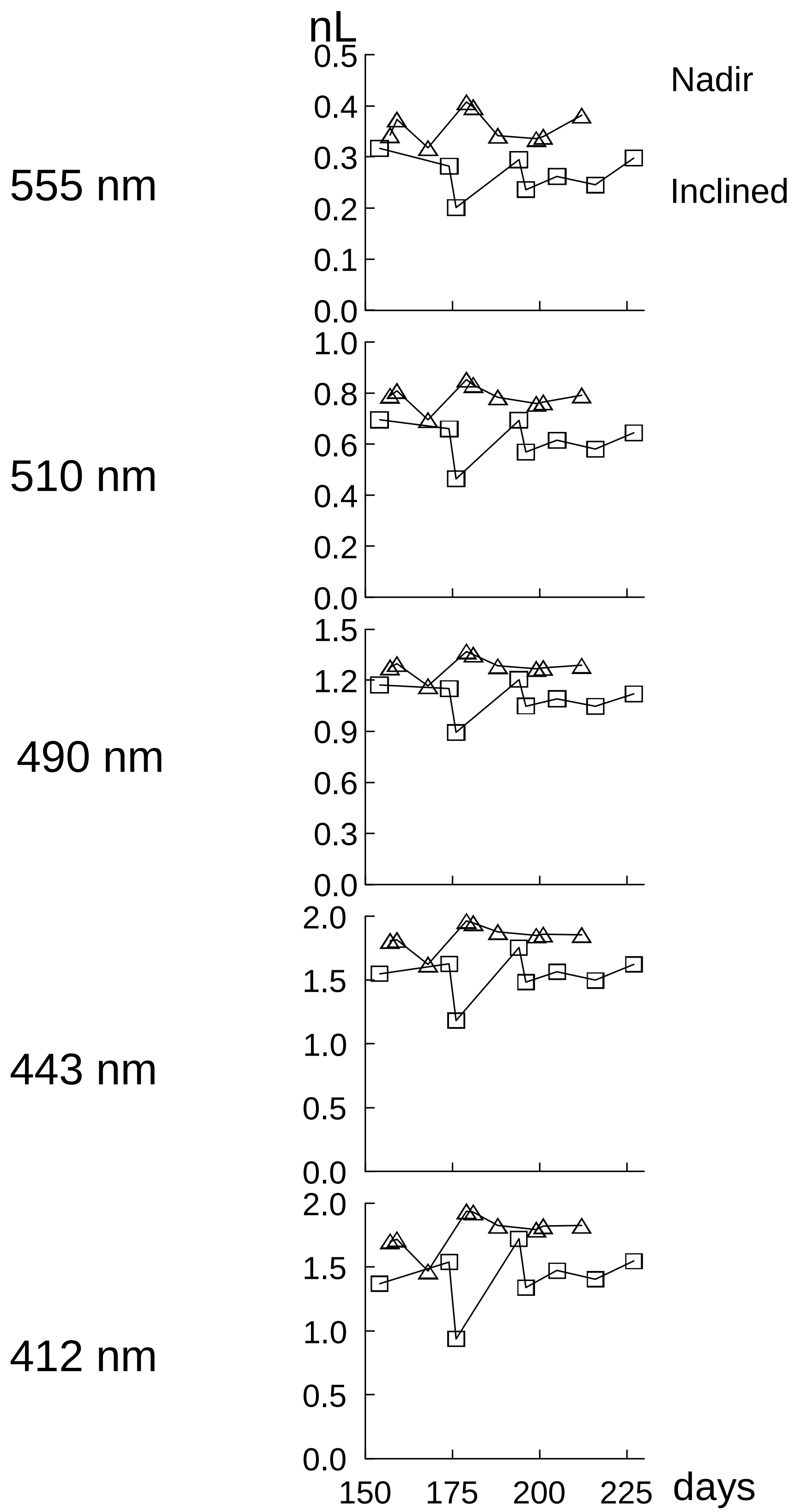

Figure 2. Comparisons between the Lwn values derived under conditions of small (triangles) and large (squares) scan angles (July-august 1998).

Table 1. Comparison between the values of the water-leaving radiances (W. $m^{-2}\mu^{-1}$. sr^{-1}), aerosol optical thickness τa^{865}, & chlorophyll concentration (mg. m^{-3}) measured and derived from SeaWiFS data with SeaDAS 3.1 and SeaDAS 3.2 versions; Δ, % is the relative discrepancy between derived and measured data.

	The Black Sea (St.2)					The Aegean Sea (St.4)				
λ, nm	L_{WN} measured	L_{WN} SeaWiFS SeaDAS 3.1	Δ, %	L_{WN} SeaWiFS SeaDAS 3.2	Δ, %	L_{WN} measured	L_{WN} SeaWiFS SeaDAS 3.1	Δ, %	L_{WN} SeaWiFS SeaDAS 3.2	Δ, %
412	0.492	0.536	+9	0.397	-19	0.732	0.770	+5	0.674	-8
443	0.708	0.752	+6	0.782	+10	0.891	0.886	-0.6	0.939	+5
490	0.998	1.036	+4	1.066	+7	0.784	0.822	+6	0.867	+11
510	0.925	0.991	+7	1.036	+12	0.537	0.592	+10	0.627	+17
555	0.772	0.770	-0.3	0.820	+6	0.272	0.271	-0.4	0.329	+21
τ_a^{865}	0.095	0.065	-31	0.080	-16	0.142	0.160	+13	0.140	-2
Chl, $mg\,m^{-3}$	0.57	1.06	+86	1.15	+102	0.089	0.184	+107	0.247	+178

Table 2. Comparison between chlorophyll-a concentrations (mg·m^{-3}) measured and retrieved by author's and operational SeaWiFS algorithms at different stations in the Black Sea (St.1-3), the Aegean Sea (St. 4, 5), and the Barents Sea (St. 1088-1281). β is the ratio between the absorption coefficients of gelbstoff and phytoplankton pigments at 440 nm.

t.	Coordinates	Chl meas.	Chl auth.	Chl SeaWiFS	β
1	42.51 N, 39.52 E	0.35	0.23	0.68	4.3
2	42.96 N, 35.60 E	0.57	0.56	1.20	3.4
3	42.90 N, 31.60 E	0.45	0.56	1.12	2.6
4	39.32 N, 25.12 E	0.089	0.086	0.21	5.9
5	39.61 N, 25.79 E	0.076	0.088	0.18	5.2
1088	70.42 N, 47.58E	0.16	0.25	0.63	5.7
1090	70.18N, 52.42E	0.5	0.77	3.3	12.7
1095	68.97N, 58.47E	0.79	0.21	10.4	114
1112	69.09N, 58.29E	0.42	0.62	9.5	36.7
1125	69.50N, 57.25E	0.23	0.06	2.8	76.2
1126	69.67N, 57.24E	0.18	0.19	2.7	33.3
1157	70.54N, 52.79E	0.25	0.17	1.09	15.0
1174	69.25N, 41.00E	1.39	1.03	1.0	2.3
1183	71.50N, 41.00E	0.38	0.32	0.81	3.8
1196	74.75N, 41.00E	0.13	0.14	0.28	3.6
1209	78.00 N, 41.00E	0.16	0.17	0.25	2.8
1281	76.00N, 42.27E	0.27	0.41	0.44	2.2

Chapter 26

Intensive and Extensive Field Programs for Data Product Validation of OCTS/ADEOS and GLI/ADEOSII

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26.1 INTRODUCTION

Increased international cooperation in satellite ocean color remote sensing of the global and coastal oceans is very timely owing to the large number of sensors planned for launch over next 10 years. The Advanced Earth Observing Satellite (ADEOS) was successfully launched August 17th 1996 by the National Space Development Agency of Japan (NASDA). ADEOS has eight earth observation sensors including the Ocean Color and Temperature Scanner (OCTS) which has 8 bands in visible and near infrared region for receiving the chlorophyll a concentration in the sea and 4 bands in thermal region for retrieving sea surface temperature (Saitoh, 1995). Although the ADEOS lifetime was relatively short (about 10 months), OCTS left a huge, invaluable data set for oceanographic research (Kawamura and The OCTS Team, 1998). NASDA has already started to develop advanced ocean color sensor Global Imager (GLI) which will be mounted on ADEOS II. We realize the importance of best use of those scheduled missions by developing a methodology and operational capability to combine data products from various ocean color missions in a manner that ensures the best possible global coverage, and exploits best complementary missions of the sensors (NASA, 1996). We, Japanese ocean color science community, decided to participate the SIMBIOS program for contribution of best and comprehensive utilization several ocean color missions including OCTS/ADEOS and GLI/ADEOS II. Our main objectives were:

- enhance Cal/Val activities for OCTS and GLI through the intensive and extensive
- field program in the northwestern North Pacific
- validate the data products of OCTS/ADEOS, SeaWiFS/orbview-2 and GLI/ADEOS II
- develop regional bio-optical algorithm
- comparison OCTS with SeaWiFS
- keep and validate the heritage from OCTS to GLI

In the past, we have already carried out the validation and development of bio-optical algorithm in the waters around Japan using ship and moored optical buoy system (Saitoh et al., 1997; Kishino et al., 1997a, 1997b; Ishizaka et al., 1997).

26.2 RESEARCH ACTIVITIES

Ocean color variability at KNOT station

We applied ocean color remote sensing data sets both OCTS from October 1996 to June 1997 and SeaWiFS from September 1997 to July 1999, in order to grasp the temporal and spatial variability of chl-a distribution at the Japan JGOFS time series station KNOT (Kyo-do Northwest Pacific Ocean Time Series) (at 44°N, 155°E) and its adjacent waters in the Subarctic north-western North Pacific, and to understand the mechanisms of chlorophyll-a distribution during 1996-1999. Furthermore to analyze short-term variability, we carried out synoptic ship observations at Stn. KNOT and its adjacent waters.

Field programs for validation of SeaWiFS

Eight cruises were carried out in the study area, northwestern North Pacific from May 1998 to May 1999 (Figure 1). Radiometric profiles and fluorometric chlorophyll a samples, and inherent optical properties were measured in the same period. We conducted subsurface radiance/irradiance profile using a Biospherical Instruments MER2040 in conjunction with a MER2041 Deck Unit. The MER2040/2041 bands are :

- 13 bands Ed, Es (412, 443, 465, 490, 510, 520, 555, 565, 625, 665, 670, 683, 710nm);
- 13 bands Lu (412, 443, 465, 490, 510, 520, 555, 565, 625, 665, 670, 683, 710nm)

26.3 RESEARCH RESULTS

Relatively low chlorophyll-a concentration (about 0.3–0.8mg/m^3) dominated throughout the year at the station KNOT, but remarkable peak was seen in bloom period (in May and October), winter (in November and December) and summer (in August 1998). In adjacent sea area, most remarkable high chl-a (more than 10mg/m^3) was seen northward to station KNOT along the Kuril-Islands and adjacent waters in May 1999, moreover high concentration remain over a month during the bloom season. Year-to-year variability of chl-a was seen. Chl-a (about 1.4mg/m^3) at the Stn.KNOT in November 1997 was higher than that in November during 1996-1999. Chl-a around the center of Western Sub-arctic Gyre in October 1998 was higher than that in October 1997.

Using data from the study area, northwestern North Pacific (Figure 1), we determined the match-up between the weekly SeaWiFS chlorophyll a and *in-situ* chlorophyll a for eight cruises (Figure 2). Total sample number and r^2 are 62 and 0.82, respectively.

26.4 WORK PLAN

We will continue to gather bio-optical data sets at station KNOT and adjacent waters. In January 2000, we will have an interdisciplinary cruise in the northwestern North Pacific including Stn. KNOT by R/V Mirai. In March 2000, we will have a research cruise in Funka Bay, coastal region of Hokkaido Island by T/S Oshoro-Maru. In July 2000, we will operate bio-optical cruise in the Gulf of Alaska and the Bering Sea through the IARC/NASDA project. In September 2000, we will go to East-China Sea for sampling CASE-II water data sets by R/V Hakuho-Maru.

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Figure 1. Map of the observation area, ship transect and stations in this study

Figure 2 Comparison between in-situ and SeaWiFS chlorophyll a concentration

GLOSSARY

ACE	Aerosol Characterization Experiment
ADEOS	Advanced Earth Observation Satellite
AERONET	Aerosol Robotic Network
AM-1	Not a acronym, used to designate the morning platform of EOS
AOP	Apparent Optical Properties
AOT	Aerosol Optical Thickness
APV	Autonomous Profiling Vehicle
ARGOS	Not an acronym, but the name given to the data collection and location system on the NOAA Operational Satellites.
ASCII	American Standard Code for Information Interchange
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Advanced Visible and Infrared Imaging Spectrometer
BATS	Bermuda Atlantic Time-series Study
BBOP	Bermuda Bio-Optics Profiler
BBSR	Bermuda Biological Station for Research
BNL	Brookhaven National Laboratory
BTM	Bermuda Test Mooring
Cal/Val	Calibration and Validation
CalCOFI	California Cooperative Oceanic Fisheries Investigation
CALVAL	Calibration Validation
CARICO	Carbon Retention in a Colored Ocean
Case-1	Water whose reflectance is determined by absorption.
Case-2	Water whose reflectance is significantly influenced by scattering.
CCD	Charge-Coupled Device
CDOM	Chromophoric Dissolved Organic Matter
CHN	Carbon, Hydrogen and Nitrogen
CHORS	Center for Hydro-Optics and Remote Sensing
CICESE	Centro de Investigation Cientifica y de Edcacion Superior de Ensenada
CIMEL	The name of a sun photometer manufacturer
CNES	Centre National d'Edudes Spatialle
CONICIT	Consejo Nacional de Investigaciones Cientifica y Technologicas (Venezuela)
CRAM	Conditional Relaxation Analysis Method
CTD	Conductivity-Temperature-Depth
CZCS	Coastal Zone Color Scanner
DAAC	Distributed Active Archive Center
DLR	Deutshe Forshungsanstalt f r Luft-und Raumfahrht (German Aerospace Center)
DMF	Dimethylformamide
DOC	Dissolved Organic Carbon
DoD	Department of Defense
DOE	Department of Energy
ECOHAB	Ecology of Harmful Algal Blooms
EEZ	Exclusive Economic Zone
EORC	Earth Observation Research Center
EOS	Earth Observing System
FFP	Firm-Fixed Price
FOV	Field of View
ftp	File transfer protocol
FWHM	Full Width Half Maximum
GAC	Global Area Coverage, coarse resolution satellite data with a nominal ground resolution at nadir of approximately 4 Km
GB	Gigabyte, or about one billion bytes
GF/F	Not an acronym, but a specific type of glass fiber manufactured by Whatman.
GLI	Global Imager
GoCal	Gulf of California
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HIVE	High-Latitude Intercomparison and Validation Experiment
HOBI	Hydro-Optics, Biology and Instrumentation
HOT	Hawaii Ocean Time series
HPLC	High Performance Liquid Chromatography
HQ	Headquarters
HRPT	High Resolution Picture Transmission
ICESS	Institute for Computational Earth Science System
IDL	Interactive Data Language
INDOEX	Indian Ocean Experiment
IOCCG	International Ocean Color Coordinating Group
IOP	Inherent Optical Properties
IR	Infrared
IRS	Indian Remote Sensing Satellite
ISCCP	International Satellite Cloud Climatology Project
ISPO	Interim SIMBIOS Project Office
JGOFS	Joint Global Ocean Flux Study
JPL	Jet Propulsion Laboratory
LAC	Local Area Coverage, fine resolution satellite data with a nominal ground resolution at nadir of approximately 1Km
LIDAR	Light Detection and Ranging Instrument
LED	Light Emitting Dicode
LOA	Laboratorie d'Optique Atmospherique
MARMAP	Marine Resources Monitoring, Assessment and Prediction
MBARI	Monterey Bay Aquarium Research Institute
MB	Megabyte, or about one million bytes
MER	Multispectral Environmental Radiometer
MERIS	Medium Resolution Imaging Spectrometer

MFRSSR	Marine Fast Rotating Shadow-band Spectral Radiometer
MISR	Multi-angle Imaging SpectroRadiometer
MOBY	Marine Optical Buoy
MODAPS	Modular Ocean Data and Power System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOS	Modular Optoelectronic Scanner
MSL12	Multi-Sensor level-1B to level-2 code
MTPE	Mission to Planet Earth
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NAVOCEANO	Naval Oceanographic Office
NDBC	National Data Buoy Center
NIMBUS	Not an acronym, but a series of NASA experimental weather satellites containing a wide variety of atmosphere, ice, and ocean sensors.
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NOPP	NIMBUS Observation Processing System
NRA	NASA Research Announcement
NSF	National Science Foundation
NSPO	National Space Program Office
NTOU	National Taiwan Ocean University
OCI	Ocean Color Imager
OCTS	Ocean Color and Temperature Sensor
ONR	Office of Naval Research
ORCA	Optical Research Consortium of the Arctic
OSC	Orbital Sciences Corporation
OSU	Oregon State University
PAR	Photosynthetically Available Radiation
PHILLS	Hyperspectral Imager for Low Light Spectroscopy
PI	Principal Investigator
PM-1	Not a acronym, used to designate the afternoon platform of EOS
POLDER	Polarization Detecting Environmental Radiometer (France)
PRR	Profiling Reflectance Radiometer
R&D	Research and Development
R/V	Research Vessel
ROCSAT	Republic of China (Taiwan) Satellite platform for the OCI sensor.
RR	Round-Robin
SAB	South Atlantic Bight
SBE	Sea-Bird Electronics
SCOR	Scientific Committee on Oceanic Research
SDDC	Science Data Distribution Center
SeaOPS	SeaWiFS Optical Profiling System
SeaBAM	SeaWiFS Bio-optical Algorithms Mini-workshop
SeaBASS	SeaWiFS Bio-optical Archive and Storage System
SeaDAS	SeaWiFs Data Analysis System
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SIMBAD	The name of a sun photometer
SIMBIOS	Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies
SIO	Scripps Institution of Oceanography
SGI	Silicon Graphics, Inc.
SIRREX	SeaWiFS Intercalibration Round-Robin Experiment
SLOWDROP	Slow Descendent Rate Optical Profiler
SMSR	SeaWiFS Multispectral Surface Reference
SOOP	Ship of Opportunity Program
SOW	Statement of Work
SPMR	SeaWiFS Profiling Multi-channel Radiometer
SQM	SeaWiFS Quality Monitor
ST	Science Team
TB	Terabytes
TOA	Top of the Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOTO	Tongue of the Ocean
TSM	Total Suspended Matter
TSRB-II	Tethered Spectral Radiometer Buoy - II
XBT	Expendable Bathythermograph