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SIMBIOS Project 2001 Annual Report

G.S. Fargion and C.R. McClain

National Aeronautics and
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Preface

The purpose of this technical report is to provide current documentation of 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 validating and 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.

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Chapter 22

Measurements and modeling of apparent optical properties of ocean waters in support to ocean color data calibration, validation, and merging

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22.1 INTRODUCTION

This progress report does not show any results in terms of *in situ* data because the buoy' deployment is only planned for late January 2002. The advancement of the buoy development and testing, of the instrument integration and testing, and of all other preparatory activities (in particular monthly cruises to the deployment site) are succinctly described here. The objectives and the analyses that are planned thanks to the data to be collected are also reminded. This project is supported by the European Space Agency (ESA/ESTEC contract N° 14393/00/NL/DC), the French Space Agency "Centre National d'Etudes Spatiales (CNES)", the "Centre National de la Recherche Scientifique (CNRS-INSU)" and the "Observatoire Océanologique de Villefranche sur mer". A prerequisite to building long-term (over decades) archives of ocean color, in response to the need for assessing the response of the oceanic biota to climate changes, is to accurately calibrate the top-of-atmosphere satellite observations, then to validate the surface geophysical parameters derived from these observations. Ensuring coherence between these geophysical products, as derived from different sensors, is also an important aspect to consider. When ocean color observations from different sensors are considered in view of data merging, their cross-calibration and validation might be facilitated if it could be "anchored" on continuous long-term *in situ* stations (IOCCG, 1999). Deploying and maintaining moorings that operate in a continuous way is, however, a difficult task.

In response to these concerns, we propose to carry out match-up analyses and vicarious calibration experiments, based on a data set to be built from a permanent marine optical buoy. This new type of marine optical buoy has been specifically designed for the acquisition of radiometric quantities, and has been already deployed in the Mediterranean sea in July 2000 (a deployment of 3 months for validating the mooring concept), between France and Corsica.

The vicarious calibration experiments should allow the top-of-atmosphere total radiance to be simulated and compared to the satellite measurements, in particular for the European MERIS sensor. By this way, the need for a change of the pre-flight calibration coefficients for a given sensor might be evaluated, and its amount quantified. From this data set, match-up analyses shall be also possible for chlorophyll concentration and water-leaving radiances, as well as algorithm evaluation (atmospheric correction and pigment retrieval). Because of a certain commonality in the band sets of the new-generation ocean color sensors, the data acquired with the buoy might be used for several of these sensors, and then contribute to the international effort of cross-calibrating them and of cross-validating their products, which are amongst the basic goals of SIMBIOS. In addition, some protocol issues (measurements) are specifically linked to the use of buoys, while others, of general concern to marine optics measurements, may find specific answers in the case buoys are used. We propose to examine these aspects, which, to our knowledge, have not been thoroughly investigated up to now.

Description of the planned analyses

Two main "vicarious" calibration paths exist to produce ocean color products of the desired accuracy, *i.e.*, water-leaving radiances within an error of about 5% in the blue for an oligotrophic ocean (Gordon, 1997, Antoine and Morel, 1999). The first one is usually referred to as "vicarious calibration", and consists in forcing the satellite-derived water-leaving radiances to agree with a set of *in situ* water-leaving radiances ("match-up analyses"). A set of "vicarious calibration coefficients" is therefore obtained, which is applied to the Top-of-atmosphere (TOA) total radiances measured by the sensor. The second procedure, which is also an indirect ("vicarious") calibration is sometimes referred to as a "radiometric calibration", and consists in simulating the TOA signal that the sensor should measure under certain conditions, and to compare it to the measured signal. Inconveniences of the first type of "vicarious calibration" is that it is dependent upon the procedure used for the atmospheric correction of the TOA observations. The advantage of this technique is, however, and besides the fact that atmospheric measurements are not needed, that the marine signals delivered by several sensors that use different atmospheric correction algorithms can be cross-calibrated provided that the same set of *in situ* water-leaving radiances is used to perform the vicarious calibration. This is presently the case, for instance, for the SeaWiFS and OCTS sensors. Inconveniences of the vicarious "radiometric calibration" is that it requires a set of *in situ* measurements that is usually difficult to gather, among other things because a high accuracy is needed. In addition to the in-water measurements of the water-leaving radiances, this data set includes : sea state and atmospheric pressure, ozone concentration, aerosol optical thickness, aerosol type, and even aerosol vertical profile if the aerosols reveal to be absorbing. If this data set is successfully assembled, the great advantage of the vicarious "radiometric calibration" is that it is independent of the atmospheric correction algorithms, so that the TOA signals of various sensors can be cross-calibrated. Then it is up to any user to apply its preferred atmospheric correction to these TOA signals. The marine signals in that case might be inconsistent if significant differences exist in the various atmospheric corrections.

Match-up analyses

Match-up analyses should be possible for water-leaving radiances, as well as for chlorophyll concentrations, which are, however, only collected on a monthly basis (HPLC), during servicing to the mooring. The chlorophyll fluorescence is recorded in a continuous way, yet we cannot ascertain that its conversion into chlorophyll units, based on the monthly HPLC determinations, will be able to generate concentrations with an accuracy suitable for match-ups.

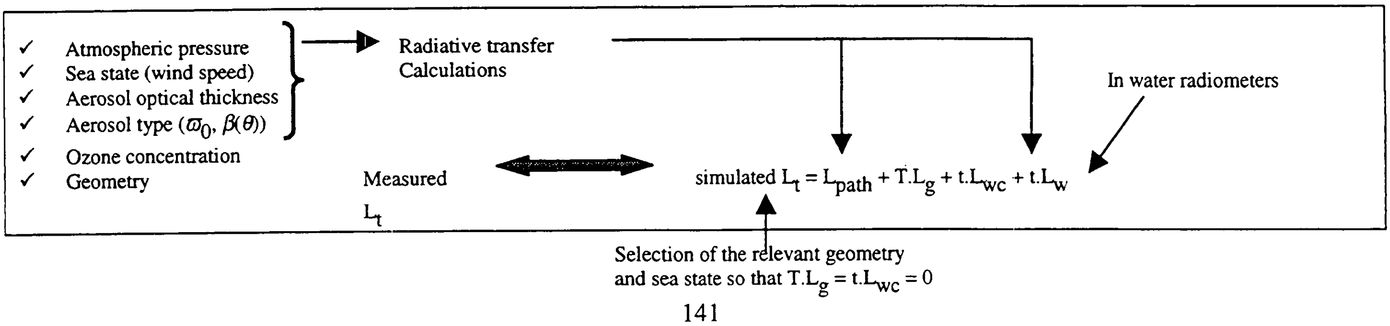
Vicarious calibration experiments

This is probably one of the most challenging parts of this project, aside from technological development. Indeed, we should have in hand all the necessary tools and data to generate TOA total radiances and to compare them to their "satellite equivalent" (*e.g.*, see Gordon, 1998), yet it would be risky to warrant in advance that a 5% absolute accuracy (*i.e.*, what is aimed at with the new-generation ocean color sensors, *e.g.*, Gordon , 1997) will be reached.

The greatest difficulty, at least to our opinion, lies in a correct estimation of the aerosol optical thickness, phase function, and single scattering albedo. These parameters are accessible through the inversion of sun photometer measurements, yet uncertainties inevitably occur when applying such methods. Assembling all data needed for these vicarious calibration experiments will be often compromised only because aerosol parameters are not accurate enough. Nevertheless, we hope that over the 3 years of the project, enough relevant data will be gathered for that purpose. Therefore, we will set up a "toolbox" based on codes available at LOV, and which will be fed with all observation listed in the preceding sections, with the aim of generating the TOA radiances needed for vicarious calibrations. The error budget of these computations will be also examined. This may include, not exhaustively, the assessment of the impact of (1) the various ways of computing the water-leaving radiance from the below-water measurements of radiances and irradiances, (2) the uncertainties in the representation of surface roughness, and (3) the selection of a given RT code.

Inversion of the sun photometer measurements in order to get the aerosol optical thickness will follow the usual procedure, as described for instance in Frouin *et al.* (2000). There exist a variety of algorithms for the inversion of the sky radiance measurements (Wang and Gordon, 1993; Nakajima et al., 1983, 1996; Dubovik and King, 2000; Dubovik et al., 2000). Evaluation of these various algorithms is out of our scope, yet we will try to implement the most adapted ones in order to get some idea about the uncertainties attached to our retrievals. The routine processing performed by the AERONET will anyway already provide the necessary data, so that implementation of procedures at LOV will mostly be motivated by scientific purposes, which not necessarily intervene in the frame of the MERIS cal/val activities.

When the desired data are obtained, they will be used as inputs and boundary conditions to radiative transfer calculations. We can use several codes available at LOV, namely a Monte Carlo code (cross-validated with respect to other codes in Mobley *et al.*, 1995), the Hydrolight® code (Mobley, 1994), and the MOM code (Matrix Operator Method, developed by J. Fischer and collaborators at the Free University of Berlin). The simulated TOA total radiances will be then compared to their equivalent extracted from MERIS full resolution images. The principle is the following (L is for radiance, and the subscripts "t" for total TOA, "g" for sun glint, "wc" for white caps, and "w" for water-leaving; T and t and the direct and diffuse atmospheric transmittances, respectively):



Preparatory activities: Buoy's design

The design of the buoy, managed by the ACRI-in company, started in fall 1999 and led to a totally new type of optical buoy. The following paragraphs summarize the rationale for its design and the main characteristics of the system. Platforms developed for oceanographic purposes are rarely adapted to the deployment of radiometers at sea. Indeed, recording the light field within the ocean interior is difficult because the instruments themselves and, more dramatically, the platform onto which they are installed, inevitably introduce perturbations. Other difficulties originate from the need to keep the instruments as much horizontal as possible, either because a plane irradiance is aimed at (cosine sensor), or if a given direction (generally nadir) is aimed at. The actual measurement depth is also difficult to accurately assess, because rapid vertical displacements of the instruments sometimes occur, which prevent any precise estimation of pressure, thence of depth. Considering the above observations (among others), we have developed a new type of platform, dedicated to radiometry measurements, able to minimize shadowing effects, to minimize perturbation of the sub-marine light field, and to warrant the stability of the instruments.

The principle is that of a "reversed pendulum", with Archimedes thrust replacing gravity. A large sphere (Ø 1.8 m) is stabilized at a 18 meters depth out of the effect of most swells (a cable goes down to the sea floor), and creates the main buoyancy. Above the sphere, a rigid, tubular, structure is fixed, which hosts the instrumentation onto horizontal arms (at 5 and 9 meters). An ~3 tons thrust ensures the stability of the system, which is subject to very limited forces from the so-called "transparent-to-swell" superstructure. With such a design, there is no large body at the surface generating shade.

Reduced-scale model of the buoy and tests in an engineering pool

A reduced scale model (scale 1/10) has been developed in order to verify the theoretical predictions, and it has been tested in an engineering pool (dimensions in meters 24x16x3, with a 10-meters shaft), by applying to it several types of swells and currents (mono chromatic or random swells, up to 5 meters real scale). Results of these tests have fully confirmed the theoretical predictions that were previously carried out, in terms of horizontal and vertical displacements (the latter are extremely low), as well as in terms of angular deviations from the vertical. For instance, the mean tilt of the buoy is ~4° (with ±~4° of pitching), for a 4.6-meter swell of period 5.2 seconds. These tests have also confirmed that no "hidden defect", hardly discernible via calculations only, was compromising the feasibility of the system. The tests were fully conclusive and led to the construction of the first "beta version" of the buoy, in aluminum.

Qualification by a 3-month test deployment of the buoy on site

The full scale "beta version" was built in spring 2000 (Figure 22.1). The material was aluminum. It is made of two parts, the lower one which is from –20 meters to –9 meters below the surface and consists of the sphere and a simple tubular structure, and the upper one which goes from –9 meters below the surface to +4.5 meters above the surface, and which hosts the instrumentation. The full-scale beta version has been deployed on site during 3 months (20 of July to 20 of October, 2000), which allowed to encounter a variety of meteorological situations. The buoy was equipped with two inclinometers, a pressure sensor, an ARGOS beacon and a flashlight. The goal of this deployment was to qualify the new concept of buoy as well as to identify possible problems necessitating modifications. The results of the qualification deployment showed a certain lack of righting torque, with consequences on the behavior of the buoy when the swell becomes greater than about 2 meters. Although not dramatic, this behavior is not totally satisfactory, so that it was decided to introduce slight modifications in the design and construction of the buoy in order to improve the percentage of time for which the requirements in terms of inclination is satisfied.

Modifications introduced in the buoy's design and construction

One modification has been introduced in the design, by installing the sphere at 17 meters instead of 18 meters. By this way, the distance from the center of the sphere to the fixation of the buoy to the mooring cable is one meter greater (the righting torque is therefore much larger). Another modification has been introduced in the materials used to build the upper part of the buoy (the one hosting the instrumentation), from aluminum to carbon composite. A specific study has been conducted to check that this composite material was adapted to our problem, which is definitely the case.

The impacts of these 2 changes on the upper part of the system are : rigidity is improved, weight is diminished by the 2/3, corrosion is eliminated, the drag coefficient is reduced by the use of tubes with a lower diameter, and the elastic limit is larger than it was in comparison to the forces imposed by breaking waves. At the end, a net gain of 60% in the righting torque has been obtained for the full buoy. The first deployment of this modified version of the buoy, fully equipped, is planned for no later than the end of January 2002, weather permitting.

The instrumentation on the buoy

The full system, developed by Satlantic Inc., has been delivered in Villefranche on the 24th of October, 2001. Its physical integration on the buoy and the subsequent testing will probably last until mid December 2001. It is reminded that the system comprises:

- Radiometers of the Satlantic 200 series, measuring E_s (at +4.5 meters above surface), and E_d, E_u, and L_u (nadir) at 2 depths, namely 5 and 9 meters. The 2-axis tilt and the pressure are also recorded. The buoy orientation with respect to the sun is also recorded.
- Fluorometers, at the 2 same depths, for a proxy to Chl.
- Transmissometer, at the deepest sampling depth, *i.e.*, 9 meters, for a proxy to the particle load.
- CTD, at 9 meters, mainly for pressure and temperature.
- Backscattering meter for a proxy to b_b at 2 wavelengths (443 and 560 nm), at 9 meters.
- The set of parameters directly derived from the measurements is described in section 11.
- From these measurements, various AOPs or IOPs might be derived, as the water-leaving radiance, L_w, the diffuse attenuation coefficients for upwelling and downwelling irradiance, K_u and K_d, the attenuation coefficient for upwelling radiance, K_L, the diffuse reflectance just below the sea surface, R, the "nadir Q" factor, E_u/L_u, the attenuation and backscattering coefficients, c and b_b. The absorption coefficient, a, will be tentatively derived through inversion of the AOPs (using for instance K_d and R).

All measurements will be simultaneously collected, and centralized by a unique (acquisition / storage / communication) system, that will merge the data and send them to the visiting ship via a RF link. Part of the data is transmitted in real time by an ARGOS link (only for checking that everything's working well and that batteries are Ok).

The coastal site for atmospheric measurements

A coastal site (Cap Ferrat, in front of the laboratory) should be equipped with an automatic sun photometer station, introduced within the AERONET. This equipment should provide continuous record of the sky radiances at this site, from which information about aerosol types and aerosol optical thickness will be retrieved.

Atmospheric measurements : ship-of-opportunity

In order to increase the number of determination of the aerosol optical thickness on the buoy site, a portable sun photometer shall be installed on the ships that daily cross from Nice to Corsica, and which go near the buoy site. The operation of such an instrument is simple enough to expect a significant percentage of good-quality measurement, if performed by trained crewmembers. These operations are under negotiation with the company that manages the ships.

Set up of the monthly additional measurements and BOUSSOLE site characterization

Eighteen days of ship time have been obtained in 2001 from CNRS-INSU, as 6 campaigns of 3 days. They were initially planned for starting the monthly servicing of the buoy, in case it would have been deployed in July 2001 (initial plan). Because the buoy is still not deployed, the first 4 of these campaigns (end of July, beginning of September, October and November) have been used to prepare and organize most of the activities that will be necessary during monthly servicing to the buoy. These activities have included:

- Verification of the mooring line by divers (still on site; only the buoy has been removed).
- Deployment of several optical profilers (50 vertical profiles have been acquired), including the LOV' SPMR, the NASA' MicroNESS (collaboration Stan Hooker) and a new hyper-spectral profiler developed by Satlantic Inc. (collaboration M. Lewis).
- Pigment determination (HPLC; 35 surface samples).
- CTD profiles (25 profiles).
- Inter-comparison between above-water and below-water determination of the water-leaving radiances.
- Characterization of the spatial heterogeneity of the site, by following a grid pattern with a fluorometer, the pattern being then calibrated in terms of chlorophyll concentration by taking discrete samples along the grid.

The remaining two campaigns to be carried out until the end of 2001 (beginning and mid of December) will be devoted to the same kind of activities, and to the testing of the instrumentation of the buoy (using a rosette frame to be deployed from the ship). The other operations and measurements that will be progressively introduced in 2002 are :

- Replacement of radiometers by divers
- Cleaning/verification of the buoy

- IOP profiles (absorption, attenuation), IOP determination on the HPLC samples.

Inter-comparison between above-water and in-water determination of the water-leaving radiance

As part of the preparatory activities that we carry out in the frame of BOUSSOLE, we have pursued the comparative evaluation of the above-water determination of the water-leaving radiances against the under-water determination of this key parameter. The above-water data have been collected with a SIMBADA radiometer (developed and maintained by LOA in Lille, France; data processing also performed by LOA), and the in-water determination from our SPMR profiler and the MicroNESS profiler (NASA; only in July). The data are still under processing and the results of these inter-comparisons will be probably available in 2002. From these results, it will be decided whether or not it is useful to continue the above-water measurements.

Plans for calibration of the radiometers

The SQM-II (*i.e.*, the high stability lamp used for relative calibration) will be kept in the laboratory, and we will replace each month one set of instruments by a new, cleaned and calibrated, set of instruments. The recovered set of radiometers is brought back to the lab for calibration, cleaning, and repair if necessary. One month later, the exchange is again performed and so on. We first have set up the installation of the SQM-II and have worked towards establishing the routine operations that will be necessary each month on each set of radiometers (the so-called "SQM sessions").

Bidirectionality of the ocean reflectance: Selection of adequate IOP for Case 1 waters

A revision of the inherent optical properties of oceanic waters, which includes the consideration of the absorption values by pure waters (Pope and Fry, 1997), has been published (Morel and Maritorena, 2001). In addition, a new parameterization of the particle volume scattering function (VSF) has been developed, which allows the shape of the VSF to be regularly changing with the chlorophyll concentration (Chl). With these VSF, the backscattering ratio is decreasing, from 1.23 to 0.45 % when Chl increases from 0.01 to 10 mg m^{-3}. These values are more realistic when introduced in a reflectance modeling, and when the modeled results are compared to actual reflectance spectra. They remove the weaknesses which previously resulted from the use of a single particle VSF (that of Petzold, with a backscattering ratio of 1.9%), whatever Chl. The shape and magnitude of the VSF are crucial in driving the angular pattern of the upward radiance field, and thus the BRDF properties (and Tables). The recent radiative transfer computations and the production of the BRDF Lookup Tables have been performed by using these revisited IOPs.

Raman scattering influence on the upward radiance field and bidirectional properties.

In addition, the computations of these tables have been carried by accounting for the inelastic Raman scattering. The BRDF parameters are, as expected, sensitive to this emission for Chl values up to 0.3, even 1 mg m^{-3} (in the red part of the spectrum). These Tables have been transferred to NASA. They are commented in detail in a Chapter of the revised version of the Ocean Optics Protocols for Satellite Ocean Color Sensor Validation (Version 3) prepared by J. Mueller (Chapter XIII « Normalized water-leaving radiance and remote sensing reflectance : Bidirectional reflectance and other factors »). This chapter describes the implication of bidirectionality onto ocean optics measurements, particularly in the frame of calibration of satellite data through in situ measurements (above and in-water determinations of water-leaving radiances). The bidirectional properties have also been summarized and their consequences examined when the merging of various satellite data is envisaged (Correction of bidirectional effects for an optimal binning of ocean color data). This will be a part of a document currently prepared by a Ad Hoc group, set up by IOCCG in January 2001 (D. Antoine, Chairman), with the aim of examining the binning issues of ocean color data.

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