Final Report for Training Programme

Evaluation of satellite ocean-colour algorithms and products in coastal regions of Central and South America

Under the Auspices of

Nippon Foundation – Partnership for Observation of the Global Oceans (NF – POGO) Visiting Professorship and Associated Training Opportunity

In Association with

National Institute for Space Research, Brazil and Oceanographic Institute of the University of São Paulo, Brazil

Conducted by

Dr. Robert Frouin, Scripps Institution of Oceanography (SIO), La Jolla, USA

<u>Venue</u>:

National Institute for Space Research (INPE), São José dos Campos, São Paulo, Brazil
Oceanographic Institute of the University of São Paulo (IOUSP), São Paulo, Brazil

<u>Dates</u>:

Part I: April 17 – May 12 2006
Part II: August 7 – August 25 2006

1. Introduction

Satellite ocean-color sensors are providing data to study various biological and ecological issues. For quantitative use of the data, the algorithms and products need to be evaluated in varied atmospheric and oceanic regimes. Current evaluation programs are limited (a couple of fixed buoys, a few dedicated cruises). Insufficient measurements are made, especially in the southern hemisphere.

ANTARES, an integrated network of long-term time series stations in Central and South America, provides the opportunity to extend existing evaluation programs and, therefore, to improve the quality of global ocean-color data sets. Radiometric and biological measurements made at the stations would facilitate the development of regional bio-optical algorithms, allowing a comparative analysis of variability, by means of remote sensing, over the entire coastal region of Central and South America.

On the other hand, Argentina and Brazil have launched or will launch in space sensors with ocean-color capabilities, e.g., CBERS CCD and SAC-C MMRS. Exploiting these sensors' capabilities in quantitative applications requires the development of specific bio-optical algorithms and atmospheric correction schemes, and adequate calibration and evaluation plans.

In this context, INPE made a successful proposal to NF-POGO to host a Visiting Professor, Dr. Robert Frouin. With the help of experts in the international ocean-color community, Dr. Frouin provided training to Central and South American graduate students and junior scientists in the use of remotely sensed ocean-color data as a tool for analysing the marine ecosystem.

The initiative aimed at developing the ANTARES project, which main goal is to detect and understand the impact of climate change and human activities on coastal ecosystems of Central and South America and to provide the scientific basis for ecosystem definition and management.

2. Training Objectives

The objectives of the training programme were as follows.

1. To build capacity in Central and South America to exploit satellite ocean-color and other, complementary data sets in the quantitative study and monitoring of coastal waters and ecosystems;

2. To augment the measurement suite at the ANTARES and other stations with radiometric data, by making available SIMBADA radiometers on a quasi-permanent basis;

3. To develop strategies for long-term successful observations and research in biological oceanography of the coastal ecosystems in the region.

4. To promote long-term cooperation between Central and South American countries and to improve the North-South American dialogue within the American continent.

The intention was to transfer knowledge and expertise to researchers who will continue to study the coastal ecosystems of Central and South America in the future, and who will help train the next generation of scientists.

2. Training Activities

The training included two major group activities, with formal lectures, theoretical work, laboratory measurements, field experiment, and data analysis. The major aspects of ocean color remote sensing were covered, from fundamental principles to modeling, inversion, instrumentation, and measurements.

Sixteen trainees were selected to participate in those activities, i.e., three from Mexico, one from Peru, one from Colombia, one from Venezuela, one from Argentina, and nine from various Brazilian Universities and Institutions, including three from INPE. The selection was based on academic credentials, motivation, and recommendations. One of the trainees, Mr. David Correa from Peru, could not attend the second part of the course, due to a change of government, which did not allow him, a state employee, to travel abroad during the transition period.

The trainees were divided into three teams composed of biologists and physicists. Each team had to produce reports and make presentations about the work accomplished. The format allowed the trainees to learn and familiarize themselves with various aspects of ocean color remote sensing, to apply and deal practically with the theoretical concepts introduced in the formal lectures, to interact among themselves, and to develop strategies for their individual research in biological oceanography and remote sensing.

During the course, SIO journals, serials, and other materials were accessible electronically via a proxy server, which proved to be a valuable resource for the trainees.

Part 1

The first group activity, April 7 to may 12, 2006, focused on ocean color, i.e., spectral marine reflectance, with lectures on processes affecting marine reflectance, modeling of marine reflectance, measurement of marine reflectance, and inversion of marine reflectance. Other lectures related to optics of particulate and soluble material in water, measurement of ocean optical properties and regional differentiation, and phytoplankton photosynthetic physiology and measurement of photosynthesis. Drs. Greg Mitchell from SIO and Vivian Lutz from INIDEP joined Dr. Robert Frouin in giving the lectures.

The activity was divided in four modules. The first module (one week) was held at INPE in São José dos Campos, with lectures, the second module (one week) at the Oceanographic Institute of the University of São Paulo, with lectures and laboratory work, the third module (third week) at a marine station in Ubatuba, with field work, and the last module at INPE in São José Dos Campos, with more lectures.

Regarding the theoretical work, the trainees were asked to develop a semi-analytical model of marine reflectance, to compare the result with Hydrolight simulations, to examine the impact of yellow substances, sediments, and angular geometry on the performance of band-ratio algorithms, and to make an inventory of available data on particulate and soluble absorption and backscattering coefficients for coastal regions of Central and South America.

Regarding the experimental work, the trainees were first initiated in above-water radiometry, fluorometry, and spectrophotometry, including measurement protocols and data processing. This was accomplished in the field and in the laboratory, through demonstrations by the instructors and hands-on practice. The trainees were then asked to collect water samples and radiometric data in coastal waters off Ubatuba, to process the water samples into particulate and soluble absorption and chlorophyll-a concentration, to process the radiometric data into marine reflectance, and to evaluate the OC4V4 algorithm, with analysis of discrepancies. Each team sampled different stations (all Case 2 waters) and, therefore, analyzed a separate data set.

During the last week, back at INPE in São José Dos Campos after the field work, the trainees presented the individual research projects they were undertaking at their home institutions (objectives, results, issues, needs). Originality, importance, approach, data, etc., were discussed at length. The instructors provided guidance on how to resolve issues and needs.

Each team wrote a report about the theoretical and experimental work accomplished. The activity concluded with presentations by the trainees of results and accomplishments, a discussion of experiences and difficulties, and comments by the instructors.

Part 2

The second group activity, August 7 to 25, 2006, focused on ocean color remote sensing from space, with lectures on processes affecting ocean color viewed from space, modeling of the solar radiation reflected by the ocean-surface-atmosphere system, atmospheric correction schemes, inverse modeling, satellite ocean-color sensors, calibration of ocean-color sensors, evaluation of ocean-color products, and modeling of primary production from space. The lectures were complemented by practical sessions about SeaDAS, ocean-color programming, and primary production modeling. Prof. Ichio Asanuma from Tokyo University of Information Sciences and Dr. Ewa Kwiatkowska from NASA joined Dr. Robert Frouin in giving the lectures and conducting the practical sessions.

The practical work included radiation-transfer modeling, satellite image processing, and match-up data analysis. The trainees were provided with a variety of radiation-transfer codes to simulate the top-of-atmosphere reflectance in the solar spectrum and to calculate surface PAR, with satellite and concomitant in situ data collected off Patagonia onboard R/V Ioffe during March 8 to 12, 2002, and with other satellite data sets. Using these tools and data, they were asked to perform the following tasks.

First, they had to simulate the top-of atmosphere signal and to compare it with the signal backscattered by the water body.

Second, they had to build an analytical model of the top-of-atmosphere reflectance, with water, surface, and atmosphere components, and to compare the various contributions.

Third, they had to process SeaWiFS imagery acquired during the R/V Ioffe cruise into aerosol and ocean color products, to generate match-ups between SeaWiFS estimates and in situ data, to compare estimated and measured values of marine reflectance, chlorophyll-a concentration and absorption coefficients (particulate, soluble), and to interpret differences.

Fourth, they had also to implement and apply to global SeaWiFS and MODIS imagery primary production models of varying degree of complexity, from wavelength-resolved to wavelength-integrated to time-integrated to depth-integrated, and to compare results in various oceanic regions.

All the lectures and practical sessions took place at INPE in São José Dos Campos. During the three weeks of the activity, the interactions were close between trainees and instructors, who made sure, through the practical work, that the theoretical concepts were assimilated properly. The instructors also received input and feedbacks from the participants on data needs, and hardware and software needs, for their research projects.

As in Part 1, each team wrote a report about the theoretical and practical work accomplished, and presented the results, which were discussed with the instructors. The study performed by the trainees on the evaluation of ocean color products during the R/V Ioffe cruise, based on careful analysis and interpretation of match-ups, produced original findings and, therefore, might result in a publication by the group in a peer-review journal.

Other activities

Between Part 1 and Part 2, Dr. Robert Frouin traveled to Mar Del Plata, Argentina, to bring a SIMBADA radiometer to INIDEP for routine measurements at their ANTARES time series station, and to train INIDEP students and scientists in the use of the instrumentation. Various applications of the radiometer were discussed, notably controlled experiments with algal cultures.

From October 17 to November 4, 2004, Dr. Robert Frouin will travel to São José Dos Campos and Ubatuba to test newly acquired optical instrumentation, to refine measurement protocols, to compare radiometric techniques, to participate in the October 2006 ANTARES cruise in Ubatuba, and to discuss collaborative projects with INPE scientists, including the development by INPE of a new satellite mission for observing ocean color and aerosols.

5. Final Remarks

The list of trainees and instructors, including contact information, is given in Appendices 1 and 2, the instructors' lectures and trainees' presentations are listed in Appendices 3 and 4, and the team reports are available at http://genius.ucsd.edu/~john/NF-POGO/Report2/. As part of the training programme, equipment (spectrophotometer, laboratory scalar PAR sensor, field planar PAR sensor, SIMBADA radiometers, etc.) was purchased for or made available quasi-permanently to the host Institute, as well as software (Hydrolight 4.2 code, 6S code, Monte Carlo code, successive orders of scattering code, PAR code), and scientific books (remote sensing, ocean biology, inversion, data analysis). The list of equipment, software, and books is given in Appendices 5, 6, and 7, respectively.

A web page was developed for the course, i.e., http://www.dsr.inpe.br/nfpogo. This page, written in English and Portuguese, includes information about course application, content, and format, a list of trainees and instructors, lectures, trainee presentations, and photographs. Links to the web pages of the main sponsors and organisations are also included. Two other web pages were created, one for Part 1, http://genius.ucsd.edu/~john/NF-POGO/training1.html, and the other one for Part 2, http://genius.ucsd.edu/~john/NF-POGO/training2.html. These pages contain the material used in the group activities, including radiation-transfer codes, software to process radiometric data, satellite and in situ data sets, and important journal articles and publications. The above web pages will be maintained after the course to facilitate the exchange of material and information among the participants.

The trainees expressed a lot of interest for the course. They were motivated and hard working, spending long hours on their assignments, even entire nights. The format was demanding, but greatly helped with understanding the theoretical concepts introduced in the formal lectures, as evidenced in the team presentations and reports. The Oceanographic Institute of the University of São Paulo was very supportive of the laboratory and field activities. INPE was incredibly efficient in making available computers, software, Internet access, secretarial support, and transportation. This made the experience especially enjoyable. The best measure of success, however, will be to see the trainees progressing in their research and achieving notoriety, and to read, in the peer-reviewed literature, their future articles in ocean-color remote sensing and biological oceanography.

6. Acknowledgments

We would like to thank the people at POGO and Nippon Foundation, as well as the Director and staff of INPE for giving us the opportunity to organize and realizing this training programme in Brazil, allowing the participants to get hands-on experience in ocean-color remote sensing, photosynthesis, and primary production. We believe that the experience was beneficial to the trainees, who learned a difficult subject, were exposed to new concepts and ideas, got some of the best tools available, and developed interactions for future collaboration. Our special thanks go to Dr. Shubba Sathyendranath, Dr. Venetia Stuart, Prof. Ichio Asanuma, Dr. Ewa Kwiatkowska, Dr. Vivian Lutz, and Dr. Greg Mitchell, Mrs. Maria Cristina dos Santos (INPE Secretariat), the INPE drivers, the IOUSP ship crew, and all the participants for their direct and/or indirect support.

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Appendix 1: Trainees

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Appendix 2: Instructors

Dr. Robert Frouin, Lead
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Prof. Ichio Asanuma
Department of Environmental Information
Tokyo University of Information Sciences

Dr. Ewa Kwiatkowska
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Dr. Brian Gregory Mitchell
Scripps Photobiology Group
Scripps Institution of Oceanography
University of California

Appendix 3: Formal Lectures

Part 1

- Processes affecting marine reflectance (R. Frouin)

- Modeling the diffuse reflectance of natural waters (R. Frouin)

- The measurement of marine reflectance (R. Frouin)

- The SIMBAD and SIMBADA radiometers (R. Frouin)

- Inversion of the marine reflectance (R. Frouin)

- Optics of particulate and soluble material in water (B. G. Mitchell)

- Measurement of ocean optical properties and regional differentiation (B. G. Mitchell)

-Phytoplankton photosynthetic physiology and measurement of photosynthesis (B. G. Mitchell)

- Structure and function of the photosynthetic apparatus (V. Lutz)

- Phytoplankton pigment composition (V. Lutz)

- Phytoplankton absorption in relation to Pigment composition (V. Lutz)

- Phytoplankton fluorescence (V. Lutz)

- Estimation of chlorophyll and other components by remote sensing of ocean color (V. Lutz)

- The ANTARES project (V. Lutz)

- Primary Production in the SE Brazilian Coast (S. Gaeta)

- Benthic Dynamics in the SE Brazilian Coast (P. Sumida)

Part 2

- Processes affecting ocean color observed from space (R. Frouin)
- Modeling of solar radiation reflected by the ocean-atmosphere system (R. Frouin)
- Atmospheric correction algorithms and inversion schemes (R. Frouin)
- Algorithm to estimate PAR from satellite ocean-color data (R. Frouin)
- Calibration of ocean color sensors: definitions and requirements (R. Frouin)
- Ocean color satellite sensors, past, present, and future (E. Kwiatkowska)
- NASA ocean-color web site (E. Kwiatkowska)
- SeaDAS; Ocean-color programming (E. Kwiatkowska)
- Ocean color data processing and merger (E. Kwiatkowska)
- Ocean color calibration/validation and match-ups (E. Kwiatkowska)
- Ocean color imagery and applications (E. Kwiatkowska)
- Modeling Primary productivity from space (I. Asanuma)

Appendix 4: Trainee presentations

- The use of ocean color data to study meso-scale processes and phytoplankton primary production (A. Gonzalez)
- Characterization of oceanic regions of ecological importance in the Patagonian Shelf using ocean color remote sensing and in situ data (A. Dogliotti)
- Dinámica fisica, química, y planctónica de la surgencia costera frente al departamento del Magdalena, Caribe Colombiano (C. Llano)
- Study of Amazon floodplain water composition using Hyperion/EO-1 and field reflectance data for the comprehension of temporal variability of optically active constituents (C. Rudorff)
- The Peruvian system of upwelling (D. Correa)
- The Phytoplankton Ecology Team (POPEYE) program (E. Santamaría)
- The São Francisco River basin and coastal zone, East Brazil: Alterations induced by dam constructions - Remote sensing overview (E. Negri)
- Grupo de Oceanografia de Altas Latitudes (GOAL) projects (E. Miranda)
- The solution of radiative-transfer problems in hydrologic optics (E. Chalhoub)
- Remote sensing of coastal processes and environments (F. Ruddorff)

- Phytoplankton abundance and community structure in the region of the Patagonia shelf break (M. de Souza)

- Remote sensing of the South Brazilian Coast (M. Noernberg)

- Ubatuba ANTARES time series station (M. Pompeu)

- The assessment of the dynamics of suspended material on the continental shelf off Santos, Brazil (M. Carvalho)

- Hydrological spatial patterns identification in the Northwest of Venezuela (R. Ayala)

- Oceanographic studies using remote sensing in Mexico and the Caribbean (S. Cerdeira)

Appendix 5: Equipment

- Ultraviolet-visible spectrophotometer with integrating sphere, SHIMADZU Model UV-2450

- Quantum PAR sensor, LICOR Model Li-190-SL

- Scalar PAR sensor, BSI Model QSL 2100

- SIMBADA radiometers (four), made available by Scripps Institution of Oceanography

- Reflectance plaque (50%, 10x10 inches), LABSPHERE Model SRT 50-100

Appendix 6: Software

- Hydrolight 4.2 radiation transfer code (to simulate radiative transfer in natural waters)

- 6S radiation transfer code (to simulate radiative transfer in the atmosphere and ocean)

- Successive orders of scattering code (to simulate radiative transfer, including polarization, in the atmosphere)

- Monte Carlo code (to simulate radiative transfer in the atmosphere and ocean)

- PAR code (to estimate photosynthetically available radiation at the ocean surface)

- Marine reflectance code (to simulate the diffuse marine reflectance of Case 1 waters)

Appendix 7: Books

- Light and Photosynthesis in Aquatic Ecosystems, by J. T. Kirk

- The Oceans and Climate, by G. R. Bigg

- Measuring the Oceans from Space: The principles and Methods of Satellite Oceanography, by I. S. Robinson

- Satellites, Oceanography, and Society, by D. Halpern

- Color of Inland and Coastal Waters: A Methodology for its Interpretation, by D. Pozdnyakov, H. Grassl, and A. Lang

- Optical properties and Remote Sensing of Inland and Coastal Waters, by R. P. Bukata

- Optical Properties and Remote Sensing of Multicomponental Water Bodies, by H. Arst

- Data Analysis Methods in Physical Oceanography, by W. B. Emery and R. E. Thompson

- Digital Image processing, by R. C. Gonzalez

- Image Transfer through a Scattering medium. E. P. Zege, A. P. Ivanov, and I. L. Katsev

- Radiative transfer, by S. Chandrasekhar

- Light and Water, by C. D. Mobley

-Hydrologic Optics, by R. W. Preisendorfer

- A distribution-Free Theory of Nonparametric Regression, by L. Györti, M. Kohler, A. Krzyzak, and H. Walk

- Regularization of Inverse Problems, by H. W. Engl, M. Hanke, and A. Neubauer

- Introduction to the Mathematics of Inversion in Remote Sensing and Indirect Measurements, by S. Twomey

- Primary Productivity and Biogeochemical Cycles in the Sea, by P. G. Falkowski and A. D. Woodhead

- Primary Productivity of the Sea, by P. G. Falkowski

- Biological Oceanography, by C. B. Miller

- Ocean Biological Dynamics, by J. L. Sarmiento

- Introduction to the Modelling of marine Ecosystems, by W. Fennel, and T. Neumann

- Dynamics of Marine Ecosystems: Biological-Physical Interactions in the oceans, by K. N. Mann and J. R. N. Lazier

- Phytoplankton Productivity: Carbon Assimilation in marine and Freshwater Ecology, by P. B. Williams, D. N. Thomas, and C. S. Reynolds