Ocean Colour 2007 Africa, 24 September-5 October 2007, Mombasa, Kenya

Photo Gallery

Within the 7th Framework Programme, the ***Joint Research Centre (JRC)*** is building the observation, monitoring, modelling and analytical capacity of an 'ACP (African, Caribbean, Pacific) Observatory for Sustainable Development'. The system will provide ready-to-use information on environment, food security and crisis issues on which to base appropriate policy responses.

The implementation of such an Observatory involves both European based activities as well as direct capacity building in ACP countries. Accordingly, through its Action 'Monitoring Natural resources for Development Co-operation' (MONDE), the ***Global Environment Monitoring Unit (GEM) of the Institute for Environment and Sustainability (JRC-IES)*** has offered a 2-weeks training course on:

"Methods and Applications of Ocean Colour Remote Sensing in African Coastal and Regional Seas".

Group Picture - first week

This course has been designed to provide the theoretical basis of ocean colour satellite measurements, as well as key applications in monitoring and managing the coastal zone, in protecting the marine ecosystems and their resources.

The course has been organed jointly by the IES-GEM Unit and the Kenya Marine Fisheries Research Institute ***(KMFRI)*** with further partnership from:

- International Ocean Colour Coordinating Group (IOCCG);
- Group on Earth Observation (GEO International);
- Western Indian Ocean Marine Science Association (WIOMSA);

- Regional Programme for the Sustainable Management of the Coastal Zones of the Indian Ocean Countries (ReCoMap);
- Benguela Current Large Marine Ecosystem Programme (BCLME);
- Land-Ocean Interactions in the Coastal Zone (IGBP-LOICZ);
- Indian Ocean- Global Ocean Observing System (IOC Perth Office).

The Course was further endorsed by the ***Partnership for Observations of the Global Oceans (POGO)*** and the ***Global Ocean Observing System (IOC/GOOS-Africa)***. The course is a contribution to the activities of the ChloroGIN (GEO EC-06-07) network.

Course structure

The Training Course was intensive and included a series of lecture sessions chaired by international experts from Europe and Africa *(see list of participants)*. The session topics were selected such as to cover the physical principles of ocean colour measurements from space, as well as various applications addressing important environmental issues in coastal and marine waters.

Session 1: Ocean colour sensors principles and atmospheric corrections (R. Doerffer, GKSS, Germany);

Session 2: Introduction to water optics (S. Bernard, CSIR, South Africa);

Session 3: Optical variability in marine waters (A. Bricaud, LPCM, France);

Session 4: Ocean colour algorithms (M. Dowell, JRC, Italy);

Session 5 : Phytoplankton biomass and Functional types (N. Hoepffner, JRC, Italy; S. Bernard, CSIR, South Africa);

Session 6: Primary production and the marine carbon cycle (M. Kyewalyanga, IMS, Zanzibar, Tanzania; N. Hoepffner, JRC, Italy);

Session 7: Application to ecosystem assessment including fisheries (N. Hardman-Mountford, PML, United Kingdom);

Session 8: Coral reefs and coastal habitats mapping (S. Andrefouet, IRD, Noumea, New Caledonia);

Session 9a: GIS applications for coastal management (L. Scott, SAIAB, South Africa);

Session 9b: African Marine Information System and SAR applications (S. Djavidnia, EMSA, Portugal).

Dr. M. Kyewalyanga - session 6

The course also included practical sessions during which participants were trained on various image processing and applications software, such as Envisat-BEAM (trainer: R. Doerffer, GKSS, Gremany), BILKO (trainer: V. Byfield, SOC, UK), and SeaDAS (trainer: C. Whittle, UCT, South Africa). Practical sessions continued in the form of 'mini-projects' where participants conducted a short study applying knowledge recently gained during the lectures and software demonstrations.

To support the practical sessions, a total of 11 computers were rented from a local company in Mombasa. The computers were configured with the appropriate software and database such as to optimize the efficient use of either one of the image processing tools.

Ph. Simons & S. Ngete - preparing computers

More details on Lectures and practical sessions are presented in the 'Course Synopsis'.

Course Highlights

The Training Course was attended by 18 participants coming from different countries in Africa and western Indian Ocean Islands, and selected out of 62 applications received. Represented nations were Ghana (1), Ivory Coast (1), Namibia (1), South Africa (3), Mozambique (2), Tanzania (2), Kenya (3), Madagascar (1), Mauritius (2), Seychelles (1), and Comoros (1). For a full list please see the list of participants.

Group Picture - second week

The Course event started with an opening address by Dr. J. Kazungu (KMFRI Director) and N. Hoepffner (IES-GEM), respectively presenting KMFRI activities and the general structure of the JRC including its role to support the EU's Development and Aid strategy through the 'ACP (African, Caribbean, Pacific) Observatory for Sustainable Development'.

Dr. J. Kazungu - Director KMFRI

As part of the General Introduction to the Course, Roland Doerffer showed a 40-minutes movie on “The Science of Ocean Colour”. Topics covered by the video included the determination ocean colour, techniques used on board a research vessel during an ocean optics cruise, ocean colour from space, processing satellite data, and the role of the IOCCG.

The lecture and practical sessions were presented according to the planned time table (see Course synopsis). All lectures were very well prepared to provide high quality and up-to-date information on different issues concerning the use of ocean colour from space, and also its application to the marine and coastal environment as a stand alone tool, as well as with other types of sensors or measurement platforms. All participants received a CD with all lectures and various presentations made during the Course period.

The participants adhered to the practical sessions with great enthusiasm, reflecting the quality of the demonstrations and the effort of the training staff to support participants in doing the application exercises.

Lecture & Practical Sessions

The results of the mini-projects done by the students during second week of the course last week were presented the last day of the Course. The presentations and their content were of very high quality, underlining the outstanding work conducted during the practical sessions.

The mini-projects focused on various themes:

- Detection of coccolithophores in Namibian coastal waters;
- Influence of river discharges on coastal waters along Ivory Coast;
- Chlorophyll variability and TSM between Comoros and Madagascar;
- Characterization of coral reefs habitats along the coast of Tanzania;
- Influence of tropical cyclones on SST and Chla in the Mozambique Channel;
- Full processing of a Southern Benguela SeaWifs scene with SeaDAS;
- Assessment of phytoplankton concentration variability in Kenyan marine waters;
- Spatial variation of chlorophyll in the northern Mozambique Channel;
- The use of ocean colour remote sensing to monitor the impacts of storm surges and extreme high tides along the Eastern Cape coast of South Africa.

Mini Projects presentations

Indicators for Success

At the end of the course, an anonymous evaluation sheet was given to all participants to collect their appreciations on various aspects of the lectures, practical sessions, as well as the overall organization, accommodations, logistics and equipment during the course period.

The results of this poll were very encouraging as illustrated from the plots in Annex A.

Various students expressed the wish of the creation of an informal network, an arena where to discuss and exchange Ocean Colour remote sensing information, and keep building and maintaining links and facilitate future collaboration between African and Indian Ocean scientists. Within this context it is worth emphasising that such a framework could be the Chlorophyll Global Integrated Network (ChloroGIN) project, which aims to promote in situ measurement of chlorophyll in combination with satellite derived estimates.

Acknowledgments

In conclusion, we believe that Ocean Colour 2007 Africa has been a very successful event. Many thanks are addressed to all participants, trainees and trainers, for their excellent contributions and for their enthusiasm in sharing their knowledge and their time during the course.

Further to this we are deeply grateful to all of the sponsorship organizations for supporting the students and giving them the possibility to attend. We very much look forward to further opportunities of collaboration.

Social Events

Nicolas Hoepffner
Course Chairman

Samuel Djavidnia
Course Co-Chair

Ocean Colour 2007 Africa

"Methods and Applications of Ocean Colour Remote Sensing in African Coastal and Regional Seas"
(Mombasa, Kenya, Sept. 24th- Oct. 05th)

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Ocean Colour 2007 Africa

“Methods and Applications of Ocean Colour Remote Sensing in African Coastal and Regional Seas”

(Mombasa, Kenya, Sept. 24th- Oct. 05th)

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Ocean Colour 2007 Africa:

"Methods and Applications of Ocean Colour Remote Sensing in African Coastal and Regional Seas".

(Mombasa, Kenya, Sept.24th – Oct.5th)

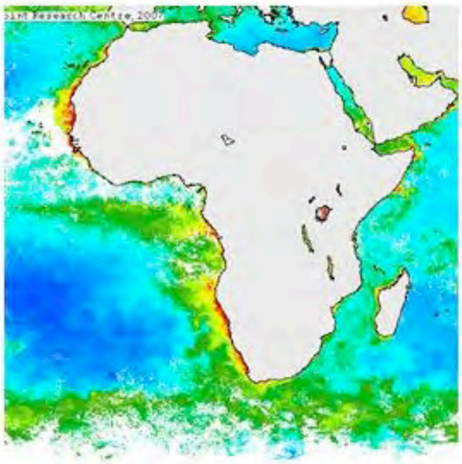
COURSE SYNOPSIS

EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

Institute for Environment and Sustainability

Kenya Marine and Fisheries Research Institute
K.M.F.R.I

IOCCG
International Ocean Colour Coordinating Group



ReCoMaP
INDIAN OCEAN

BCLME
Benguela Current Large Marine Ecosystem Programme

WIOMSA
Western Indian Ocean Marine Science Association

GEO Group on Earth Observations

Intergovernmental Oceanographic Commission
Regional Programme Office - Perth

LOICZ

UNESCO

		Mon 24/09	Tue 25/09	Wed 26/09	Thu 27/09	Fri 28/09
09:00	*10:30*	welcome (N. Hoepffner) Opening (Dr. Kazungu, KMFRI Director)	**Session 2: *S. Bernard*** In-water optics Basic theory and measurements/instrumentation	**Session 3: *A. Bricaud*** Optical variability case 1 / case 2 waters	**Session 4: *M. Dowell*** Ocean colour in-water algorithm empirical/ analytical regional & coastal waters algo.	**Session 5: *S. Bernard/N. Hoepffner*** Phytoplankton biomass phyto funtional groups HABs
11:00	*12:30*	Intro to Satellite oceanography				
		LUNCH	LUNCH	LUNCH	LUNCH	LUNCH
14:00	*17:30*	**Session 1**: ***R. Doerffer*** Fundamentals of Ocean Colour sensors and Atmospheric correction (processes)	**practical 1: *R. Doerffer*** *(+D. Odermatt)* BEAM Envisat and MERIS Toolbox	**practical 2: *V. Byfield*** Bilko Software	**practical 3: *C.Whittle*** *(+D. Odermatt)* SeaDAS / IDL software	**practical 3bis: *C.Whittle*** *(+D.Odermatt)* SeaDAS/ IDL software (cont.)

		Mon 01/10	Tue 02/10	Wed 03/10	Thu 04/10	Fri 05/10
09:00	*12:30*	**Session 6: *M. Kyewalyanga/ N. Hoepffner*** Photosynthesis satellite Primary production carbon cycle	**Session 7: N. Hardman-Mountford** OC and fisheries ecosystem analysis, time series ecosystem indicators	**Session 8: S. Andrefouet** OC and coral reefs assessment habitat mapping (shallow water remote sensing)	**Session 9: L. Scott /S. Djavidnia** coastal management GIS application oil spills	Final course conclusions Mini-projects presentation (10 min each) closing Training Course
		LUNCH	LUNCH	LUNCH	LUNCH	LUNCH
14:00	*17:30*	**Mini-project**	**Mini-project**	**Mini-project**	**Mini-project**	

Supervision : C.Whittle, S. Djavidnia, D.Odermatt (+others)

Introductory Session (Sept.24th , 11:00 – 12:30)

Introduction to Satellite Marine Studies

Nicolas Hoepffner
Global Environment Monitoring Unit
Institute for Environment & Sustainability,
European Commission – Joint Research Centre, Ispra, Italy

Roland Doerffer
GKSS – Institute for Coastal Research
Max-Planck-Str. 1, 21502 Geesthacht, Germany

Sophisticated satellite observations systems have significantly contributed to the objective of major international scientific programme aiming at a better understanding of the dynamics of the ocean, the biogeochemical cycles at the global and basin scales, as well as the climate system. Wind speed and direction, surface heat fluxes, momentum and material including carbon dioxide, the biological production of organic material, and the variability of surface currents are now being investigated from various satellite sensors. These observations in turn are used to initiate and constrain appropriate models of the upper ocean, based on advanced data assimilation techniques. A quick review of various ocean observation techniques will be presented with their specificity to address environmental issues in the coastal and marine waters.

This introduction will be followed by the projection of a film " The Science of Ocean Colour " (30-40 min.) produced by Dr. Roland Doerffer

Lecture Sessions

Lecture Session 1 (Sept. 24th, 14:00 – 17:30):

Ocean Colour Sensors: characteristics and signal processing

Roland Doerffer
GKSS Institute for Coastal Research
Max-Planck-Str.1, 21502 Geesthacht, Germany

Basic Principles of ocean colour satellite sensors

Past, present and future sensors

Calibration of sensors and accuracy issues

principles of atmospheric correction

special requirements for atmospheric correction for coastal waters

Validation procedures

MERIS on ENVISAT

MERIS products for coastal waters

This session will be followed by the projection of a film "Interview with Professor André Morel " (45 min.) produced by Dr. Roland Doerffer

André Morel is Emeritus Professor at the University Pierre et Marie Curie (Paris, France), and responsible for the Marine Optics and Remote Sensing Lab at the Oceanographic Centre of Villefranche/mer (France). Prof. André Morel has received many awards for his numerous outstanding contributions to optical oceanography. He is leading our modern understanding of ocean colour, particularly in case 1 waters where the optical properties are dominated by biology. He is the author of many key publications on the interpretation of satellite observations of ocean colour, ranging from the theoretical basis of signal processing to primary production modeling and analyses of the carbon cycle.

Lecture Session 2 (Sept. 25th, 09:00 -12:30):

Introduction to In –Water Optics: Theory and Measurements

Stewart Bernard
Ecosystem Earth Observation
Council for Scientific and Industrial Research, Cape Town, South Africa

The ability to describe and explain the behaviour of light in natural waters is fundamental to understanding the science and applications of ocean colour. The course will start by describing the nature of the underwater light field, and the principal bio-optical concepts and attributes needed to understand the behaviour of light in the sea. The session will then focus upon the interaction of light with the various dissolved or particulate substances present in the upper ocean, their optical properties and subsequent effects on the underwater light field, and how these processes impact upon ocean colour.

The course will encompass the following:

Introductory Theory

- Re-introduction to the nature of electromagnetic energy in the visible.
- Defining and describing the light field: the theory of radiative transfer, the angular structure of the light field, definitions and theory of apparent optical properties (AOPs).
- Defining and describing the optical properties of seawater constituents: definitions and theory of inherent optical properties (IOPs), absorption, elastic and inelastic scattering, the identity and character of primary IOPs in the sea.

Measurements & Modelling

- Measuring AOPs: typical instruments, techniques and applications; above and in-water radiometry, preliminary characterisation of common AOPs.
- Measuring IOPs: typical *in situ* and laboratory instruments, techniques and applications; absorption/scattering measurements and underlying theory, preliminary characterisation of common IOPs, a brief introduction to IOP modeling techniques.
- Reflectance and radiative transfer modeling – bringing it all together by modeling AOPs based on IOPs and their underlying constituent character.

The focus will be on allowing students to gain a descriptive (as opposed to mathematical) understanding of in-water bio-optics, and use this to approach remotely sensed ocean colour from an analytical perspective. Examples using different applications in a variety of oligotrophic and coastal systems will be used.

Lecture Session 3 (Sept. 26th, 09:00 -12:30):

Optical variability of Case 1 and Case 2 waters

Annick Bricaud
Laboratoire d'Océanographie de Villefranche,
CNRS and Université Pierre et Marie Curie, Villefranche-sur-mer, France

The knowledge of the inherent optical properties (absorption, total scattering, backscattering coefficients…) of marine waters, and of their natural variability, is needed to predict the propagation of light within the ocean and its return toward the atmosphere, with all the subsequent applications (bio-optical modeling, ocean color algorithms, estimation of primary production, interpretation of optical measurements in terms of biogeochemical quantities etc…).

In this course we will first address the sources of variability in the inherent optical properties (IOPs) of marine waters. In oceanic « Case 1 » waters, these IOPs are ruled by phytoplankton and associated non-algal (particulate and dissolved) matter. In spite of this apparent simplicity, the sources of optical variability are numerous and will be reviewed :
- the absorption and scattering properties of phytoplankton are highly variable according to the dominant species, due to variable physical characteristics (pigment composition, refractive index, size and shape of cells) ;
- for a given population, the IOPs are dependent on the physiological state of cells, and therefore on environmental factors (light, nutrients…); in particular the dial variability of IOPs will be examined ;
- the non-algal compartment includes various components (biogenous detritus, heterotrophic bacteria, viruses, colored dissolved organic matter...) ; these components have variable absorption and scattering properties, and their relative abundance, with respect to phytoplankton, is also fluctuating.

The problem is still much more complex in the so-called « Case 2 » waters (essentially, but not exclusively, the coastal waters affected by terrigenous inputs). In these waters, in addition to phytoplankton and associate detrital matter, other components (mineral particles of terrestrial or atmospheric origin, terrigenous colored dissolved organic matter…) have variable specific optical properties, and vary also in their relative proportions, thus contributing to the large optical variability of these waters. The IOPs of these components will be reviewed.

We will then describe the various (empirical or semi-analytical) parameterizations for the absorption and scattering properties of Case 1 and Case 2 waters, and how the « biological noise », resulting from the above mentioned sources of variability, can affect these parameterizations.

Finally we will examine the impact of the variability of IOPs on the apparent optical properties of sea waters, and particularly on their spectral reflectance properties (ocean color). The emphasis will be put on some regions of the world ocean (e.g. Mediterranean Basin, Black Sea, Antarctic ocean…) which have revealed peculiar bio-optical properties (with respect to the « average » optical behavior of the world ocean), leading to the development of regional algorithms for estimating their algal biomass content from ocean color data.

Lecture Session 4 (Sept. 27th, 09:00 -12:30):

Ocean Colour In-water Algorithms

Mark Dowell
Global Environment Monitoring Unit
Institute for Environment & Sustainability,
European Commission – Joint Research Centre, Ispra, Italy

This session on in-water algorithms will trace the history of the development of algorithmic methods applied to Ocean Colour data starting with the very first algorithms applied to global datasets obtained from the CZCS sensor.

We will outline the evolution of algorithm development as the knowledge on the optical properties of both open ocean and coastal waters have improved over the last three decades. Additionally we will examine the mathematical and statistical approaches (neural networks, non-linear optimisation, spectral un-mixing, principal component analysis etc.) that have been explored to make best use in using the radiometric quantities measured by the sensors in retrieving the relevant geophysical quantities of interest.

Specific attention will be placed on underlining the complexities of applying such methods in coastal regions (which is of specific interest to many of the applications considered in the present course), and considerations will be made on the limitation and uncertainties that need to be understood.

Furthermore we will analyse the parallel progress of both the empirical and semi-analytical method, and consider the merits and deficiencies of each of these, providing a clear understanding of the difference between these methods and their practical application in the operational processing of data.

Complimentary to this we will specifically consider the results from an intensive round robin inter-comparison of different semi-analytical methods (performed by the IOCCG).

In considering all of these various aspects of different available algorithms we will underline which algorithms have been considered for routine processing by the major space agencies (and why ?).

Continuing we shall address the relative benefit of using standard global coverage products compared to regional algorithms and visa versa, and explore various alternatives for the implementation of regional algorithms. Here we will investigate the “minimum requirements” for the implementation of such regional algorithms (i.e. required datasets, “Level” of satellite data required, computing knowledge, infrastructure).

Finally we will make some considerations on the future direction for research on these topics. And deal with any real world examples/questions that participants may have and want to address.

Lecture Session 5 (Sept. 28th, 09:00 -12:30):

Phytoplankton Biomass, Phytoplankton Functional Types, Harmful Algal Blooms

Stewart Bernard
Ecosystem Earth Observation
Council for Scientific and Industrial Research, Cape Town, South Africa

Nicolas Hoepffner
Global Environment Monitoring Unit
Institute for Environment & Sustainability,
European Commission – Joint Research Centre, Ispra, Italy

Phytoplankton plays a crucial role in the oceans, representing the primary source of organic carbon that supports the entire marine ecosystem and off chain, including the upper trophic levels (fishes, and shellfishes) of major importance to society. The estimation of phytoplankton biomass is therefore prerequisite to any marine ecosystem assessments and biogeochemical studies.
This session will review our current knowledge on phytoplankton composition, their categorization according to several criteria such as size or pigment composition, the challenges in measuring biomass, and the role of satellite to examine the spatial and temporal variability of the phytoplankton biomass.

The following topics will be addressed:

Phytoplankton composition in the ocean
Basic definitions and properties of marine phytoplankton
Use of pigments to discriminate phytoplankton species:
pigments species, photosynthetic vs protective pigments, pigments association
Pigment optical signatures: absorption and fluorescence.

Phytoplankton biomass
Biomass of phytoplankton is defined as the total weight of all the organisms in a given area or volume. Its estimation is not straightforward and depends on whether carbon or photosynthetic pigments are used as mass units.
Pros and cons of using Chlorophyll as a proxy for phytoplankton biomass
Chlorophyll/Carbon ratio
Chlorophyll as a measure of the physiological state of phytoplankton
Optical properties as a proxy for biomass

Measurements of phytoplankton biomass
Many techniques and methods are applied for measuring chlorophyll biomass and pigments, ranging from chemical (e.g. HPLC) to optical methods (spectrophotometry, fluorometry), and from the use of a single cell (flow cytometry) to the basin scale observations using satellite. Each of these methods will be reviewed with specific

consideration on protocols well agreed within the scientific community, as well as on new and promising technologies.

Spatial and temporal variability of the phytoplankton biomass

The phytoplankton biomass is highly variable in space and time. Temperature, stratification and destratification, incident solar irradiance, all these impact on the phytoplankton growth, resulting in a biomass distribution that depends on latitude and season. This part of the lecture will address the role of OC satellite data to analyze the complex interactions between phytoplankton and physics, as well as possible variations of the phytoplankton distribution as a result of climate change.

Session 5/2. Phytoplankton Functional Types: Detecting Species Variability with Ocean Colour.

Ocean colour has been used primarily to determine variability in phytoplankton biomass; an emerging application is the use of more sophisticated algorithms to describe variability in the composition of algal populations. There are many potential applications e.g. the detection of harmful algal blooms; the study of system ecology with regard to phytoplankton and trophic function; assessing export production and the role of the ocean as a carbon sink.

Phytoplankton functional types are generally defined operationally, typically for ecophysiological- or ocean colour-modelling. A functional group may be defined with regard to ecological or trophic function, or detectable bio-optical properties, or a combination of these properties that is of particular relevance to the application. PFT definition is therefore variable, depending both upon application and algorithm, and application of PFT methods must start with an understanding the basis for PFT definition.

There are also a variety of phytoplankton functional type (PFT) models available for use with ocean colour data. These algorithms use a variety of analytical, empirical and rule-based methods, and a good understanding of their operation is necessary for multi-system application. This session examines the science underlying phytoplankton functional type definition, some of the models used to detect PFTs, and typical applications, including:

PFT definitions commonly used: conventional taxonomy and the bio-optical approach
What can we reasonably expect to see from space? Causality and the sensitivity of ocean colour to phytoplankton assemblage variability.
Common analytical reflectance algorithms and bio-optically defined functional types
Common spectral discriminant models and taxonomically defined functional types
Common rule-based algorithms and environmentally based functional types.

The session will use a variety of examples ranging from harmful algal bloom detection to analyses of the global ocean.

Lecture Session 6 (Oct.1st, 09:00-12:30):

Photosynthesis and Primary Production: Estimation from Ocean Colour satellite

Margareth Kyewalyanga
Department of Marine Biology and Resources Management,
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Life in the ocean stems primarily from the conversion by phytoplankton of the radiant energy from the sun into biochemical energy, i.e. the process of photosynthesis. This energy will then be used for the production of organic matter through the primary reduction of inorganic carbon in the upper layer of the ocean (so-called Primary Production).

1. Photosynthesis and primary production

The first part of session will provide an introduction to photosynthesis process, its basic formulation, its manifestation in phytoplankton through carbon fixation and oxygen evolution, and the role played by chlorophyll-a in energy transfer.

The different methods used to determine primary production at local scales and the factors contributing to its spatial and temporal variations will be reviewed, taking into consideration the well-known physiological techniques (^{14}C, O_2), as well as more recent methods ranging from small-scale molecular biology to large scale methods of bulk properties of the water column and remote sensing of ocean colour.

2. Primary production modelling

Different formulations exist for calculation of primary production at a given location. These models can be differentiated by their degree of complexity and explicit resolution in depth, time, and irradiance. However, an exact mathematical representation of primary production lies commonly in the response of phytoplankton photosynthesis to irradiance. In this session, the terminology and models of the P-I relationships will be reviewed. Emphasis will be put into models used in calculation of daily-water-column primary production and the model inputs, reviewing the following topics:

- Photosynthesis – Irradiance formulations
- Accounting for the irradiance at the surface
- Vertical biomass profiles

- Integration over depth and time
- Models and Associated errors

3. Model implementation using satellite data

There are two significant aspects of this task which are not directly amenable to remote sensing, the first being vertically resolving the chlorophyll profile and the second the determination of the photosynthetic parameters. In broad terms two distinct fields of thought have developed on how to best address this limitation of the satellite-based primary production estimates. The first approach strives to identify "environmental proxies" (such as temperature or trophic state) to map out the required parameters the second makes the use of biogeographical template of provinces for the oceans as a means to assign the required parameter in the model parameterization. Specific items presented will include

- Requirement for mapping primary production at synoptic scale
- Limitations of satellite datasets in addressing primary production
- Conceptual basis of different approaches
- Biogeochemical Provinces for parameter assignment
- Dynamic Provinces

4. Ocean Colour and the Carbon Cycle

The variability in the space-time domain and long-term changes in the marine primary production has important consequences on the major biogeochemical cycles and the distribution of marine resources. We will see that the role of satellite is determinant to understanding the carbon seasonal cycle and its variability.

- Description of basic features of the carbon cycle
- The concept of new and regenerated production, and the *f*-ratio
- Quantitative aspects of the ocean margin carbon cycle
- Estimates of carbon pool size using Ocean Colour satellite

Lecture Session 7 (Oct.2nd , 09:00-12:30):

Application of ocean colour data to the analysis of ecosystems (incl. fisheries)

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The ecosystem (based) approach is now widely accepted as an appropriate model for the management of the marine environment and its natural resources. From state-of-the-environment reporting to indicators of ecological processes, ocean colour data provides much information on marine ecosystems that can be usefully employed to aid this management process. This course session will combine the theoretical/conceptual basis for using ocean colour for ecosystem analysis and management, with case studies and examples of the use of the techniques and concepts, as outlined below.

Ecosystems are emergent units, arising from interactions between biological organisms and their physico-chemical environment. Thus, the term comprises concepts of both ecology (the study of organisms within their environment) and a level of structure and organisation (a system). Systems have a number of properties, including persistence and hierarchy, structured within the dimensions of space, time and complexity. This framework can be used to help interpret ecosystem-relevant information from ocean colour sensors. Two key concepts in linking ecosystems to ocean colour are pattern and scale. Pattern arises from complex interactions within a system, has a spatial expression and temporal duration. As such it can be seen as a descriptor of the system. The time frame for which a spatial pattern persists can indicate the duration of the system. Systems exist at nested spatial and temporal scales, so the scale of investigation is critical to the scale of the systems studied.

Ocean colour provides information on the base trophic-level of the ecosystem: the phytoplankton. Chlorophyll a concentration can be derived as a measure of biomass and several models for calculating primary production have been published. A number of algorithms have recently been published suggesting broadscale classification of size classes and dominant phytoplankton groups is possible (these are covered in a different session). To interpret phytoplankton information within the context of the ecosystem, understanding of their spatial distribution and dynamics in relation to physico-chemical drivers and other ecosystem components is necessary. Marine ecosystems cannot be described from ocean-colour data alone so interaction with other information sources is required. Some of this information can be provided from satellite sensors (SST from infra-red radiometers, geostrophic currents and sea state from altimeter, winds from scatterometer); in other cases in situ measurements are required. The wider biological context of the ecosystem requires information on higher trophic levels (zooplankton, fish and top predators) that remote sensing cannot provide.

By its nature, therefore, ecosystem analysis is a dynamic (i.e. temporally changing) and multivariate problem. Time-series analysis is an essential method for investigating the temporal variability of ecosystems: seasonality, seasonal timing/phenology (e.g. spring bloom) and interannual variability are all important considerations. Similarly, classification of spatial patterns can be used to define appropriate horizontal scales for analysis (e.g. large marine ecosystems or provinces). Scales of variability often co-vary in space and time, so both dimensions may need to be considered together. Techniques to achieve this goal range from simple space-time plots (e.g. Hovmuller plots) to multivariate statistical procedures such as principal components analysis (PCA) and neural network techniques such as self organising maps (SOMs).

The relationship between commercially important fish populations and ecosystem dynamics is a key area for the application of ecosystem management. Key concepts for the understanding of fish recruitment-environment interactions include the Hjort– Cushing 'match-mismatch' hypothesis, Cury and Roy's 'optimal environmental window' and Bakun's 'ocean triad' of enrichment, concentration and retention. Ocean colour data can provide information on these key processes, e.g. front maps, chl concentration, size classes. Furthermore, the relationship between fish population biomass and oceanographic features, such as fronts, can be used to guide the distribution of fishing effort. Achieving ecosystem (based) management of the marine environment requires a policy-based monitoring programme. Simple measures (indicators) need to be derived for both state variables and ecosystem processes, together with information on the baseline state and levels of natural variability, that allow for the simple detection of change in relation to management objectives.

Suggested further reading:

Agostini, V.N. & Bakun, A. (2002). 'Ocean triads' in the Mediterranean Sea: physical mechanisms potentially structuring reproductive habitat suitability (with example application to European anchovy, *Engraulis encrasicolus*). *Fisheries Oceanography* **11** (3): 129-142.

Dwivedi, R. M. et al. (2005). Exploration of fishery resources through integration of ocean colour and sea surface temperature, *Indian Journal of Marine Sciences* **34** (4): 430-440.

Fuentes-Yaco, C. et al. (2007). Shrimp (*Pandalus borealis*) growth and timing of the spring phytoplankton bloom on the Newfoundland-Labrador Shelf. *Fisheries Oceanography* **16** (2): 116-129.

Hardman-Mountford, N.J. et al. (2003). Relating sardine recruitment in the Northern Benguela to satellite-derived sea surface height using a neural network pattern recognition approach. Envifish Special Issue. *Progress in Oceanography* **59** (2-3): 241-256.

and other papers in the Envifish Special Issue: *Progress in Oceanography* **59** (2-3).

Longhurst, A. (1998). *Ecological Geography of the Sea*. San Diego: Academic Press, 398 p.

Platt, T. et al. (2003). Spring algal bloom and larval fish survival. *Nature* **423**: 398-399.

Platt, T. et al. (2007). Biological oceanography and fisheries management: perspective after 10 years. *ICES Journal of Marine Science*, doi:10.1093/icesjms/fsm072 (in press).

Lecture Session 8 (Oct.3rd, 09:00-12:30):

Indirect and direct remote sensing of coral reefs

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I Definitions (15')

- Direct and indirect remote sensing of coral reefs
- Scale of interest (global to community-scale)

II Indirect remote sensing (30')

- Sea Surface Temperature and coral bleaching
- Coral reef connectivity
    - Case study: land-reef and reef-reef connectivity matrices using ocean color data

III Direct remote sensing (105 ')

- Sensors: airborne and spaceborne, multispectral and hyperspectral
- The status of hyperspectral technology for coral reef assessment
- Benthic mapping using multispectral data: geomorphology and habitat mapping and accuracy
- Resource assessment using habitat maps
- Habitat suitability ecological modeling using remote sensing products
- Case studies
    - Stock assessment of benthic commercial resources using field and remote sensing data
    - Definition of Marine Protected Areas
    - East-Africa, Madagascar and Indian Ocean islands geomorphology mapping

IV Discussion and questions (30')

Lecture Session 9 -1 (Oct.4th, 09:00-10:30):

Using Geographic Information Systems (GIS) to support integrated coastal zone management and decision-making.

Lucy Scott
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South African Institute for Aquatic Biodiversity
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The study of coastal resources and the establishment of area-based management plans requires a spatial decision-making framework. This lecture presents the process of establishing a coastal Geographic Information System (GIS) in collaboration with coastal and marine stakeholders and managers. The use of historical data from past projects will be addressed, together with methods and tools for new data collection and integration to provide relevant information in a useful form to support current and future coastal planning.

The content will be presented in four parts:

i) Theory

An introduction to GIS concepts and principles
Mapping for decision-making
An overview of different types of marine and coastal data
Using remote sensed data for coastal management
Spatial science in coastal management

ii) Practical lessons and tools

An introduction to GIS software tools
Techniques for data collection (bathymetry mapping, GPS mapping)
Links to other sections of the Ocean Colour Course
Data mining

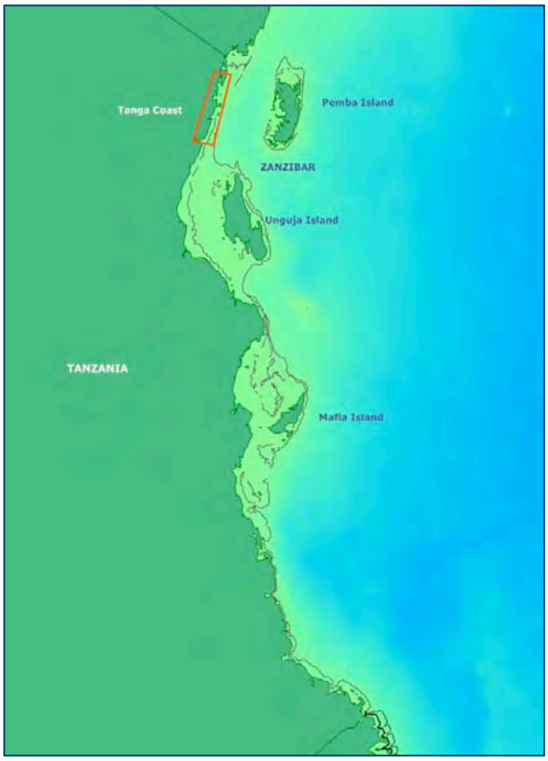


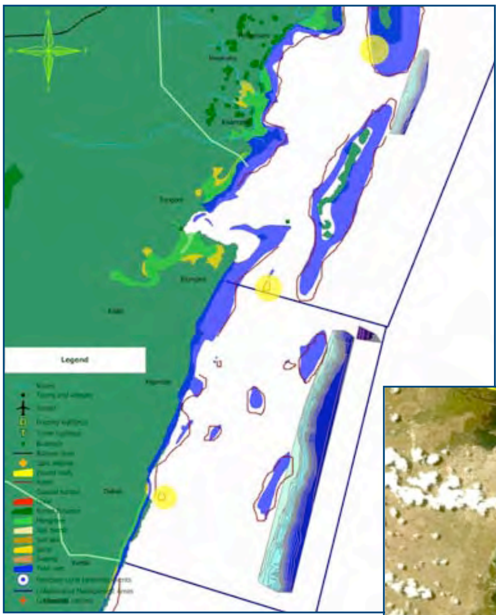
Figure : The Tanga coast

iii) Resources for coastal managers and scientists who use GIS

Data and information resources
Software resources
Sources of funding

iv) Case study: A GIS for the Tanga coast of Tanzania

History and context
Methods
Preliminary products



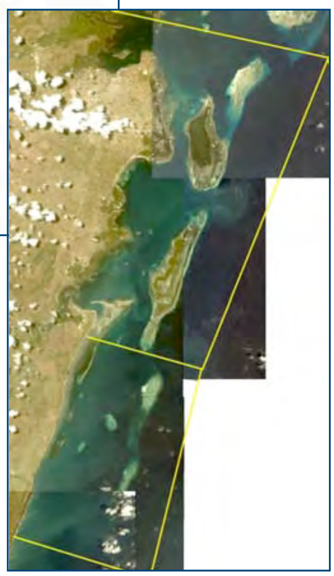


Figure: Tanga Case Study: area of interest (inset: RS images)

Lecture Session 9 -2 (Oct.4th, 11:00-12:30):

Operational Oil Spill Monitoring: can Ocean Colour be of help?

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In this presentation, we will investigate the possibilities of integrating satellite Synthetic Aperture Radar (SAR) derived information with Ocean Colour data for the management of marine resources.

The discharge of oil from ships, oil platforms and other sources causes significant damage to our coasts and to the marine environment in general. Due to the large sea areas involved, deliberate, illegal discharges are more difficult to detect and that is the main reason for the development of operational remote sensing monitoring systems for oil spill detection based on synthetic aperture radar (SAR) satellite images.

The SAR makes use of the radar principle to form an image by utilising the time delay of the backscattered signals. SAR sensors send out short pulses of microwave energy and then record the strength and origin of the returning reflections. As the line of sight direction changes along the radar platform trajectory, a synthetic aperture is produced by signal processing that has the effect of broadening the antenna. In order to map the ground surface the radar beam is directed to the side of the platform trajectory.

Since radar interacts with the ground features in ways different from the optical radiation, special care has to be taken when interpreting radar images. The detection of oil spills by radar systems is based on the dampening effect oil has on the capillary surface waves. An oil slick at sea "smoothes" the water surface and thus reduces the radar backscatter to the sensor. This creates a darker signature in the image which, after automatic processing, experienced analysts can then interpret as a possible oil slick.

Many factors affect the interpretation of an image and can result as dark patch on the radar image. False positives can be due to: sea ice; turbulence generated by a ship propeller; rain; reduced wind speeds in wind shadow areas; reduced wind stress due to colder sea surface temperature and naturally occurring algae blooms,. It is therefore extremely complicated to unambiguously identify oil slicks on the sea surface by associating them only with areas of reduced radar backscatter in the satellite images.

Different types of algorithms exist for detecting oil slicks in SAR images. Operators assess the images together with supplementary supporting information to determine the likelihood of the presence of oil on the sea surface. This ancillary information is currently meteorological data such as wind, waves and currents: ocean colour information is to date not operationally used.

We will examine how Ocean Colour data and SAR imagery can be used in synergy to:

i) discriminate sea surface anthropogenic induced oil films from natural algae blooms;
ii) monitor the structure and fine-scale features of algae blooms;
iii) observe algae blooms in all weather conditions;

and will conclude by examining how images acquired from optical/NIR imaging sensors, can reveal smoothed regions such as those affected by oil pollution.

Special evening Seminar:

Remote Sensing of Inland Water

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CH-8057 Zurich, Switzerland

Introduction to European lakes

Less than 2% of Europe's surface is covered by lakes, which are usually fresh water and mostly of glacial origin. The largest lakes are found in Russia and Scandinavia (Lakes Ladoga, Onega, Vänern, Peipus), and were formed by the glacial Scandinavian ice shield and its consequent isostatic rebound. At sizes of thousands of km^2 (Ladoga: 17.700 km^2), their average depth is rather shallow (10-50 m). Prealpine lakes north (Lakes Geneva, Constance) and south (Lake Garda) of the Alps were formed by retreating glaciers, resulting in longish, comparably small (Geneva: 580 km^2), but deeper (50-150 m in average) basins. Lake Balaton finally is a rift lake with a surface area of 600 km^2 but only 3 m average depth.

The range of primary productivity in European lakes is wide, from oligotrophic (Vänern: 0-3 μg chl-a/l in summer) to hypertrophic (Pihkva: 50 μg chl-a/l in average). With growing anthropogenic pressure in the second half of the last century, eutrophication and pollution became a widespread phenomenon in most lacustrine areas. Simultaneously, water consumption and people's need for natural recreation areas increased further, and water protection actions such as sewage conditioning or regulation of fertilization had to be taken. As a result, reoligotrophication is currently leading to a significant extending of macrophyte populations in prealpine lakes due to an enhanced availability of photosynthetically active radiance.

See World Lakes Database.

Current inland water quality monitoring programs in Europe

Water chemistry monitoring of European lakes started in 1950-1960, and hydrobiological investigations followed soon after. Parameters covered are nitrogen, nitrite, ammonia, phosphorus, silicon, orthophosphate, sulfate, chloride, calcium, magnesium, phytoplankton species and biomass, chlorophyll a-c, zooplankton species and biomass, bacterioplankton, macrozoobenthos, macrophytes, transparency, alkalinity, temperature. Sampling is usually done in one pelagic site for smaller and in a couple of dispersed sites for bigger lakes, thus the monitoring data lacks a spatial resolution.

The monitoring is in most cases carried out by national environmental agencies (i.e. in Sweden) or regional authorities (i.e. in Switzerland). Where several abutters border a lake, international commissions account for a common resource management, such as IGKB (International Commission on Water Protection for Lake Constance) or CIPAIS (International Commission on Water Protection for Italo-Swiss Waters).

The integration of remote sensing methods in lake water quality monitoring programs had been addressed in European projects such as SALMON (Satellite Remote Sensing for Lake Monitoring, Finland/Italy/Sweden 1996-1999). Nevertheless, no operational service exists to date, due to a divergence between products and end user requirements on the one hand, and due to a lack of influential end-usership on the other hand.

Characteristics of optical inland water remote sensing

Investigating the same optically active substances (chl-a, TSM, CDOM), the fundamental, physical principles of inland water remote sensing are the same as for coastal zones. Until recently, standard MERIS products haven't been adequate for either area. This has changed with the regional case II algorithm and a variety of experimental algorithms which are getting closer to operationalisation. Most of these algorithms were successfully applied for both types of case II waters, and underlie the same constraints regarding previous knowledge of the specific inherent optical properties (SIOP), atmospheric correction and adjacency effects.

The spatio-temporal variation is high in both cases, but even more critical in lakes, because of their secluded position. The smaller a lake is, the shorter the duration of processes, such as the dispersion of a spring bloom. Furthermore, regions of different optical properties alter rather continuously on ocean coasts, while they are of discrete character with lakes. Altogether, only some of the largest European lakes are appropriate for investigation with common ocean color sensors (MERIS, MODIS, SeaWiFS, i.e.), whereas the variety of smaller lacustrine environments (lakes and rivers) opens manifold applications at improved spatial resolution, including single-pass airborne sensors (APEX, HyMap, CASI, ROSIS, i.e.) or upcoming space missions (Sentinel, EnMap, i.e.).

Standard water processors account for the retrieval of chl-a, TSM and often CDOM. Most of them include an own atmospheric correction module. They normally use water body specific bio-optical models to calculate LUTs, most often by HYDROLIGHT Such algorithms are HYDROPT c-WOMBAT-c, MIP and MERIS case 2 regional. They use different inversion methods, such as root mean square minimization, linear matrix, simplex and neural network, respectively. While most of these algorithms were developed for coastal water applications (and often for a specific sensor) and adapted to inland water, MIP has evolved the other way round. Therefore, MIP can be used with all sorts of sensors and offers additional modules, such as bathymetry in shallow waters and bottom coverage mapping, whereto the influence of the water body is corrected for in the same manner as with atmospheric influence.

Specific issues in inland water remote sensing are the correction of adjacency effects, the in situ measurements needed to account for the variety of SIOPs, the improvement of atmospheric correction and distribution of results among competent limnologists.

Practical Sessions

Practical Session 1 (Sept. 25th , 14:00 -17:30):

Introduction into Ocean Colour Remote Sensing of Coastal waters using MERIS and BEAM Software

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Daniel Odermatt
Remote Sensing Laboratories, Department of Geography
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CH-8057 Zurich, Switzerland

BEAM is the Basic ERS & Envisat (A)ATSR and Meris Toolbox and is a collection of executable tools and an application programming interface (API) which have been developed to facilitate the utilisation, viewing and processing of ESA MERIS, (A)ATSR and ASAR data. The purpose of the BEAM is not to duplicate existing commercial packages, but to complement them with functions dedicated to the handling of Envisat MERIS and AATSR products.

Exercises with BEAM

Introduction into BEAM Software

Basic functions of BEAM

Implementation of own procedures in BEAM

Validation of MERIS data using BEAM

Production of a chlorophyll and suspended matter map using BEAM

Practical Session 2 (Sept. 26th , 14:00 -17:30):

The UNESCO-Bilko image processing software

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National Oceanographic Centre
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The session offers hands on training in using the UNESCO-Bilko image processing software to process data from ENVISAT-MERIS and other ocean colour sensor. We will also be looking at seasonal variability in ocean colour, SST and altimetry in the Indian Ocean.
The software is free to registered users, and can be downloaded from the Bilko website at www.unesco.bilko.org by logging in and following links to the download area of the site.

The session will explore the usage of Bilko through a case study on the Benguela upwelling, information on this component of the session is as follows.

The Benguela Current System (BCS) is one of four major eastern boundary upwelling systems of the world oceans. It spans three countries on the west coast of Africa from about 14°S in Angola, through the entire coast of Namibia to about 37°S off the southern tip of Africa. It extends along the south coast of South Africa to the eastern edge of the Agulhas Bank at about 37°E.

The Agulhas Bank region south of Africa is a very important area for pelagic fish spawning from November to March (Hutchings et al. 2002). After spawning, the eggs and larvae drift northwards, until juvenile fish recruitment occurs north of St Helena Bay. Adult fish then make their way back to the Agulhas Bank to spawn in the following austral spring-summer.

This exercise explores a coastal upwelling event which took place during the summer (1-8 February) 2004, using data from two Envisat sensors - the Advanced Along Track Scanning Radiometer (AATSR), and the Medium Resolution Imaging Spectrometer (MERIS).

This lesson looks at some of the techniques currently used to study plankton productivity in coastal upwelling systems. Using the Benguela Current System as an example, the lesson demonstrates how Sea Surface Temperature (SST) data and ocean colour data may be used synergistically to provide information about upwelling events. By the end of this lesson you should be able to:

create a colour composite suitable for illustrating the bright colour signature of coccolithophore blooms and sulphur eruptions, both common in the Benguela system,

use meta-data information and Bilko formulae to convert 8-bit integer chlorophyll data to true chlorophyll concentrations apply MERIS and AATSR level 2 flags to mask areas affected by cloud

create temporal composite images from several MERIS and AATSR scenes

compare chlorophyll concentrations derived from measurements by different sensors

investigate the relationship between sea surface temperature and chlorophyll concentrations

Lesson content

Creating a colour composite of a coccolithophore bloom

Dealing with cloud in MERIS level-2 data

Using formulae to calculate chlorophyll

Creating an 8-day composite from MERIS data

Comparing MERIS and MODIS chlorophyll

Examining relationships between SST and chlorophyll

Summary and conclusions

Practical Session 3 (Sept. 27th and 28th , 14:00 -17:30):

Training on SeaDAS and IDL

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The SeaWiFS Data Analysis System (SeaDAS) is a comprehensive image analysis package for the processing, display, analysis, and quality control of ocean color data.

SeaDAS 5.1 is currently available for PC Linux (Red Hat), Macintosh OS X, Sun Solaris, and SGI IRIX platforms. The SeaDAS development team may try to port SeaDAS to other platforms in the future. The SeaDAS source code is publicly available, and if any group is interested in porting SeaDAS to another platform, the development team will be happy to give any kind of assistance possible.

The Interactive Data Language (IDL) from Research System Inc. (RSI) is used to build all the GUI and display-related programs in SeaDAS. Purchasing an IDL license is no longer required in order to run SeaDAS. Instead, users may choose to use "runtime" SeaDAS, which makes use of an IDL embedded license that is provided with the SeaDAS package. SeaDAS also includes prebuilt Hierarchical Data Format (HDF) libraries developed primarily at the National Center for Supercomputing Applications (NCSA). These are required when building certain SeaDAS programs. Vendor C and FORTRAN77 compilers are required only if you want to modify the source code and rebuild the executables.

Mini - Projects

Students will be grouped, possibly in teams of 2, and will undertake an 'informal' ocean colour project. The goal of the mini-project is to demonstrate some of the skills acquired during the Ocean Colour Course.

The topic for the project is selected together by the students and tutors. In case students have a pre-defined project idea and already have a data-set on which they want to work, they are encouraged to bring it with them.

Material for the project will be available in the form of regional and/or global satellite data from different ocean colour sensors and processing levels. Computers will be available and will be equipped with the software used during the practical sessions.

Some examples of the tasks to be conducted during the projects are the following:

- Data extraction for a specific area and/or period.
- Application of atmospheric correction algorithms.
- Evaluation of the water optical properties.
- Derivation of bio-geo-chemical products (e.g. Chlorophyll-a and Primary Production).
- Image binning in space and time.

On Friday 14/10/2005 each team/participant will give a 5 to 10 minutes informal presentation, where all group members are invited to talk, and also submit a final project summary document.

Note: The final structure of the mini-projects will be further discussed on Friday 28/09/2007 afternoon.