Ocean color instrument intercomparisons and cross-calibrations by the SIMBIOS Project

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ABSTRACT

The Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Project has a worldwide, ongoing ocean color data collection program, plus an operational data processing and analysis capability. SIMBIOS data collection takes place via the SIMBIOS Science Team and the Aerosol Robotic Network (AERONET). In addition, SIMBIOS has a calibration and product validation component The primary purpose of these calibration and product validation activities are to (1) reduce measurement error by identifying and characterizing true error sources such as real changes in the satellite sensor or problems in the atmospheric correction algorithm, in order to differentiate these errors from natural variability in the marine light field; and (2) evaluate the various bio-optical algorithms being used by different ocean color missions. 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., Centre National D'Etudes Spatialle (CNES) and National Space Development Agency of Japan (NASDA) for Polarization and Directionality of the Earth's Reflectance (POLDER) and Ocean Color and Temperature Sensor (OCTS), respectively. In the near future the Project is looking forward to collaborate with Global Imager (GLI), Ocean Color Imager (OCI) and international entities such as the International Ocean-Colour Coordinating Group (IOCCG) and Space Application Institute (Joint Research Center).

Keywords: SeaWiFS, MOS, OCTS, POLDER, sensor intercomparison, SIMBIOS

1. INTRODUCTION

The Coastal Zone Color Scanner (CZCS) proof-of-concept experiment has led to a series of increasingly sophisticated instruments: the Modular Optoelectronic Scanner (MOS), OCTS, POLDER, and Sea-viewing Wide Field-of-view Sensor (SeaWiFS) were launched in 1996-1997, and the Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging SpectroRadiometer (MISR), Ocean Color Imager (OCI), GLI, Medium Resolution Imaging Spectrometer (MERIS), and POLDER-2 are scheduled to be launched in 1999-2001. These ocean color missions are highly complementary and congruent in many important respects. However, they also exhibit significant differences in technical approach which have implications for calibration, navigation, atmospheric correction and bio-optical algorithm development and data products. From the user perspective, an open question is to what extent the data will be compatible. To answer this question, the differences among missions must be resolved or explained. The SIMBIOS Program goal is to assist the international ocean color community in developing a multi-year time-series of calibrated radiances which transcends the spatial and temporal boundaries of individual missions.

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The specific objectives of the SIMBIOS Program are: (1) to quantify the relative accuracies of the ocean color products from each mission, (2) to work with each project to improve the level of confidence and compatibility among the products, and (3) to develop methodologies for generating merged level-3 products. SIMBIOS has identified the primary instruments to be used for developing global data sets. These instruments are SeaWiFS, OCTS, POLDER (ADEOS-I and II), MODIS (AM and PM), MISR, MERIS, and GLI. The products from other missions (e.g., OCI and the two MOS sensors) will be tracked and evaluated, but are not considered as key data sources for a combined global data set.

The SIMBIOS Program consists of the SIMBIOS Science Team and the SIMBIOS Project Office[1]. The group of National Aeronautics and Space Administration (NASA) SIMBIOS Science Team Principal Investigators are primarily composed of persons selected under the SIMBIOS NASA Research Announcement (NRA) 1996[2], some members of the MODIS Ocean Team, and certain members of the SeaWiFS Project Office. A new SIMBIOS NRA is scheduled for release sometime in the summer of 1999 (NRA-99) and a strong international participation is expected. The present Science Team is grouped under three working areas: 1) Ocean Bio-optical and Sensor Characterization Studies, 2) Data Merger Studies, and 3) Atmospheric Correction Studies. In addition, there are many more US and international co-investigators and collaborators actively participating in the SIMBIOS Program.

The SIMBIOS Project incorporates aspects of instrument calibration, algorithm development and evaluation, product merging, data processing, and interagency and international coordination (see http://simbios.gsfc.nasa.gov). The Project does so by integrating information from each mission, augmenting activities where appropriate, and providing feedback to each project. The SIMBIOS Project fosters collaborations between the various space agencies and science working groups to assist in achieving these objectives.

2. METHODOLOGY AND DATA

Satellite instruments use a variety of onboard measurements, including lamps[3], solar diffusers with ratioing radiometers[4], and lunar measurements[5], to monitor changes in sensor operation on orbit. These onboard methods vary from instrument to instrument, and, as such, they do not provide a method for intercalibrating the ensemble of ocean color sensors. However, there are vicarious calibration test sites, both instrumented[6] and uninstrumented[7], which complement the on-board measurements. For SeaWiFS[8] the Marine Optical Buoy (MOBY)[9] provides the principal instrumented test site for vicarious calibration measurements[10], and the Sargasso Sea[11] provides a useful uninstrumented test site.

The SIMBIOS research program, through strong international partnering, can assist the satellite/sensor providers in determining how best to accomplish data merger. Recently, the IOCCG stated that to be effective, satellite/sensor providers must have a common strategy[12]. A simple comparison of available atmospheric correction algorithms (i.e., CZCS, OCTS, SeaWiFS, POLDER, GLI, MERIS and MODIS) on generated data sets would provide valuable lessons in the evaluation of the strengths and weaknesses of these algorithms and is a goal of the SIMBIOS Project Office.

The application of identical atmospheric methods to different sensors helps to separate algorithm problems from sensor problems, leading to more robust atmospheric correction algorithms. Specifically, the use of multi-view instruments like POLDER and MISR can be used to test the consistency of the algorithm as a function of satellite viewing angle. Also instruments with similar center wavelengths but differing band can provide data on effects of out-of-band response. Presently, the SIMBIOS Project and SeaWiFS Program have available for use the Gordon and Wang[13,14] atmospheric correction algorithm which is being incrementally improved. However, in the future additional algorithms will be used as they are made available.

2.1 Vicarious calibration

The primary purpose of SIMBIOS calibration activity is to reduce measurement error by identifying and characterizing error sources such as real changes in satellite sensors and problems in the atmospheric correction algorithm, in order to differentiate them from natural variability in the marine light field. 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.

Presently, SIMBIOS uses a combination of vicarious (*in situ*-based observation) test sites as a means of comparing ocean color satellite instruments. Using the vicarious calibration approach, results retrieved from different sensors can be meaningfully compared and possibly merged. More importantly, one can recalibrate satellite sensors using *in situ* ocean and atmospheric optical property measurements with the same procedure.

The present calibration strategy is to focus on regions where the optical properties of the marine atmosphere and ocean are well understood and homogeneous, i.e., where the errors in the atmospheric correction and the *in situ* optical measurements are expected to be minimal. The MOBY project[9] supports the validation of ocean color data that is collected by SeaWiFS, and soon, MODIS (see http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html). MOBY is deployed off Lanai (Hawaii) and is a 14-meter long buoy system developed and instrumented to measure upwelling radiance and downwelling irradiance at the surface and at three different depths. Light is transmitted by fiber optics to the spectrograph for the continuous energy measurements at subnanometer resolution from 340-950 nm. Other data collected include standard meteorological observations. MOBY collects and transmits data that is processed and made available to the SeaWiFS Project Office on a daily basis. MOBY has been successfully used for SeaWiFS[10], OCTS, POLDER and MOS calibration[15].

The present approach used by the SIMBIOS Project Office (Table 1) is to develop a Level-1b to Level-2 software package (MSl12) which is capable of processing data from multiple ocean color sensors using the standard SeaWiFS atmospheric correction algorithms of Gordon and Wang[13,14]. The integration of a new sensor into MSl12 involves the development of a set of input functions and derivation of band-pass specific quantities such as Rayleigh scattering tables and Rayleigh-aerosol transmittance tables. Once the processing capability has been established, the vicarious calibration can be tuned using match-up data from the MOBY site and/or cross calibration with another sensor (e.g., SeaWiFS). The SIMBIOS Project can thereby provide a completely independent assessment of instrument calibration and sensor-to-sensor relative calibration. We are also able to provide insight to the sensor team in understanding how differences in calibration techniques and atmospheric correction algorithms propagate through the processing to produce differences in retrieved optical properties of the water.

In addition, the SIMBIOS Project can provide an independent assessment of the standard Level-2 products produced by a sensor team. Using the SeaWiFS Bio-optical Archive and Storage System (SeaBASS)[16], a growing database of *in situ* measurements to validate the satellite-retrieved water-leaving radiances and pigment concentrations, we can compare the standard Level-2 products from one sensor with products from SeaWiFS or another sensor.

Table 1

CURRENT SIMBIOS LEVEL -2 PROCESSING APPROACH
• Multi-sensor Level 1B to Level 2 software package • Software currently able to process MOS, SeaWiFS, OCTS and POLDER • Software presently validated against SeaWiFS production code (possible multiple code comparisons in future) • Identical atmospheric correction algorithm used for all sensors • Common ancillary data sources for all sensors and match-up analyses

2.2 Validation of bio-optical properties

The SIMBIOS Project funds numerous investigators in order to obtain *in situ* optical and pigment data for primarily Case I water characterization. Additional investigators are also supported to develop new algorithms or scientific approaches in accordance with the goals of the SIMBIOS Project. The SIMBIOS Project has an extensive set of *in situ* data for match-up analysis from the SeaBASS database, which is presently comprised of data from over 250 cruises and includes 400,000 pigment records. The *in situ* data in SeaBASS include measurements of water-leaving radiance and other related optical and pigment measurements, from ships, moorings and drifters. Various methods are deployed to collect of SeaBASS data, including the use of subsurface and above-water measurement devices[17,18]. In addition to the optical and pigment products listed, measurements of total suspended matter (TSM), colored dissolved organic material (CDOM), and other typically nonplankton derived optical components are recorded in SeaBASS.

SeaBASS data are used by the SIMBIOS Project to validate SeaWiFS and other (OCTS, POLDER, etc.) postlaunch imagery and to develop new operational chlorophyll algorithms. The SIMBIOS L_{wn} and chlorophyll a matchup procedure and analysis are described in Schieber and McClain (in press). Presently, SeaBASS data sets include data from calibration round robins, the SeaWiFS prelaunch calibration and characterization data and a large number of bio-optical data sets for product validation and algorithm development. A current description of the SeaBASS system is available via the World Wide Web at http://seabass.gsfc.nasa.gov.

2.3 Validation of aerosol optical thickness

SIMBIOS is comparing and validating the SeaWiFS aerosol optical products with *in situ* measurements mainly derived from the data of the Aerosol Robotic Network (AERONET)[19]. The primary objectives of these comparisons are to validate the aerosol optical thickness products[20], and to determine the validity of the suite of aerosol models currently used by SeaWiFS for atmospheric correction.

AERONET is a network of ground-based automated sun photometers owned by national agencies and universities. AERONET data provides globally distributed, near-real time observations of aerosol spectral optical depths, aerosol size distributions, and precipitable water. These data allow for algorithm validation of satellite aerosol retrievals as well as characterization of aerosol properties. Such validation and characterization are critical for atmospheric correction of ocean color sensors. The first instruments within the AERONET network were CIMEL sun photometers, manufactured in France, the majority of which were in continental locations.

The SIMBIOS Project augmented this instrument pool with atmospheric instruments by purchasing 12 MicroTops hand-held sun photometers; 2 PREDE (Japanese built) sun photometers; 1 micro-pulse lidar and an additional 12, specially "hardened," CE318 CIMEL and 4 SIMBAD University Lille sun photometers developed by the Laboratoire d'Optique Atmospherique (LOA). The 12 "hardened" CIMEL instruments augment the AERONET network with coastal and island stations. These CIMEL instruments better withstand the corrosive marine environment after undergoing a robust re-engineering. Confirmed (delivered or negotiated) CIMEL sites include Lanai Hawaii (with backup in Honolulu), Ascension Island, Bahrain, Tahiti, Wallops Island (Virginia, USA), South Korea, and Turkey (Black Sea).

3. RESULTS

The SIMBIOS Project uses vicarious test sites to compare ocean color satellite instruments. Several intercomparisons and cross-calibrations have been completed or are in progress. In the last year, SIMBIOS has successfully collaborated with Japan on OCTS, with India and Germany on MOS and with France on POLDER. Data processing (Raw-0 to Level-2) software for OCTS and MOS were completed.

3.1 MOS

This activity included evaluations of the navigation, calibration (detector-relative and absolute), atmospheric correction, and bio-optical algorithms[21, 22]. For the intercalibration of SeaWiFS and the MOS, a German instrument onboard the Indian IRS-P3 satellite[22], co-located measurements in the Adriatic and Mediterranean Seas and the Atlantic Ocean were used.

Wang and Franz[22] demonstrate that it is possible and efficient to vicariously intercalibrate two different ocean color sensors. In this study, the SeaWiFS normalized water-leaving reflectance and aerosol models were used as "truth" to re-calibrate the MOS spectral bands. After MOS band re-calibrations, the differences in retrieved normalized water-leaving reflectances between MOS and SeaWiFS are much reduced. The MOS retrieved $\varepsilon(750, 870)$ values are much more reasonable and very similar to the SeaWiFS measurements after re-calibration. This cross-calibration analysis showed that the MOS 750 nm band gain (relative to SeaWiFS) varied with atmospheric conditions. To mitigate that problem, the atmospheric correction algorithm was modified such that the MOS 685 and 870 nm bands can be used to determine aerosol type. Therefore, consistent gain coefficients for the MOS bands 1-6 and 8 can be used for various MOS scenes obtained at different times and locations. Wang and Franz[22] show the efficacy of the vicarious calibration approach by applying the method to a MOS scene acquired 4 to 5 months prior to the data used in deriving the gain coefficients. The MOS results are in reasonable agreement with SeaWiFS.

On February 1999 SIMBIOS Project began operating a receiving station at NASA's Wallop Flight Facility (WFF) to acquire data from the MOS spacecraft instrument. The data from WFF are processed at NASA's Goddard Space Flight Center (GSFC), with routine distribution of Level-0 data sets to the German Remote Sensing Data Centre (DLR-DFD). Data are freely available to the public in accordance with the data distribution policies of DLR-ISST (see MOS browse at http://seawifs.gsfc.nasa.gov /mos_scripts/mos_browse.pl)

3.2 OCTS

From measurements of the MOBY buoy and from other sites by OCTS, vicarious calibration coefficients have been derived by the NASDA ocean color team and by the SIMBIOS Project[1]. Considering that the two projects use different atmospheric corrections[23] and different *in situ* measurements for calibration, the two sets of results are in very good agreement (see Table 2). The largest difference is in the 765nm band, which NASDA does not use for atmospheric correction, but which SIMBIOS uses and corrects for oxygen absorption.

Table 2

BANDS	NASDA	SIMBIOS
1	1.14	1.13
2	1.03	1.01
3	0.9394	0.94
4	1.00	1.00
5	1.04	1.03
6	1.00	0.99
7	1.02	0.91
8	0.89	0.89

Match-up comparisons between field and OCTS data used match-up subscenes provided by NASDA. Vicarious calibration of the OCTS was performed using *in situ* data from the MOBY buoy. Two validation analyses were performed: a comparison of OCTS data processed by SIMBIOS to in situ measurements obtained from the SeaBASS data set (see http://simbios.gsfc.nasa.gov/~alice/octs_matches/OCTS_MATCHUP_SUMMARY.html) and a time series study of Sargasso Sea data compared with non-temporally equivalent SeaWiFS data (see http://simbios.gsfc.nasa.gov/~alice/Sargasso /Sargasso.html).

Furthermore, Gregg et al.[24] assessed geometric and radiometric performance of a limited set of OCTS data from the US east coast and the Gulf of Mexico. Results indicated: a geometric offset in the along-track direction of 4-5 pixels that was attributed to a tilt bias; but radiometric stability was inconclusive due to daily variability. Comparison with co-located in situ measurements showed that the pre-launch calibration required adjustment from -2% to +13%[24].

On November 1996 SeaWiFS Project began processing and distributing US data from the OCTS spacecraft. Data is freely available to the public in accordance with the data distribution policies of NASDA (see OCTS browse at http://seawifs.gsfc.nasa.gov/seawifs_scripts/octs_browse.pl).

3.3 POLDER

During Spring of 1999 the SIMBIOS Project started collaborating with scientists from CNES and the University of Lille, France. Joint papers are anticipated from this collaboration, and the SIMBIOS Project plans to implement POLDER processing within SeaDAS[25].

In an attempt to directly compare the POLDER and OCTS instruments, the SIMBIOS Project has mounted an effort to process both OCTS Level 1B or Level 0 and POLDER Level 1 ocean color data using SIMBIOS processing methods. Since POLDER and OCTS both flew aboard the ADEOS-I satellite, their data are temporally coincident though their spatial resolutions are different.

Insofar as possible, we will perform similar vicarious calibration and validation of procedures for POLDER as was done with OCTS. CNES has supplied us with both Level 1 and Level 2 data sets encompassing the dates and locations used for our OCTS studies. Matchup comparison of POLDER Level 2 data to MOBY and Marine Optical Characterization Experiment (MOCE) data tuned to POLDER response functions is underway and preliminary results may be seen at http://simbios.gsfc.nasa.gov/~alice/polder_matches/INDEX.html. A complete set of matchups of POLDER Level 2 data to SeaBASS in situ data will be finished by September 1999. At the same time, vicarious calibration of POLDER will be done using MOBY matchups, and the POLDER data then processed by SIMBIOS will be run through the matchup analysis procedure. Large-scale statistics of the Sargasso Sea data will be generated as well. A meaningful comparison of the OCTS and POLDER will be accomplished using these results. This comparison will identify both consistent similarities and differences between the instruments.

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5. REFERENCES

1. C.R. McClain and G.S. Fargion, SIMBIOS Project 1998 Annual Report, NASA Tech. Memo. 1999-208645, NASA Goddard Space Flight Center, Greenbelt, Maryland, 105 pp., 1999.
2. National Aeronautics and Space Administration (NASA), Sensor Intercomparison and Merger for Biological and Interdisciplinary Ocean Studies, (SIMBIOS), NASA Research Announcement (NRA) 96-MTPE-04, National Aeronautics and Space Administration, Washington, DC, 1996.
3. M. Dinguirard, G. Begni, and M. Leroy, SPOT 1 Calibration results after two years of flight, SPIE, 924, 89-95, 1991.
4. W.L Barnes, T.S. Pagano, and V.V. Salomonson, Prelaunch Characteristics of the Moderate Resolution Imaging Spectroradiometer (MODIS) on EOS-AM1, IEEE Trans. Geosci. Remote Sens., 36, 1088-1100, 1998.
5. R.A. Barnes, R.E. Eplee, Jr., and F.S. Patt, SeaWiFS measurements of the moon, SPIE, 3498, 311-324,1998.
6. R. Santer, X.F. Gu, G. Guyot, J.L. Duze, C. Devaux, E. Vermote, and M. Verbrugghe, SPOT calibration at the La Crau test site (France), Remote Sens. Environ., 41, 227-237,1992.
7. H. Cosnefroy, M. Leroy, and X. Briottet, 1996: Selection and characterization of Saharan and Arabian desert sites for the calibration of optical satellite sensors, Remote Sens. Environ., 58, 101-114, 1996.
8. R.A. Barnes and A.W. Holmes, Overview of the SeaWiFS ocean sensor, SPIE, 1939, 224-232,1993.
9. D. K. Clark, H. R. Gordon, K. K. Voss, Y. Ge., W. Brokenow,, and C. Trees, Validation of atmospheric correction over oceans, J. Geophys. Res., 102, 17,209-17,217, 1997.
10. C.R. McClain, M. L. Cleave, G.C. Feldman, W.W. Gregg, S.B. Hooker, and N. Kuring, Science quality SeaWiFS data for global biosphere research, Sea Technol., 39, 10-16, 1998.
11. A. Isaacman, B. Franz, and R.E. Eplee, Jr., An investigation of time variability in water-leaving radiances retrieved from ocean color measurements, ALPS99 Workshop (POLDER), Meribel, France, 1999.

12. J.A. Yoder et al., Status and Plans for Satellite Ocean Colour Missions: Considerations for Complementary Missions, IOCCG Report Number 2, 43 pp., 1999.
13. H.R. Gordon and M. Wang, Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: A preliminary algorithm, Appl. Opt., 33, 443-452,1994.
14. H.R. Gordon and M. Wang, Influence of oceanic whitecaps on atmospheric correction of ocean color sensors, Appl. Opt., 33, 7,754-7,763, 1994.
15. A. Isaacman, Sargasso Sea - Bermuda Area Vicarious Calibration Experiment, http//simbios.gsfc.nasa.gov/~alice /OCTS_MATCHUPS.html, 1999.
16. S.B. Hooker, C.R. McClain, J.K. Firestone, T.L. Westphal, E-n. Yeh, and Y. Ge, The SeaWiFS Bio-Optical Archive and Storage System (SeaBASS), Part 1, NASA Tech. Memo. 104566, Vol. 20, NASA Goddard Space Flight Center, Greenbelt, Maryland, 37 pp., 1994.
17. J.L. Mueller and R.W. Austin, Ocean Optics Protocols for Validation, Revision 1, NASA Tech. Memo. 104566, Vol. 25, NASA Goddard Space Flight Center, Greenbelt, Maryland, 67 pp., 1995.
18. S.B. Hooker, G. Zibordi, G. Lazin, and S. McLean, The SeaBOARR-98 Field Campaign. NASA Tech. Memo. 1999-206892, Vol. 3, NASA Goddard Space Flight Center, Greenbelt, Maryland, 40 pp., 1999.
19. B.N. Holben, T.F. Eck, I. Slutsker, D. Tanre, J.P. Buis, A. Setzer, E. Vermote, J.A. Reagan, Y.J. Kaufman, T. Nakajima, F. Leaven, I. Jankowiak, and A. Smirnov, AERONET - A federated instrument network and data archive for aerosol characterization, Remote Sens. Environ., 66, 1998.
20. M. Wang, S. Bailey, C.R. McClain, C. Pietras, T. Riley, 1999: Remote sensing of the aerosol optical thickness from SeaWiFS in comparison with in situ measurements, ALPS99 Workshop, Méribel, France.
21. Wang, M. and B.A. Franz, A vicarious intercalibration between MOS and SeaWiFS, Proc. 2nd Int. Workshop on MOS-IRS and Ocean Colour, Berlin, June 10-12, 1998.
22. M. Wang and B.A. Franz, Comparing the ocean color measurements between MOS and SeaWiFS: A vicarious inter-calibration approach for MOS, IEEE Trans. Geosci. Remote Sens., in press, 1999.
23. H. Fukushima, A. Higurashi, Y. Mitomi, T. Nakajima, T. Noguchi, T. Tanala, and M. Toratoni, Correction of atmospheric effect on ADEOS/OCTS ocean color data: Algorithm description and evaluation of its performance, J. Oceanogr., 54, 417-430, 1998.
24. W.W. Gregg, F.S. Patt and W.E. Esaias, Initial analysis of ocean color data from the Ocean Color Temperature Scanner. II. Geometric and radiometric analysis, Appl. Opt., accepted for publication, 1999.
25. G. Fu, K. Settle, and C.R. McClain, SeaDAS: The SeaWiFS data analysis system, Proc. 4th Pacific Ocean Remote Sens. Conf. Qingdao, China, 1998.