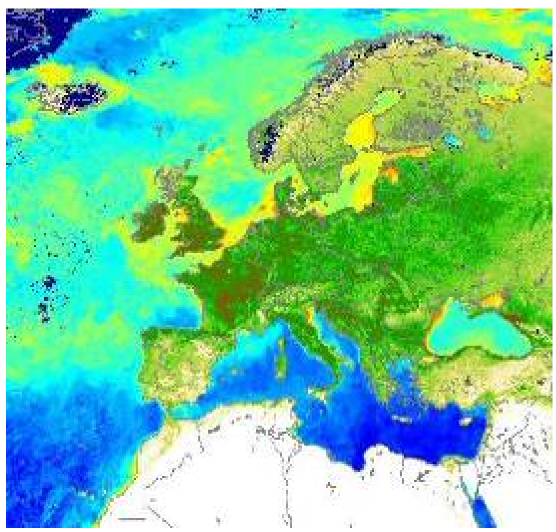
OCEAN COLOUR 2005:
METHODS AND APPLICATIONS OF OCEAN COLOUR REMOTE SENSING IN COASTAL AND REGIONAL SEAS

INLAND AND MARINE WATERS UNIT
INSTITUTE FOR ENVIRONMENT AND SUSTAINABILITY
EUROPEAN COMMISSION - JOINT RESEARCH CENTRE
ISPRA, ITALY
3-14 OCTOBER 2005

COURSE SYNOPSIS



EUROPEAN COMMISSION
DIRECTORATE-GENERAL
Joint Research Centre

ies
Institute for Environment and Sustainability

IOCCG
International
Ocean Colour
Coordinating Group

BSRP

OCEAN COLOUR 2005 COURSE

	Mon 03/10	Tue 04/10	Wed 05/10	Thu 06/10	Fri 07/10
09:00 10:30	Welcome & General Presentation (N. Hoepffner)	Water Optics I (S. Sathyendranath)	Case 1 Water Algorithm (S. Sathyendranath)	Ocean Colour Radiometry (G. Zibordi)	PP Modelling: Satellite Implementation (M. Dowell)
11:00 12:30	Oceanography Remote Sensing (F. Mélin)	Water Optics II (N. Hoepffner)	Case 2 Water Algorithm (M. Dowell)	Modelling Primary Production (T. Platt)	Ecological Indicators for the Pelagic Ocean (T. Platt)
	LUNCH	*LUNCH*	*LUNCH*	*LUNCH*	*LUNCH*
14:00 15:30	Ocean Colour Instruments (A. Neumann)	Bilko (V. Byfield)	Seadas (T. Moore)	Matlab (T. Moore)	Synergy and Integration of OC Sensors (P. Cipollini)
16:00 17:30	Atmospheric Correction (F. Mélin)	Bilko (V. Byfield)	Seadas (T. Moore)	Matlab (T. Moore)	Discussion on Topics for Mini-Project (All Invited)

	Mon 10/10	Tue 11/10	Wed 12/10	Thu 13/10	Fri 14/10
09:00 10:30	Ocean Colour and Algal Blooms (V. Barale)	Global Carbon Cycle (J.Yoder)	Specific Blooms Recognition (E. Devred)	Water Quality Monitoring (N. Hoepffner)	Mini-Projects Presentation (10 min each) Final Course Conclusions
11:00 12:30	OC and Marine Resources Management (J. Morales)	Ocean Colour and Carbon Cycle (J.Yoder)	Baltic Ecosystem (B. Mueller-Karulis/S. Kaitala)	Discussion on Regional OC (M. Dowell + All)	Course Evaluation
	LUNCH	*LUNCH*	*LUNCH*	*LUNCH*	*LUNCH*
14:00 15:30	Ocean Colour Radiometry: Lab Exc. Visit to Optical Lab (3 groups x 1/2 h.) (G. Zibordi)	Mini-Projects	Mini-Projects	Mini-Projects	
16:00 17:30	Mini-Projects	Mini-Projects	Mini-Projects	Mini-Projects Synthesis	

Monday 03/10/2005 11:00 →12:30

Oceanography Remote Sensing

Frederic Mélin
Inland and Marine Waters Unit
Institute for Environment and Sustainability
EC - Joint Research Centre
Ispra, Italia
frederic.melin@jrc.it

Remote sensing is a fundamental element in modern oceanography by its capacity of providing a synoptic view of the oceans and by the diversity of information that are delivered. This lecture provides an overview of the main remote sensing techniques used for oceanographic applications besides optical remote sensing (ocean colour) in order to give a broader view of the field. The lecture is structured as follows.

1. General principles of remote sensing, including the main radiative properties of the atmosphere and ocean
2. Infrared remote sensing
3. Passive microwave remote sensing
4. Wind Scatterometry
5. Altimetry

For each of these remote sensing techniques, the main physical principles underlying the measurement are presented, together with an introduction of their mathematical treatments, the main applications and related uncertainties are described and illustrative examples of actual use are given.

Monday 03/10/2005 14:00 →15:30

Ocean Colour Instruments

Andreas Neumann
German Aerospace Centre (DLR)
Remote Sensing Technology Institute
Berlin, Deutschland
andreas.neumann@dlr.de

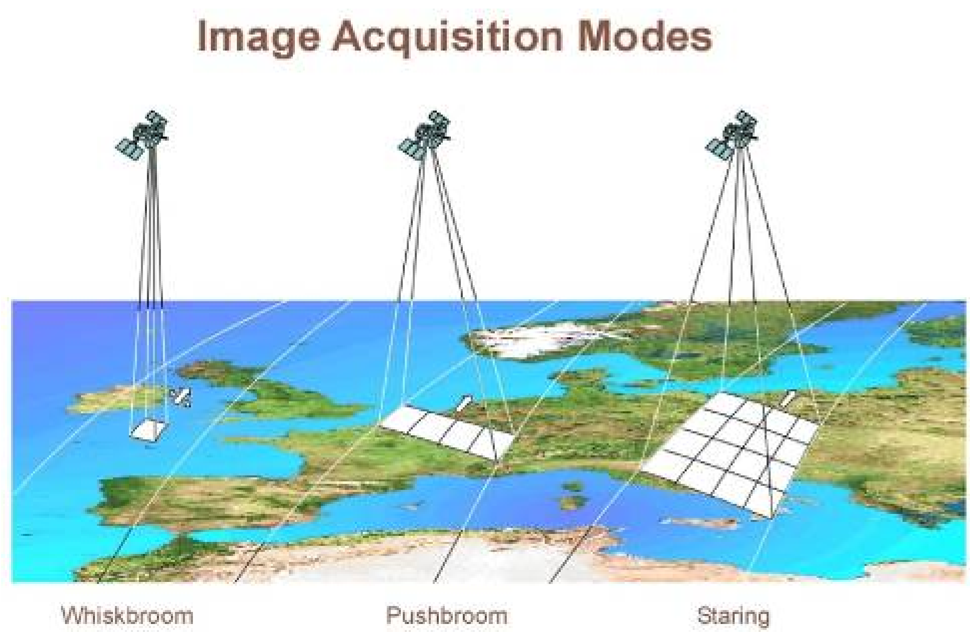
Summary

The lecture will give insight to the requirements and technical principals of spaceborne sensors dedicated to ocean colour measurements. Basic optical principals will be explained as well as sensor characterisation, calibration and main elements of on-board signal processing. Typical representatives of ocean colour instruments will be explained and an outlook to future developments will be given.

Outline

1. Introduction

This part will explain basics and background for ocean colour instruments technology and operation. Subjects like usable spectral ranges, different imaging principles for spaceborne sensors and typical remote sensing orbits will be discussed.



2. Spectro-Radiometry for Ocean Colour Applications

In this chapter technical solutions for ocean colour sensors will be discussed in more detail. Starting from scientific requirements with respect to spectral and spatial parameters different instrument concepts will be introduced and a trade-off will be made under consideration of application goals and technical effort.

3. Instrument characterisation

Here we will review the most important geometrical, radiometrical and spectral parameters that characterise an ocean colour instrument. Beside the definition of terms an overview on the laboratory procedures for the measurement and calibration of basic parameters will be given.

4. Signal and Data Processing

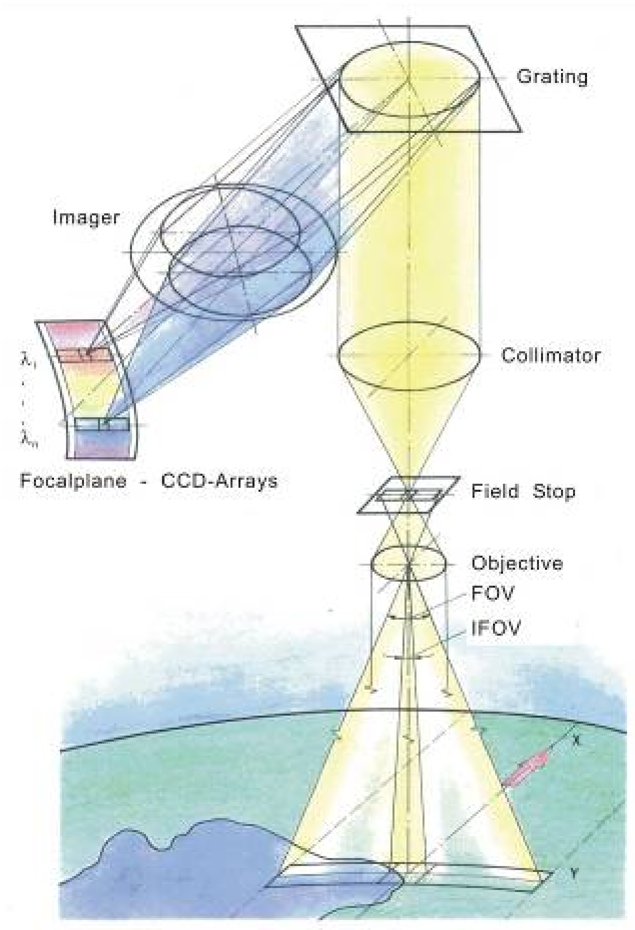
This chapter will explain the main steps of onboard signal and data handling, from the detector in the focal plane to the telemetry radio transmitter. These steps need to be accounted for during ground processing of the data from raw data to ocean colour products.

5. Typical Representatives

Concrete instrument which have been flown on satellites will be introduced to illustrate the principles under chapters 1 to 4. Typical candidates are SeaWiFS for an imaging radiometer or MOS and MERIS for imaging spectrometers.

6. Future Developments

An outlook will be given on plannings for future ocean colour instruments for operational and scientific applications.



Principle of an Imaging Spectrometer

Optical Remote Sensing: Atmospheric Correction

Frederic Mélin
Inland and Marine Waters Unit
Institute for Environment and Sustainability
EC - Joint Research Centre
Ispra, Italia
frederic.melin@jrc.it

As for all remote sensing technique aiming at providing information on the water surface, optical remote sensing needs to take into account the interactions due to the atmosphere. This is done through a process termed atmospheric correction that is described in this lecture.

1. General principles of optical remote sensing, including the main radiative properties of the atmosphere and ocean in the visible and near-infrared.

2. Mathematical expression of the problem.

3. Contributions to the total radiance

4. Aerosol characteristics and modelling.

5. Nature of the water leaving radiance.

Water Optics I: Introduction to Marine Optics

Shubha Sathyendranath
Dalhousie University
Bedford Institute of Oceanography
Dartmouth
Nova Scotia, Canada
shubha@dal.ca

Marine Optics addresses two main questions:

1. How does the spectral quality, angular distribution and magnitude of light at depth in the water column change with time and space? The main motivations for such studies are to help understand primary production and to calculate the heat budget in the oceans. In turn the results find applications in a variety of fields including marine living resources and climate change.

2. How does the spectral quality, angular distribution and magnitude of light leaving the sea surface change with abundance and community structure of phytoplankton and other material present in sea water? The main applications of such studies are in remote sensing of ocean colour.

The light field inside the ocean and the light that leaves the ocean carry coded information on the ocean biology and bio-geochemistry. Light and its interaction with pigments contained in microscopic plants, allows the ocean to support life and admit biogeochemistry, where otherwise only geochemistry would exist.

For practical purposes, oceans are often partitioned into two categories:

a) Case 1 waters, in which phytoplankton and associated, covarying material are primarily responsible for changes in all optical properties of sea water; and
b) Case 2 waters, in which phytoplankton, coloured dissolved organic matter (or yellow substances), detritus and other material in suspension vary independently of each other.

Most open ocean waters fall into Case 1 categories, and many coastal regions are Case 2 waters. By their very nature, Case 1 waters are simpler than Case 2 waters from an optical perspective, and therefore, Case 1 waters are easier to study and understand, and easier to model. It is only in recent years that scientists have begun to make progress in understanding and modelling Case 2 waters. Earlier algorithms for interpretation of ocean colour data were developed for Case 1 waters; recently, algorithms have emerged for Case 2 waters as well.

Waters can be classified into Case 1 or Case 2, according to the relative contributions of phytoplankton, yellow substances and suspended matter to the combined optical property (see Figure 1).

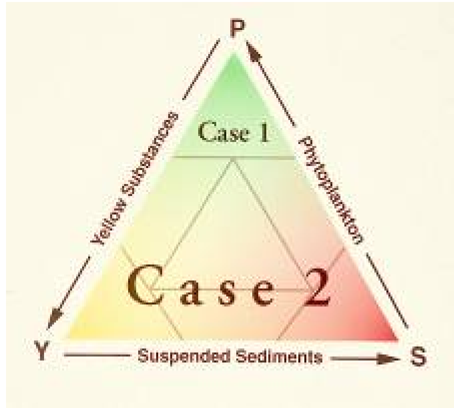


Figure 1

The sunlight reaching the outer limits of the Earth's atmosphere is modified by the intervening atmospheric gases, aerosols and clouds before reaching the sea surface. The interactions of light with the atmosphere modify its spectral quality and angular structure. For many modelling applications, it is convenient to treat the light at the sea surface as being made up of a direct component (with well-defined, collimated direction determined by the position of the sun relative to the surface of the ocean), and a diffuse component (which reaches the sea surface from a variety of directions due to scattering in the atmosphere). Both these components undergo surface reflection and refraction at the sea surface, before they are transmitted into the ocean.

The light in the sea undergoes absorption and scattering. We find absorption and scattering by the water molecules themselves, superimposed on which are the contributions to absorption and scattering from phytoplankton, yellow substances, detritus and other suspended particles. Absorption and scattering are considered inherent optical properties of the medium, in the sense that they are unaffected by changes in the quality or quantity of the incident light field. In optical models of light transmission and in remote sensing, it is also common to make use of another set of optical properties known as apparent optical properties, which are susceptible to variations due to changes in the angular structure of the light field. The main apparent optical properties of interest are the diffuse attenuation coefficient for downwelling light (important for computing light penetration underwater), and the reflectance at the sea surface (important in remote sensing algorithm development).

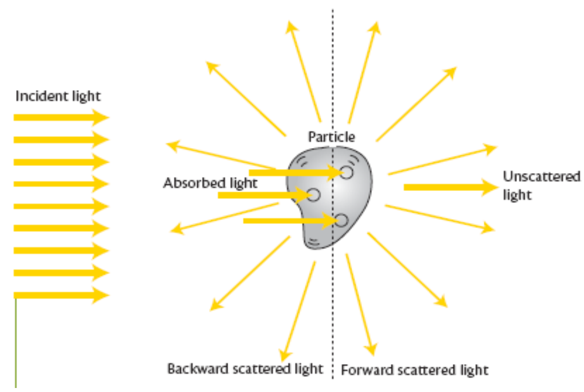
It is important to recognise that the light reaching the sea surface is spectrally structured. The absorption and scattering in water are also wavelength selective, such that the underwater light field and the light scattered out of the sea surface and back into the atmosphere change in spectral quality depending on the amount and nature of the material present in the water. These changes in spectral quality of water-leaving flux are used in remote sensing of ocean colour to infer quantitative information on material present in the water, especially the amount of phytoplankton pigments. Since light absorption by phytoplankton is also wavelength-selective, the spectral quality of light is also relevant in models of primary production underwater.

Water Optics II: Inherent Optical Properties, and Phytoplankton Pigments

Nicolas Hoepffner[1] and Venetia Stuart[2]
[1]Inland and Marine Waters Unit
Institute for Environment and Sustainability
EC - Joint Research Centre
Ispra, Italia
nicolas.hoepffner@jrc.it
[2]Dalhousie University
Bedford Institute of Oceanography
Dartmouth
Nova Scotia, Canada
Venetia.Stuart@dal.ca

Changes in the path and intensity of a light beam passing through seawater are determined by the absorption coefficient, the scattering coefficient and the volume scattering function. These properties are classified as Inherent Optical Properties (IOPs) because they do not depend on the angular structure of the incident radiations but rely, instead, only on the nature of the in-water constituents.

The lecture is an introduction to the absorption and scattering properties of natural sea water. Definitions and some general considerations are reviewed for each of the processes. Although complex, the natural variability of these properties and the factors controlling this variability have been investigated thoroughly during the last two decades because of their importance to determine the Apparent Optical Properties, including the water reflectance as seen from satellite.



Lecture Outline
1. General considerations on IOPs

2. Absorption coefficient

The reduction of light energy with water depth is mainly the result of light absorption by the water and its constituents, such phytoplankton, detrital particles, sediment, as well as dissolved organic matter. In coastal and turbid waters, all these optically-active components' are evolving independently from each other, making the bio-optical analyses of these waters more complex than in clear open ocean.

2.1 Variability of phytoplankton absorption

The phytoplankton-specific absorption coefficient, $a^*_{ph}(\lambda)$, is crucial for calculating the contribution of phytoplankton to the light attenuation in seawater, as well as for estimating the light absorbed by the algae to conduct photosynthesis. The variability in magnitude and spectral shape of $a^*_{ph}(\lambda)$ (see Fig. 1) is mainly attributed to:

2.1.1 pigment composition of the algae

The large diversity in photosynthetic and non-photosynthetic pigments and their proportions within each phytoplankton cell acts on the shape of the absorption spectra, and represents an important diagnostic marker for algal groups recognition.

2.1.2 and the package effect

The package effect results from the specific arrangement of the pigments within the chloroplasts and within the cells. Large cells with several chloroplasts may paradoxically have lower absorption efficiency than smaller cells with few chloroplasts.

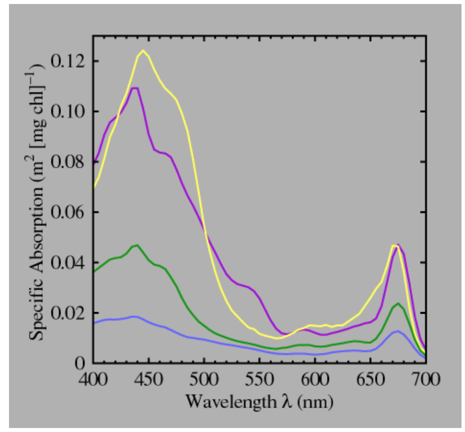


Figure 1

2.2 Absorption by non-algal particles

2.3 Absorption by dissolved organic matter

3. Scattering coefficient

Apart from absorption, light as it propagates through ocean water, interacts with particles and molecules of the medium through scattering of photons, i.e. change in the direction of the light propagation without a change in the photon frequency/energy (so-called elastic scattering').

The Volume Scattering Function (VSF) describes the angular distribution of the scattered radiant intensity (see Fig. 2). Its integration over all directions, and back direction, gives respectively:

3.1 the total scattering coefficient, $b(\lambda)$

Light scattered by particulate matter is influenced by a large diversity in size, shape, internal structure, and refractive index of living and non-living material.

3.2 the backscattering coefficient, $b_b(\lambda)$

The spectral backscattering coefficient is of primary importance to applications of optical remote sensing in oceanography. To first approximation, marine water reflectance varies as the ratio of the backscattering to absorption coefficient of seawater. As for absorption, the scattering and backscattering coefficients are showing a substantial range of variability due to the large variety of molecular and particulate matter in seawater.

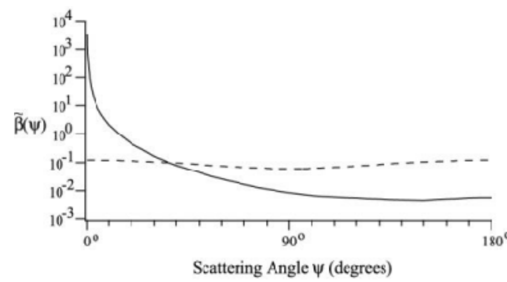


Figure 2

4. Measuring IOPs in the lab and in the field

Making direct measurements of IOPs at multiple wavelengths or covering the entire spectral range (e.g. 350-750 nm) is a very difficult task, which still drain a substantial amount of energy in research and development.

In addition to the large diversity in the structure of the optically active components in seawater, measuring techniques are confronted to the problem of too low optical density of the particles at natural concentrations.
Recent development of commercial instrumentation has been fundamental to increase our understanding on the magnitude and variability of IOPs. Concomitant measurements of absorption coefficient a(λ) and attenuation c(λ) can be done in the field at multiple wavelengths, using a profiler system (see Fig. 3)

More recently, the measurements of VSF at multiple angles (0.6º to 177.3º) have become possible using a single detector and light source. The measurement is made by varying the scattering angle between the source and detector.

As the amount of IOP data, and as confidence in the IOP determinations continue to grow, similarly bio-optical models, and their subsequent inversion scheme to retrieve biogeochemical quantities from ocean colour remote sensing are becoming more accurate. Moreover, IOPs are related to particulate and dissolved substances in water and, thus, can be used directly as optical proxies to study biological and biogeochemical processes in the oceans.

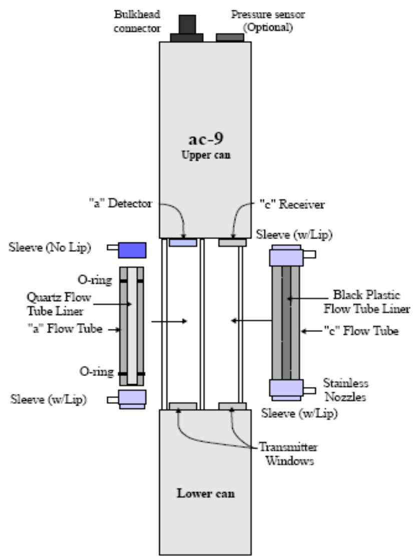


Figure 3

The UNESCO Bilko image processing software

Valborg Byfield
National Oceanographic Centre
Southampton, United Kingdom
valborg@noc.soton.ac.uk

Bilko training session

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. The session uses MERIS level 1 and 2 data from the Benguela upwelling system, and MODIS 4km global level 3 data. The practical covers the following:

1. Creating a colour composite of MERIS level 1 data from a coccolithophore bloom.
2. Creating a 3-day composite (level 3) from MERIS level 2 chlorophyll data (flags, rectification, creating the composite).
3. Comparing data from different sensors and different processing algorithms.

Platform and operating system

Bilko v 3 is designed to run on PCs running Windows 2000 and Windows XP, but will also run on Windows 95, Windows 98 and Windows NT 4.0 or later.

Software features

The latest version, currently under beta-testing, has been substantially extended and improved. The new software now features:

- Data formats supported by Bilko

Input formats

- 8-bit formats (grey-scale and paletted): GIF, PCX, BMP.
- 3 x 8-bit (true colour): BMP.
- Hierarchical data: HDF 4, NetCDF, Envisat N1 (MERIS, ASAR, AATSR, RA2.)
- Binary raster data (including byte-swapping, BSQ, BIL and BIP.)
- USGS Mapgen format.
- GeoTIFF.

Output formats

- Grey-scale or paletted: GIF, PCX, BMP.
- True colour: BMP.
- Binary flat file raster data.
- Bilko.dat - internal data format which
  - retains the geo-referencing information of the original data,
  - uses 8-bit, 16-bit or 32-bit signed/unsigned integer, or 32-bit floating point.
- Bilko.set - supports multi-band data of up to 64 channels.

Numerical data formats

- 8-bit integer.

- 16- bit integer, signed or unsigned.
- 32-bit integer, signed or unsigned.
- 32-bit floating point
- Support for NaNs and customer defined Null values. Redisplay tool for customised display of 16-bit, 32-bit and floating-point data.

- Handling of 3-D and multi-band data (up to 64 channels)

Main features

- Open bands individually or as 3-D sets (up to 64 image planes).
- Extraction of data subsets in the X, Y or Z dimensions.
- Image planes displayed as stacks (2 to 64 bands) or side by side (16 bands only).
- Apply 'Redisplay' stretches, null values and palettes individually or to all bands simultaneously
- Creation of colour composite displays.
- Animations.

Data extraction and display

- 3-D selection of points, lines or rectangles from multi-band data.
- Data-coring (spectra or time series extracted at specified points).
- Transects. (Up to 16 colours).
- Hovmoller diagrams.
- Scatter-plots.
- Multiple histograms

Other features

- Classification
- Principal Component Analysis.
- Rectification, geo-correction and re-sampling of multi-band data.
- Image calculations for up to 64 image planes.

Current limitations

- Image calculations do not support loops.
- Manual stretches must be applied to one image at a time.

- Image manipulation and display tools

Basic display tools

- Extract tool for sub-sampling in the X, Y and Z dimensions
- Zoom, Mirror, Flip and 180^{o} rotation
- Colour bar, scroll-bars and status-bar displaying pixel information

Contrast stretching

In-built stretch options:

- Gaussian with adjustable output levels and upper and lower limits.
- Logarithmic with adjustable min and max.
- Equalize with adjustable output levels.
- Autolinear with adjustable upper and lower % limits.
- Linear with adjustable min and max values.

Manual stretch applied to 8-bit display only

- Linear stretch manual adjustment at up to 10 'knees'.

- The image display changes with manipulation of stretch 'knees' allowing interactive enhancement of image features.

Other features

- Adjustable 'Redisplay' for optimal display of 16-bit, 32-bit and floating-point data.
- Stretch application based on whole image or image sub-areas.
- Option to apply / not apply stretches to output plots, images and export data.

- Application and design of colour palettes

Main features

- Application of palettes to individual images or 3-D data.
- Extracting existing palettes from paletted images.
- Copy palettes from one image to another.
- Saving palettes for use with other data.
- Creation of custom palettes.
- Adjustments to existing palettes

Easy to use palette manipulation tool

- Support for RGB and HIS colour models
- Gradient shading between defined end-colours applied across an adjustable number of palette values.
- 2-D colour space window based on Hue and Saturation with movable cursor allows end-point colour selection by eye.
- Gradient slider for adjustment of colour intensity.
- Automatic shading from one palette colour to another for adjustable number of display values.
- Context sensitive help explaining how to manipulate the palette tool

- Data processing tools

Image rectification, re-sampling, and co-registration

- Geo-correction using Ground Control Points or tie-point tables
- Automatic geo-correction of Envisat data (MERIS, ASAR, AATSR, RA-2)

Filters

Pre-defined filters:

- High-pass filters: Laplace, Roberts, Sobel
- Low-pass filters: Mean, Median.
- Variance filter
- SAR-specific filters: Lee, Frost

Custom filters:

- A small selection of edge / gradient filters as part of tutorial lessons.
- Easy to use facility for designing, applying and saving the users own filters.

Filter window:

- Adjustable window of 3 to 15 pixels.
- Independent adjustment of X and Y window dimensions.

- Image calculations using formulae with linked images

Much of the power of Bilko lies in the way in which custom-designed formula documents may be used with sets of connected images. This allows users to

- create and apply masks based on data-flags or threshold values,

- mark coastlines, country borders and regions of interest,
- transform data stored in integer format into true floating point geophysical values,
- apply their own algorithms (except those based on look-up-tables),
- create gridded composites of data from several sources or extended time periods
- carry out a number data analysis tasks that require numerical operations of one or more images.

Formula capabilities

- Operates on up to 64 connected image planes.
- Easy application by copying and pasting onto sets of connected images.
- Output either to a specified image plane or directly to a new image.
- Arithmetic, relational, logical and bitwise operators.
- Supports comments, conditional statements, brackets and constants.
- In-built functions: trigonometric, square root, natural and base10 logarithm, exponential.

Current limitations

- Loops not supported.
- No facility for combining formulae with external look-up tables.
- No in-built statistical functions.
  - Statistical calculations can be performed with user designed functions, and functions supplied with tutorials and lessons.
- No facility for calling other formulae or user-designed functions
  - Sequential application of different functions may be used as a substitute for this

Note: A number of existing formulae are available as part of lessons and tutorials. These may be modified to suit user needs. Users are also encouraged to share their own (well commented) formulae with others by submitting them to the Bilko Project office for review and dissemination.
This allows users to export data for use in other software packages such as Excel and Matlab.
Export to ASCII (text/spreadsheets) via the Windows clip-board
Context sensitive help program
Accessed from interactive menus by pointing to a menu item and pressing F1.

Downloading the Software

Bilko lessons and images are FREE and may be obtained registering on the Bilko website www.unesco.bilko.org, logging in and following links to the download area of the site.

Algorithms for Interpretation of Visible Spectral Radiometry Data for Case 1 Waters

Shubha Sathyendranath
Dalhousie University
Bedford Institute of Oceanography
Dartmouth
Nova Scotia, Canada
shubha@dal.ca

Initial algorithms for interpretation of Visible Spectral Radiometry Data were empirical in nature, and they were developed for application in Case 1 waters. These algorithms rely on the well-known phenomenon that water-leaving light, and hence reflectance at the sea surface, decrease in the blue part of the spectrum with increasing concentrations of chlorophyll in the water, such that the maximum in reflectance shifts from blue to green as phytoplankton concentration increases. The initial CZCS algorithm and the subsequent SeaWiFS algorithm rely on interpreting change in the blue signal relative to that in the green (See Fig. 1).

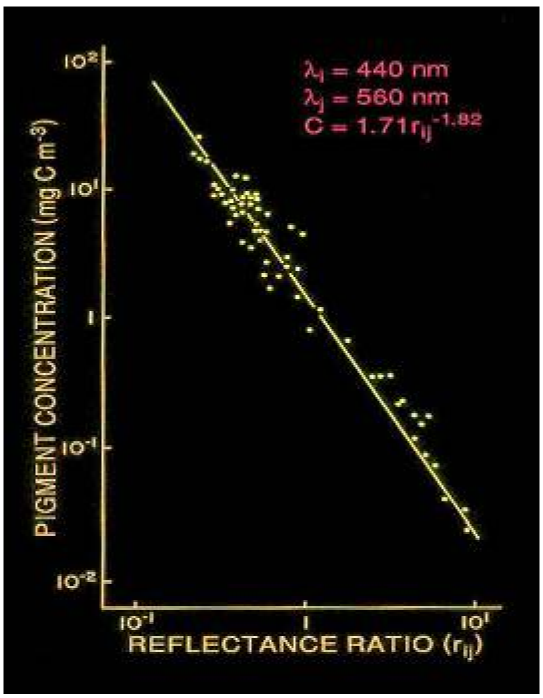


Figure 1.

These algorithms were developed by statistical analyses of variations in spectral reflectance at selected wavebands in relation to observed variations in the phytoplankton pigment concentrations.

Another approach is to base algorithms on models of ocean colour. Given our understanding of radiative transfer in the ocean, it is relatively straightforward to develop models that show how sea-surface reflectance would vary with changes in absorption and back-scattering coefficients. Once such a model is developed, the next important step in implementing it lies in the careful selection of inherent optical properties to characterise the contributions to absorption and scattering from the various constituents of sea water. This part of model development is usually referred to as the forward problem in remote sensing. The inverse problem is to use such models to infer inherent optical properties, given sea surface reflectance (see Fig. 2).

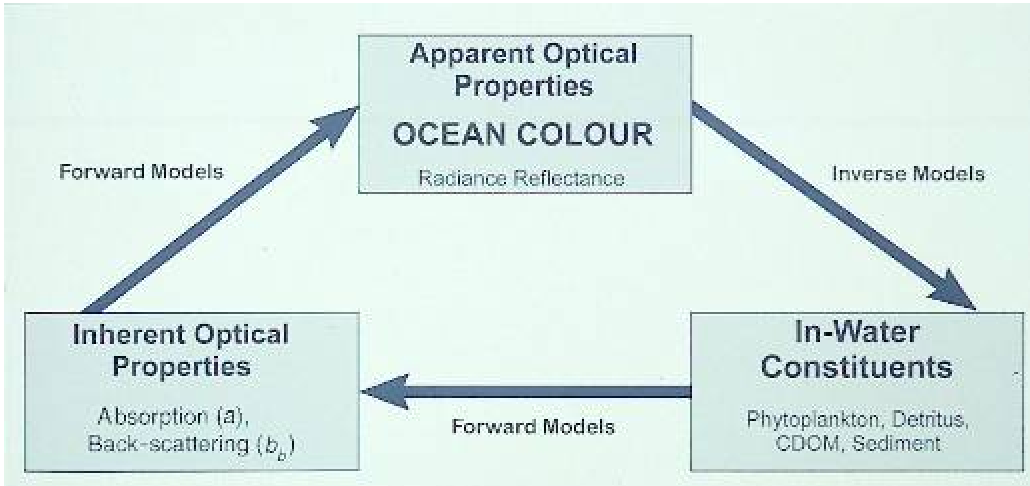
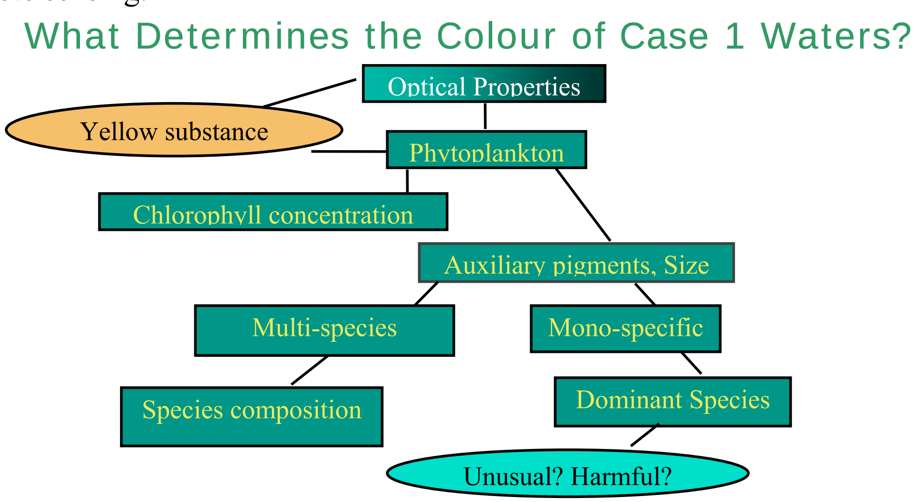


Figure 2.

Clearly, development and implementation of algorithms is more straightforward in Case 1 waters, because the system is more simple from an optical perspective, and also because we know better how to characterise the inherent optical properties of substances in open-ocean waters.

One of the advantages of modelling Case 1 waters is that all first-order changes in optical properties can be modelled as a function of a single variable: chlorophyll-a. This does not imply that chlorophyll-a is the single variable responsible for all observed variations in optical properties, but that all other properties covary in some fashion with changes in chlorophyll-a.

In recent years, there have been efforts to understand variations in spectral water-leaving radiance that arise due to changes in the phytoplankton population (Fig. 3). When distinguishing optical properties are associated with certain phytoplankton groups, they offer the potential to derive information on those taxa from remote sensing.



Case 2 Water Algorithm

Mark Dowell
Inland and Marine Waters Unit
Institute for Environment and Sustainability
EC - Joint Research Centre
Ispra, Italia
mark.dowell@jrc.it

This lecture follows on from the lecture on algorithms for Case I waters in presenting currently available methods for retrieving geophysical parameters from satellite ocean colour data in optically complex coastal waters. The specific focus of this lecture will be to explore the availability of semi-analytical approaches for optical model inversion in these regions. Specifically the lecture will cover the following specific topics:

1) Variability in the "colour" of complex coastal waters.

2) Factors contributing to the variability in "colour".

3) The semi-analytical approach versus the empirical approach.

4) Reflectance model parameterization.

5) Variability and co-variance in Optically Active Constituents.

6) Inversion methods available:
    a. Non-linear optimization.
    b. Principal Component Analysis.
    c. Neural Network.
    d. Direct Inversion/ Spectral Un-mixing.
    e. Others.

7) Advantages and disadvantages of different inversion methods.

8) Statistical comparison of different methods.

JRC Lab Sessions: SeaDAS, Matlab and IDL

Timothy Moore
University of New Hampshire
Durham, USA
timothy.moore@unh.edu

I. Introduction

1. Image Levels
2. Ocean Colour Products
3. MODIS vs Seawifs
4. IDL (Seadas) vs Matlab

II. Seadas – Level processing (Session 1)

1. Level Processing
2. Product generation
3. Remapping
4. Batch mode

III. Seadas continued – other functions (Session 2)

1. Ship extraction
2. Compositing
3. Flags
4. True Colour
5. Image manipulation
6. Histograms
7. Ship track overlay
8. Band-to-band plotting
9. JPG generation

IV. IDL and Matlab (Sessions 3 & 4)

1. Reading in hdf
2. Image displaying (scaling – image and imagesc)
3. Flags and Masks
4. Indexing
5. Histograms and plotting
6. Mapping
7. Applications
    a. Bio-optical Algorithms
    b. PP Modelling

V. Resources

1. Data Acquisition
2. Important websites
3. Books
4. Other Software

Thursday 06/10/2005 09:00 →10:30

Introduction to Ocean Colour Radiometry: Principles and Applications

Giuseppe Zibordi
Inland and Marine Waters Unit
Institute for Environment and Sustainability
EC - Joint Research Centre
Ispra, Italia
giuseppe.zibordi@jrc.it

1. Radiometry
- 1.1 Radiance
- 1.2 Irradiance

2. Radiometric calibration
- 2.1 In-air absolute
  - Irradiance and radiance calibrations
- 2.2 In-water response
  - Immersion factors for irradiance and radiance sensors
- 2.3 Cosine response of vector irradiance sensors

3. In situ measurements
- 3.1 In-water radiometry
  - Profile data analysis
  - Primary quantities
- 3.2 Above-water radiometry
  - Sky radiance removal
  - Viewing angle correction
  - Primary quantities
- 3.3 Comparison of methods

4. Uncertainties
- 4.1 Sources
  - Calibration
  - Bottom effects
  - Self-shading
  - Superstructure perturbations and wave effects
- 4.2 Budgets
  - In-water radiance and above-water radiance measurements

5. Applications
- 5.1 Empirical modelling
  - Determination of Chla from remote sensing reflectance
  - Parameterization of the Q-factor from the diffuse attenuation coefficient
- 5.2 Validation of remote sensing data
  - Match-ups data analysis
  - Space sensors inter-comparisons

Modelling Primary Production

Trevor Platt
Dalhousie University
Bedford Institute of Oceanography
Dartmouth
Nova Scotia, Canada
tplatt@dal.ca

If we examined the biosphere as a thermodynamic system, we would find that it is an open, dissipative system maintained far from equilibrium by a persistent input of energy from the Sun. Of course, the Sun is able to influence conditions on the Earth directly, without the intervention of the biota, and thus provide an energy source for a wide variety of geochemical processes. But *biogeochemical* processes become possible only if the Sun's energy can be coupled in some way to the biota. On the Earth, in marine as well as terrestrial ecosystems, the organisms responsible for coupling solar energy to the biosphere are the green plants. Although there is a great diversity of plants flourishing in the planetary ecosystem, the structure they employ to intercept the solar energy is much less variable: it is the chloroplasts with associated pigment molecules. The chloroplast is therefore the physical interface by which the biosphere is connected to the Sun. It is tuned to only part of the solar spectrum, that in the interval roughly from 400 to 700 nm, known as the photosynthetically-active region (PAR).

In the ocean, the principal characteristic of the flora is that it is made up of single-celled organisms (excepting the macrophytic forms that occur in the shallow water around the ocean margins). As well as sharing with terrestrial plants a common structure for the interception of solar energy, the marine microflora (called the phytoplankton) has the same mode of nutrition as the more highly-evolved plants found on the land: photosynthesis. Because of their small individual size (and therefore their relatively high rate of metabolism), their abundance, and their ubiquitous distribution, the phytoplankton, through their photosynthetic activity (primary production), control an enormous flux of carbon at the global and annual scale, some 50 thousand million tonnes, or roughly equal to that of the land plants. The trophic economy of the sea is commensurate with that of the land.

It is not surprising, then, that there should be considerable interest in understanding what causes marine primary production to vary with region and season, and between years. Such knowledge is important for the fisheries scientist as well as for the biogeochemist, and for anybody who studies the ocean ecosystem.

One way to develop and test our understanding is through the use of mathematical analysis. A photosynthesis – light model allows the calculation of instantaneous photosynthesis at depth. The next requirement is to calculate the instantaneous production for the entire water column through integration of the photosynthesis – light equation over depth. For the case of biomass uniformly distributed with depth, analytic solutions are possible. To get the daily production of the water column, integration of the instantaneous rate over time is necessary. Analytic solutions are available for the uniform biomass case.

Primary Production Modelling: Satellite Implementation

Mark Dowell
Inland and Marine Waters Unit
Institute for Environment and Sustainability
EC - Joint Research Centre
Ispra, Italia
mark.dowell@jrc.it

We have seen in a previous lecture on primary production modelling that there exist exact representations of the light-photosynthesis models through which primary production can be estimated based on the necessary information on the incident light field, the vertical profile of chlorophyll and the physiological parameters associated with the light – photosynthesis curve. In order to extrapolate such a relationship over space and time (benefiting from the use of satellite derived parameters) certain fundamental assumptions have to be made.

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, wile 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.

Ultimately the best solution to this issue may be a combination of these approaches. Specific items presented will include:

1) Requirement for mapping primary production at synoptic scale.

2) Limitations of satellite datasets in addressing primary production.

3) Conceptual basis of different approaches.

4) Resolving the vertical profile.

5) Temperature and maximum photosynthetic rate.

6) Biogeochemical Provinces for parameter assignment.

7) Dynamic Provinces

Ecological Indicators for the Pelagic Ocean

Trevor Platt
Dalhousie University
Bedford Institute of Oceanography
Dartmouth
Nova Scotia, Canada
tplatt@dal.ca

In the general stewardship of the ocean, it is becoming increasingly accepted that procedures for management and continuing oversight should have an ecosystem basis. In other words, it is understood that management ought not to be motivated by one or a few narrow goals, for example the yield or abundance of particular exploited fish stocks. Rather, it is believed that the ecological context should be considered in some holistic way, such that, in the example just mentioned, the integrity of the ecosystem in which the exploited fish stocks are embedded will not be jeopardised, as it might be by concentrating attention on only a small part of the whole.

The mantra then is to think broadly and think ecologically. Given this point of departure, the next requirement is identify characteristics of the ecosystem that capture the need to quantify its somewhat elusive properties such as health, vigour or resilience. In particular, we need to identify or develop ecosystem metrics that, if measured in a serial manner, will enable to detect whether the ecosystem is modified in any significant way by the suite of processes we describe, collectively, as climate change. We refer to these desired metrics as ecological indicators.

What measurable properties the pelagic ecosystem have been proposed as potential ecological indicators? We might think of those based on information theory (species diversity, species richness, ...), or those based on the topology of the pelagic food web (size spectrum, ...), or those based on the flow network (ascendancy, ...). In a more restricted view, the size structure of particular populations (especially of valued, exploited populations) has been proposed, but the connection between this and the integrity of the ecosystem as a whole remains to be demonstrated.

Given that the rationale for development of ecological indicators is to detect temporal modifications in the structure and function of the ecosystem, when they occur (for example under climate change), it follows that the indicators should be computed at intervals so that possible differences may be revealed. The requirement for serial measurements raises another issue, that of cost. Many of the candidate indicators are exceedingly difficult, and costly, to measure. Hence the frequency in time at which they should be measured may be compromised by the cost involved in making the measurement.

Similarly, the issue of the spatial scale for which the indicator may be considered representative may also be compromised by the costs involved in making the measurement. If only one location is used for all the sampling, it will be a difficult problem to know the spatial extent that this station represents. And if it is indeed representative of a particular ecological province, it will be impossible to know how the resultant indicators are influenced by conditions in neighbouring provinces (the oceanographic context).

In view of the difficulties surrounding the development and application of ecological indicators as conceived at present, it is worthwhile to consider what properties an ideal indicator might have. Ideally, they should represent some well-understood and widely accepted ecosystem property that can be quantified unambiguously in standard units. They should be measurable rapidly, at low cost, and with a repeat frequency compatible with the intrinsic time scale implied in the measurement. They should be measurable in a way that preserves the spatial structure of the information acquired for the region under survey. For any region of interest, it should be possible to acquire data in surrounding regions such that their effect on the region of interest can be evaluated. That is to say, it should be possible to assess the oceanographic context of the region of interest.

These are stringent conditions indeed, and it would be impossible to meet them using ships, the conventional platform for sampling the sea. However, they are not difficult to meet using remote sensing, provided a suitable metric can be defined. Remote sensing has the potential to provide data with high spatial resolution (1km) at high repeat frequency (1day). In developing remotely-sensed imagery, all spatial structure can be preserved. At the same time, the possibility remains of taking averages, weighted or unweighted, over any spatial domain of interest. Potentially, coverage is global, so that any degree of spatial aggregation is possible: the oceanographic context can be shown for any chosen region.

Turning to the choice of a suitable indicator, or suite of indicators, we note that one of the most useful things to know about any ecosystem is the autotrophic biomass. This is precisely the deliverable from visible-range spectroradiometry of the sea (ocean colour). It is a method to produce spatial fields of autotrophic biomass in the sea, indexed as concentration of chlorophyll. Moreover, the biomass fields can be converted to fields of primary production using methods based on the first principles of plant physiology. Thus, we have two important ecosystem properties that can be surveyed at the scales of time and space required for ecological indicators at very little cost compared with the costs of conventional surveys.

A fundamental application of remotely-sensed data on ocean colour is the construction of time series. To this effect, all available (potentially daily) imagery within a chosen period (say, one week) is combined to produce an image representative of conditions during that week. The resulting image is referred to as a composite image, and the period over which it is constructed will be the temporal resolution of the time series.

The advantages of a time series are twofold. On the one hand it permits the temporal development of ecological processes to be realised and quantified: the seasonal dynamics are accessible. On the other it permits the comparison of conditions, or dynamics, between years. Of course, the extent to which the dynamics are revealed depends on the temporal resolution of the series. But for the autotrophic biomass and the primary production, as developed from ocean colour, a resolution of one week in the composite images can be achieved easily, and this is quite sufficient to elucidate the seasonal dynamics.

Access to the seasonal dynamics opens the way to other choices for ecological indicators. If we quantify the dynamics in some way, we can base further ecological indicators on the phase relationships contained therein. For example, we could choose the spring phytoplankton bloom, and in a given year characterise it with respect to its initiation, amplitude and duration. These are objectively-determined properties of the bloom that can be expressed in standard units.

Synergy and Integration of Ocean Colour and Other Sensors at Multiple Scales

Paolo Cipollini
National Oceanography Centre
Southampton, United Kingdom
cipo@noc.soton.ac.uk

Introduction and motivation of the lecture

Brief recall of principles of non-colour remote sensing:
- Infrared
- Altimetry
- SAR

Synergy along the coasts:
- Monitoring Coastal blooms and Red Tides
- Sediment dynamics
- Colour and SAR for shallow topography
- Detection and assessment of outfalls, with some examples
- Oil spills

Synergy at small- to meso-scale:
- Productivity in marginal seas; monitoring of the bio/physical conditions
- Internal waves and their effects on phytoplankton growth
- Special Case: satellite remote sensing of river plumes by colour and infrared

Synergy at basin scale:
- Ocean colour and climate change
- Planetary waves and their signature in ocean colour, altimetry and SST

Integration with in situ measurements:
- Oceanographic campaigns
- Moorings
- ARGO floats

Open questions and discussion

Ocean Colour and Algal Blooms

Vittorio Barale
Inland and Marine Waters Unit
Institute for Environment and Sustainability
EC - Joint Research Centre
Ispra, Italia
vittorio.barale@jrc.it

1. Algal blooms as seen by optical remote sensing
Optical properties of surface waters, which depend on the presence, nature and concentration of water constituents, allow the large-scale, long-term assessment of algal bloom indicators, such as the concentration of chl3orophyll-like pigments (*chl*).

2. Space and time features of the *chl* field (European Seas)
Variable space and time features appearing in the *chl* field are related to phytoplankton growth patterns. The European marginal and enclosed seas provide examples of these features, which act as tracers of coastal and marine ecological dynamics.

3. The *chl* field in the Mediterranean Sea
The Mediterranean Sea is a scale model of the world's oceans, with limited geographic dimensions, but varied climatic and environmental conditions. The main subdivisions appearing in the *chl* field are those between *western* and *eastern* regimes, further partitioned in offshore (oligotrophic) and inshore (mesotrophic to eutrophic) domains.

4. Climatologies of remote sensing data (*chl, sst* and *wnd*)
Climatological mean fields for pigments (*chl*), temperature (*sst*) and wind speed (*wnd*) describe the main ecological provinces of the basin (areas under the impact of coastal interactions, or regions of enhanced patterns, due to the prevailing winds/currents, or pelagic areas, shaped by quasi-latitudinal frontal structures and mesoscale eddies).

5. Space and time scales of the *chl, sst* and *wnd* indices
The *chl* index varies at the smallest scales, linked to coastal processes and local phenomena, while *sst* is characterized by the (larger) scale of the main dynamical features of the basin; *wnd* has typically much larger scales, driven by meteorological events. In the time domain, the main patterns develop at the seasonal scale.

6. Seasonal cycles of phytoplankton biomass
The *chl* seasonal trend follows a bimodal pattern with *maxima* in the colder season and *minima* in the warmer one. This cycle recalls that of a sub-tropical basin, where the light level is never a limiting factor, but where the nutrient level always is. Some provinces display other seasonalities, possibly due to different boundary conditions.

7. Recurring blooms & blooming anomalies
Inter-annual and seasonal variability can be assessed computing *chl* anomalies, as the difference between yearly/monthly means and the corresponding climatological means. This allows differentiating between recurring and anomalous blooms.

8. Mediterranean rivers, impact of fluvial runoff
Near-coastal areas impacted by major rivers outflows appear to be under the direct influence of permanent plumes. Minor river discharges, concentrated drainage in enclosed bays, non-point sources of coastal runoff, all have a signature on the *chl* field.

9. Atlantic Jet in the Alboran Sea
The Alboran Sea presents unique features induced by the incoming Atlantic jet, which forms permanent anti-cyclonic gyres in this sub-basin. Upwelling along the outer edge of the gyres (and along the northern shoreline) mixes deep nutrients in the upper part of the water column, thus producing the eddy-like signature observed in the *chl* field.

10. Southern Tunisian coast, a special case
The enhanced pigment signal seen in the coastal area off southern Tunisia due to direct bottom reflection in the shallow clear waters around the Island of Kerkennah, and not to runoff or algal blooms - an example of the dangers of interpreting OC data.

11. Mesoscale gyres of the Eastern Mediterranean (and Black Sea**)**
The eastern Mediterranean presents super-oligotrophic conditions during most of the year. However, vertical mixing episodes, related to the wind-induced gyre system south of Crete, contribute to the emergence, in the *chl* field, of isolated pelagic blooms.

12. Coastal runoff in the SE Mediterranean basin
Filaments extending offshore, from the coastal zone downstream of the Nile river delta, provide nutrients, from an increasing use of fertilizers, as well as the proliferation of untreated sewage outfalls, due to population growth, to the pelagic region (see recent recovery of local fisheries, after the 1960's collapse due to the Aswan High Dam).

13. Spring blooming in the NW Mediterranean basin
The Ligurian-Provençal Sea presents low *chl* values in winter (a feature of the Gulf of Lions, and Ligurian Current area, nicknamed the *blue hole*) and massive blooming in spring, owing to the northerly wind regime, and the ensuing convection processes, leading to bottom water formation. No bloom occurs in winter, as the turbulence and deep vertical mixing generated by the wind prevent algae to be stabilized in the upper, well-lit layers. The spring bloom is triggered by the relaxation of these conditions, when the wind reduces its impact, the water column – enriched in nutrients by the long period of deep convection – becomes sufficiently stable, and stratification occurs.

14. Variations in the NW Mediterranean bloom seasonal timing
Historical data show the *blue hole* occurring as early as December and then in January, February and March, only to be replaced by widespread blooming in April. In more recent data, the deep convection period starts to appear in January, and is obvious only in February, while the blooming takes place already in March (and then in April). This variation in the timing of the Ligurian-Provençal Sea spring

bloom could be related to a warming of the basin, which would imply a strengthening, and an anticipated onset, of the stratification, therefore allowing the bloom to occur earlier in the season.

15. HAB episodes in the Mediterranean Sea

Harmful Algal Blooms (HAB) are increasing in Mediterranean Sea. Various species of *Alexandrium* (*A. minutum*, *A. catenella*, *A. taylori*), the dinoflagellate *genus* which causes most HAB episodes in the basin, have been noted (primarily) in coastal areas.

16. "Hot spots" for *Alexandrium*

In the E Mediterranean, the *genus* appeared in Alexandria, in 1993. In the W Mediterranean, *Alexandrium* blooming episodes have been recurring at several sites on the Catalan coast, as well as in Sardinia and Sicily, in the late 1990's and early 2000's.

17. Comparison with *in situ* data

A comparison of *in situ* and *chl* data suggests that the recurrence of *Alexandrium* is linked to local (near-coastal) factors, and only occasionally coincidental with mesoscale features typical of open waters – implying that the forcing functions of local (harmful) algal blooms and regional blooms are different, or overlap only marginally.

Ocean Colour and Marine Resources Conservation and Management

Jesus Morales
CIFPA "Agua del Pino"
IFAPA, Junta de Andalucia
Huelva, España
jmorales@cica.es

Fisheries oceanography is a recent research field evolving in an extremely rapid way. In the last 25 years, the initial simple integration of the information of two classical areas of marine investigation like physical oceanography and fisheries sciences has been expanding to the more recent ecosystem-based approach proposed by FAO in 2002 and approved and supported by the UN World Sustainability Conference.

From a scientific point of view the components of this new ecosystem-based approach are still under discussion, however for remote sensing scientists, the most relevant aspect of the approach deals with the biological oceanography, the marine ecology and ethology of the fisheries commercial species. In this presentation, we will try to integrate some of the satellite derived information into the ecosystem-based approach for the management of marine resources.

The presentation will be divided in two main topics: i) relevant aspects of physical and biological oceanography for the life cycle of marine fisheries species; ii) potentialities and constraints of the physical principals involved in remote sensing for its application in the exploitation and conservation of marine biological resources.

Within the first section, we will search those physical or biological marine processes related to the reproduction and feeding patterns of pelagic species. Thus, the availability of feed during of the early life stages is crucial for the fish recruitment, it is a factor closely related to physical oceanography (fronts, currents, upwelling, etc.) and biological (phytoplankton and zooplankton blooms, quality of food, etc.) processes.

Several hypotheses linking those physical and biological processes will be explained and discussed from a remote sensing perspective. In the discussion we will learn the biological background needed to discriminate those physical oceanographic features important not only for fisheries applications but also for marine conservation and management of biological marine resources.

The second part of the presentation will be focused on the remote sensing techniques used in fisheries applications. An historical review of the remote sensed data will show us how the sea surface temperature (SST) has been used as indicator of many of the physical oceanographic features we were looking for. Also, how the ocean colour data has extended the knowledge on the pelagic ecosystem introducing the biological component and more realistic information about the ecology of the upper layer of the water column and not only the ocean skin information provided by the SST image data.

More recently, altimetry data has been also used in fisheries research adding a more dynamic approach to the analysis, and providing additional information about the physical oceanography of the water column within the pelagic environment. Radar data has been also used in the evaluation of the fishing effort through the monitoring of the fishing vessels carrying blue boxes for geographical location.

A synoptic comparison about advantages and disadvantages offered by each single source of information (SST, ocean colour, altimetry data) from a fisheries perspective will be used as introduction for the discussion on the realistic and not potential use, of remote sensing in fishery sciences.

Some examples of operational applications of single or assimilated remote sensed data will provide the basis to discuss and understand the current situation of this field which basically has much more extension as a free or low cost service provided by public institutions, that as a commercial market for private companies.

Finally, some new fields of research and application of ocean colour in the conservation and management of biological resources will be discussed including the evaluation of food quality for early stages of fishes from the discrimination of functional phytoplankton groups, the identification and monitoring of harmful algal blooms, the use of archived ocean colour data for marine aquaculture site selection, integrated use of assimilated satellite oceanography data for the design and management of marine protected areas (MPAs).

Introduction to Ocean Colour Radiometry: Laboratory Exercises

Giuseppe Zibordi
Inland and Marine Waters Unit
Institute for Environment and Sustainability
EC - Joint Research Centre
Ispra, Italia
giuseppe.zibordi@jrc.it

1. Absolute calibrations (*an overview, only*)

1.1 In-air irradiance calibration
- FEL lamps
- Radiometer set-up
- Measurements

1.2 In-air radiance calibration
- Spectralon plaques
- Radiometer set-up
- Measurements

1.3 In-water response for irradiance sensors (immersion factor determination)
- Instrument set-up
- Measurements (described)

1.4 In-water response for radiance sensors (immersion factor determination)
- Instrument set-up
- Measurements (described)

Global Carbon Cycle

James Yoder
Graduate School of Oceanography
University of Rhode Island
Narragansett, USA
jyoder@gso.uri.edu

1. Introduction.

Why are we interested in the global carbon cycle?

i) What is the magnitude of the CO2 increase in the atmosphere during the past 200 years in comparison to the glacial vs interglacial change?

ii) What is the relation between mean global temperatures and CO2 content of the atmosphere during the past 200,000+ years?

iii) Why is there a relation between CO2 content in the atmosphere and the Earth's temperature?

What do most of us mean we say "carbon cycle"? What are the linkages between the C cycle and other biogenic element cycles, such as nitrogen, phosphorus, iron, etc. What is the "f-ratio"?

Why is it important to distinguish between the pre-industrial ("natural") carbon cycle and the carbon cycle that has been affected by human activities and emissions ("perturbed carbon cycle").

2. Some additional definitions: sources, sinks, "unknown" sink, fluxes, transients, pools, biological pump, solubility pump and residence times.

3. Description of the basic features of the global carbon cycle (see Fig. 1).

4. Description of the basic features of the carbon cycle in the coastal ocean and open sea (Fig. 2), and description of the biological pump (Fig. 3).

5. Quantitative aspects of the ocean margin (coastal ocean) carbon cycle – "Export hypothesis" to the "Continental Shelf Pump"

6. Carbon budgets for ocean margins and links to the N cycle – past, present and future.

The Global Carbon Cycle

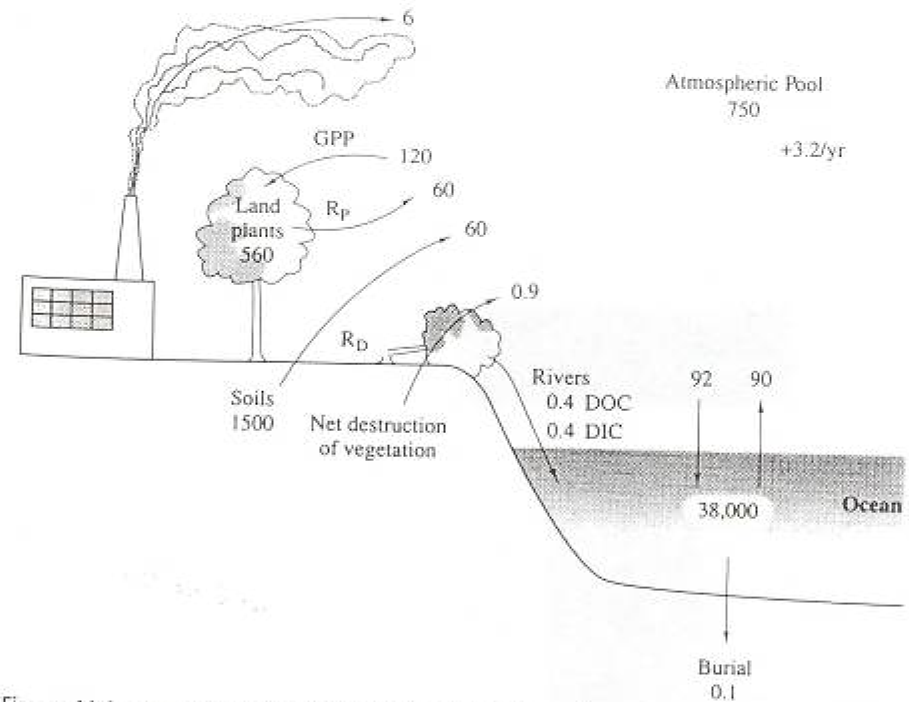


Figure 11.1 The present-day global carbon cycle. All pools are expressed in units of 10^{15} g C and all annual fluxes in units of 10^{15} g C/yr, averaged for the 1980s. Most of the values are from Schimel et al. (1995); others are derived in the text. From Schlesinger 1997

Table 11.1 Sources and Sinks of CO_2 in the Atmosphere in Units of 10^{15}g C/yr

		Net emissions	=	Net changes in the carbon cycle				
Fossil fuel emission	+	Net destruction of vegetation	=	Atmospheric increase	+	Ocean uptake	+	Unknown sink
6	+	0.9	=	3.2	+	2.0	+	1.7

Fig. 1. Schematic of the gross features of the global carbon cycle. From: Schlesinger, W.H. 1997. *Biogeochemistry. An Analysis of global change.* Academic Press, 1997. 588 pp.

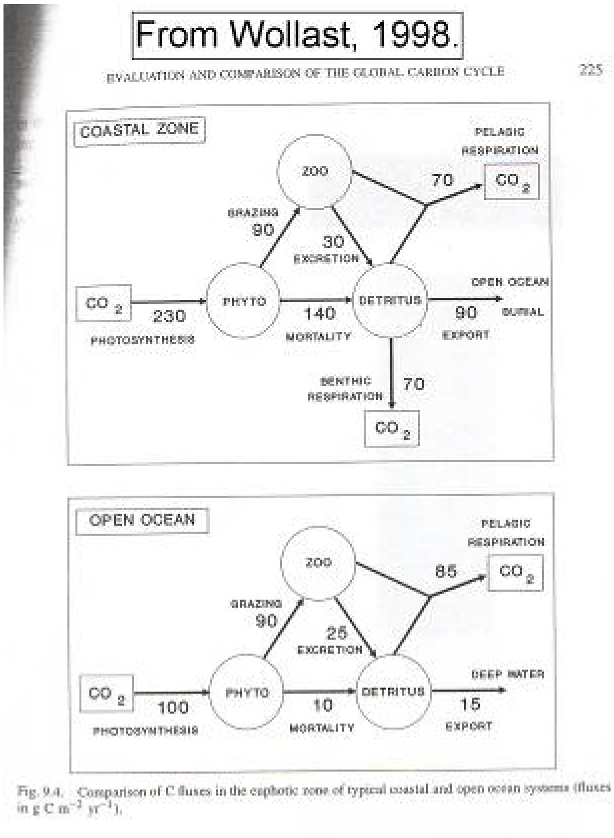


Figure 2. Schematic comparing C cycle in open ocean and coastal zone. From Wollast, R. 1998. Chapter 9. Evaluation and comparison of the global carbon cycle in the coastal zone and in the open ocean. pp 213-250, In: *The Sea*, Vol. 10 (Brink, K.H. and A.R. Robinson, eds.). Wiley & Sons, Inc.

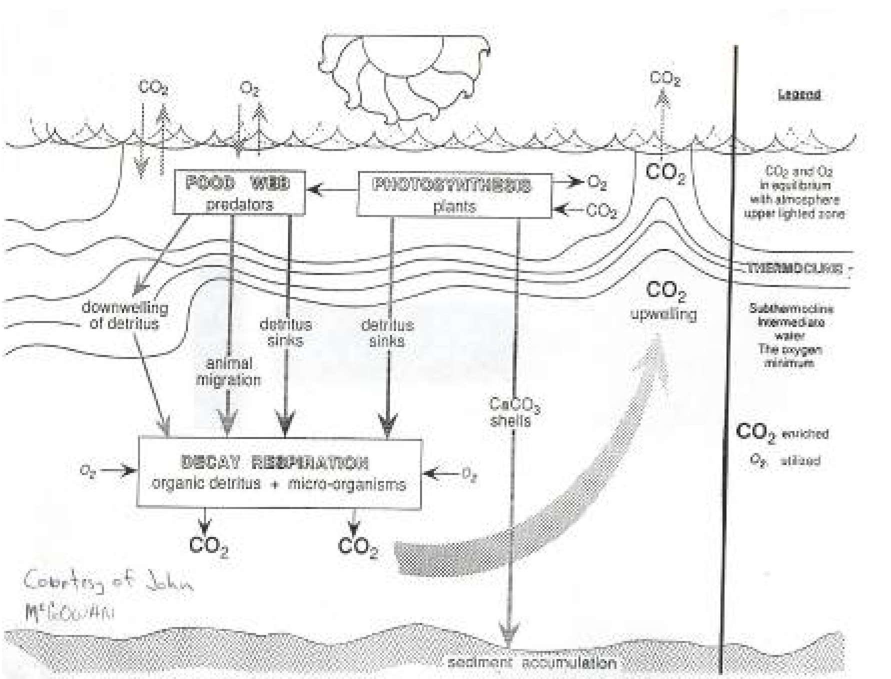


Figure 3. Schematic of the biological pump in the ocean (Courtesy of John McGowan.

Ocean Colour and the Ocean Carbon Cycle

James Yoder
Graduate School of Oceanography
University of Rhode Island
Narragansett, USA
jyoder@gso.uri.edu

I. Introduction.

Direct versus indirect contributions of ocean colour to understanding the ocean C cycle.

II. Direct contributions to understanding the biological pump in the ocean.

1. Regional and global primary production calculations: recall Platt and Dowell lectures.
2. Estimating carbon pool sizes: CDM (Fig. 1), phytoplankton carbon (Fig. 2), other.
3. Validating C-cycle models.
4. Correlation of ocean chlorophyll with C fluxes.

III. Indirect contributions of ocean colour to understanding the ocean C cycle; specifically quantifying variability of the autotrophic component of the biological pump at days to interannual time scales and 1km to ocean basin spatial scales.

1. Seasonal cycles and their variability (Fig 3).
2. ENSO and other interannual variability.
3. Mesoscale and high frequency (days to weeks) variability.

IV. Discussion with other instructors and with the students.

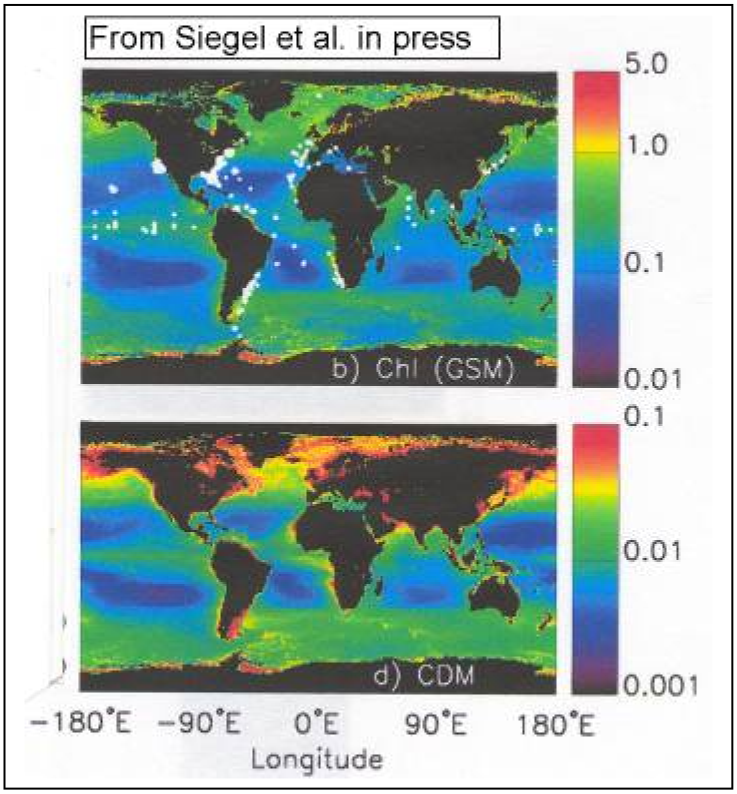


Figure 1. Global maps of chlorophyll (Chl, mg m^{-3}) and coloured detrital material (CDM, m^{-1}) from GSM inversion model.

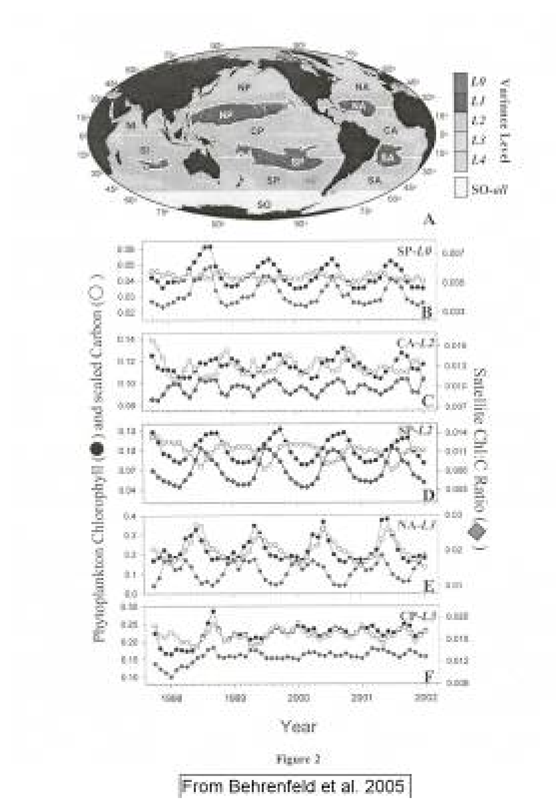


Figure 2. Chlorophyll, phytoplankton C calculated from b_b (GSM inversion model), and Chl/C ratio.

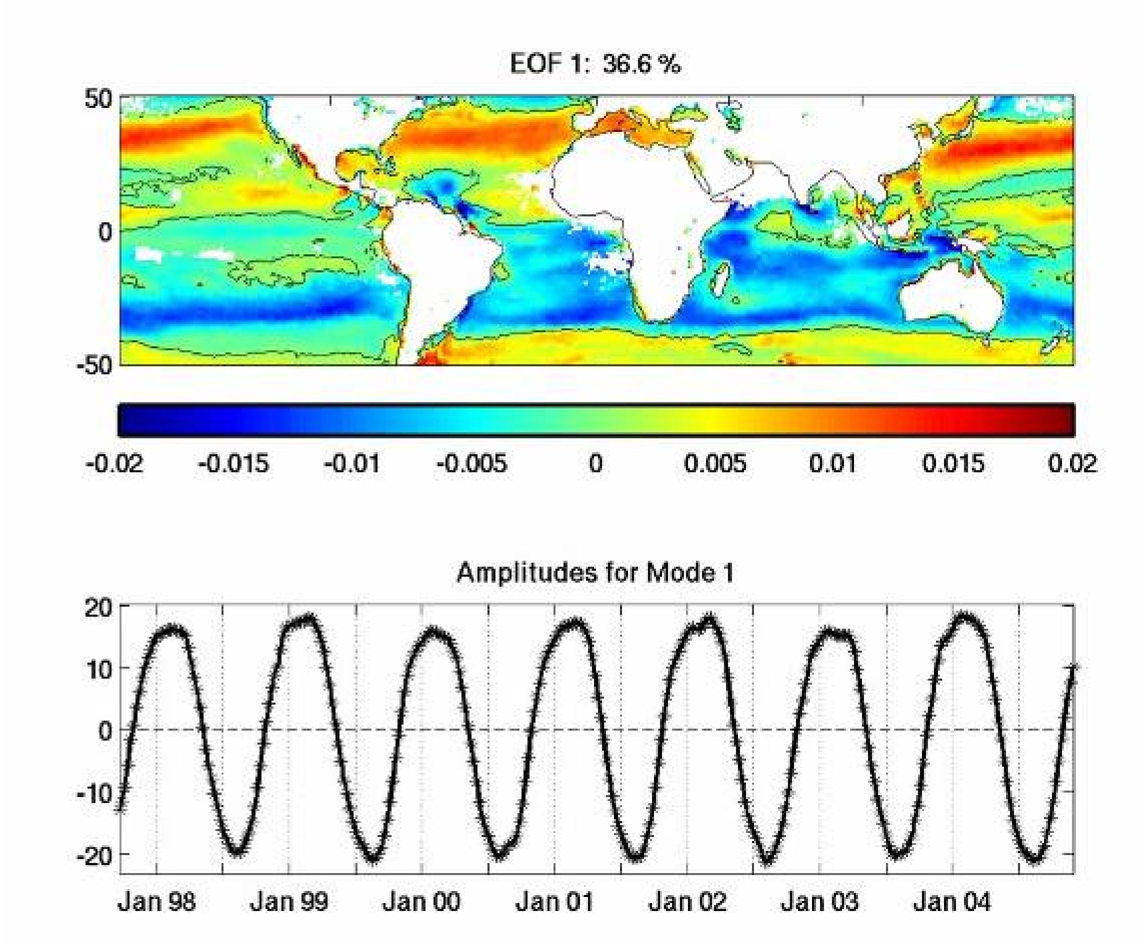


Figure 3. Mode 1 from EOF analyses of a 7-year SeaWiFS time series of 8-day global images after the 7-year mean was subtracted from each image. The signed deviation from the 7-year mean at any pixel is the product of the pixel value of the spatial pattern (upper panel) and the value at any point in the amplitude time series (lower panel). From Yoder and Kennelly 2003.

Specific Blooms Recognition

Emmanuel Devred
Dalhousie University
Bedford Institute of Oceanography
Dartmouth
Nova Scotia, Canada
devrede@mar.dfo-mpo.gc.ca

Outline
1. Introduction
2. IOPs: proxies to identify phytoplankton functional groups in blooms
   2.1 Diatoms versus other populations
   2.2 Unusually coloured phytoplankton blooms
3. A sea of algorithms
   3.1 Coccolitophore mask
   3.2 Semi analytical algorithm to identify diatoms in the North West Atlantic
   3.3 Remote sensing reflectance based algorithms
   3.4 Detection of harmful Algal bloom
   3.5 Detection in Case-2 waters, use of second derivatives.
4. Limitation of use of remote sensing in bloom detection
5. Conclusion

One of the main objectives of ocean-colour observations is to retrieve chlorophyll concentration in the ocean. Recent progress in ocean-colour sensors and algorithm performance has helped to reach the accuracy required by space agencies and other organisations. Furthermore, other applications of ocean-colour measurements, such as determination of inherent optical properties and an attempt to identify phytoplankton groups have been developed. In return, these recent advancements have resulted in an improvement to retrieve chlorophyll concentration using remotely-sensed ocean colour data.
Here, we focus on the identification of phytoplankton functional groups. The first part is dedicated to the theory behind the various algorithms that allow the recognition of phytoplankton groups. In the second part, a (non-exhaustive) number of algorithms/methods to identify specific blooms of phytoplankton are presented.

Once the atmospheric and geometric (sun position, sea surface state) perturbations have been accounted for, the water leaving radiance depends on the different components in the ocean (namely, pure seawater, phytoplankton, detritus (organic and mineral) and yellow substances) and their concentration. When phytoplankton is the dominant contributor to the optical properties of the ocean or if we assume that the effect of other components can be removed, phytoplankton can be related to water leaving radiance using its absorption and scattering properties. It is known that phytoplankton absorption is maximum between 420 and 490 nm and it increases with phytoplankton concentration due to the presence of chlorophyll-a (the main pigments). Improvement of technology (use of High Performance Liquid Chromatography, development of ocean colour sensors) allows a better understanding of the relation between phytoplankton absorption, phytoplankton-cell pigment composition and community structure. Thus, using reflectance models or in situ measurements, it is possible to relate variations in ocean colour to community structure in general, or to a particular taxa. Algorithms for phytoplankton group identification have been developed at regional or global scales. For instance, using a semi-analytical reflectance model, Sathyendranath et al. (2004) exploited the different absorption properties of phytoplankton (Figure 1) to identify diatoms using SeaWiFS data in the Northwest Atlantic (Figure 2). Similarly, Alvain et al. (In press) have developed an original method to identify four phytoplankton groups in the global ocean, this method was based on in situ HPLC measurements and associated remote sensing reflectance as observed by the SeaWiFS sensor. Operational methods have also been developed to track harmful algal blooms, a potential hazard for fisheries and tourism. NASA developed a real time observation system for the US coast that is available to professionals as well as to the public. This observation system is based on in situ sensors and real time ocean colour data.

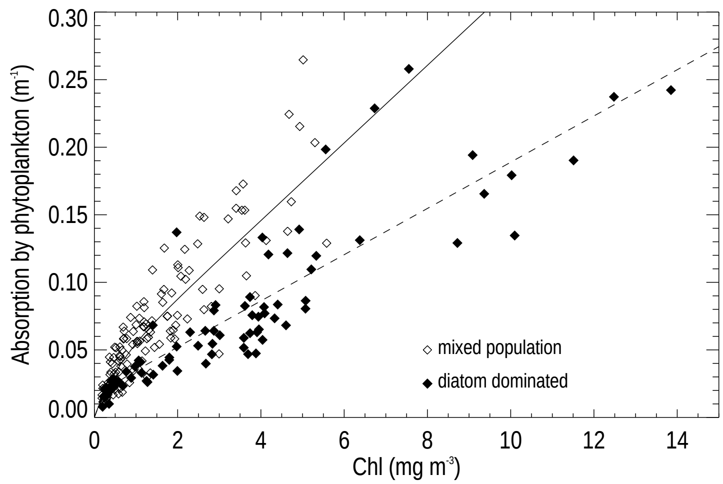


Figure 1

It is important to acknowledge the limitation of such methods. When the spectral signature of a dominant phytoplankton group does not vary significantly from other phytoplankton group, identification of this particular group during a bloom event cannot be made using satellite data alone.

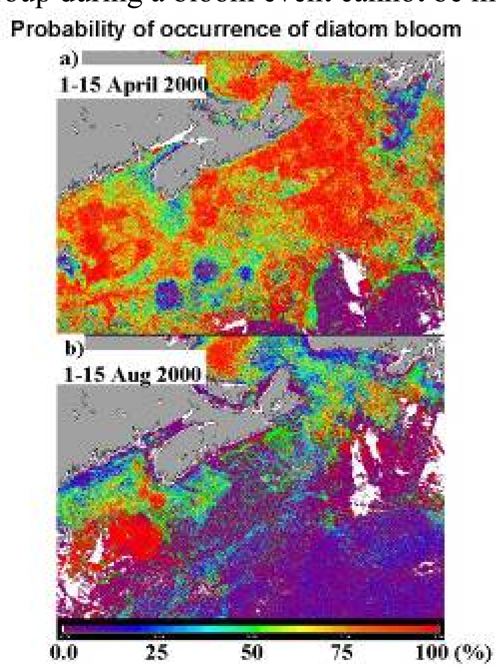


Figure 2

Wednesday 12/10/2005 11:00 →12:30

Baltic Ecosystem

Baerbel Mueller-Karulis[1] and Seppo Kaitala[2]
[1]Baltic Sea Regional Project
Institute of Aquatic Ecology
University of Latvia
Riga, Latvia
baerbel@latnet.lv
[2] Finnish Institute of Marine Research
Helsinki, Finland
seppo.kaitala@fimr.fi

Environmental threats

The Baltic Sea is one of the larges brackish water bodies on earth. Restricted water exchange with the North Sea, leading to a water residence time of about 22 years (Wulff and Stigebrandt, 1989), together with high population density in the drainage area (about 16 Mio people live along the coast and 85 Mio in the catchment area, see Fig. 1), make the Baltic Sea sensitive to anthropogenic impacts. The main threats to the Baltic ecosystem are:

- eutrophication
- overfishing
- hazardous substances
- loss of biodiversity

My presentation will focus mainly on the effects, monitoring and management of eutrophication in the Baltic Sea.

Figure 1: Baltic Sea drainage area (www.grida.no)

Baltic Sea ecosystem characteristics

The Baltic Sea is a young system, formed after the retreat of the glaciers in Northern Europe. Its development started with a freshwater ice-lake 10 000 years ago. The Danish Straits, which provide the water exchange with the North Sea, were flooded approximately 7 000 years ago, and the present salinity of the Baltic was reached only 2 – 3 000 years before present (Voipio, 1981, c.f. Elmgren and Hill, 1997).

Surface salinity in the Baltic Sea decreases along a West-East gradient, from oceanic conditions in the Skagerrak to about 15 PSU in the Kattegat, reaching finally 8 PSU in the entrance area to the Baltic Proper. The major part of the Baltic Sea, the Baltic Proper, has salinities between 6 and 8 PSU. Salinity decreases even further in the Bothnian Sea and Bothnian Bay and the Gulf of Finland.

The brackish character of the Baltic Sea is caused by the restricted water exchange with the North Sea, in combination with the positive water balance (freshwater input > evaporation). To enter the sub-basins of the Baltic Proper, North Sea water has to seep over a series of sills (Fig. 2), filling first the bottom of Arkona Sea and the Bornholm Basin, before it flows further eastward into the Eastern Gotland Sea (Hagen and Feistel, 2001). With the more dense saline water filling the bottom of the deep basin, the Baltic Proper has a vertical three-layer structure and a permanent halocline, located between 60 – 80 m depth, caps the saline bottom water. In summer, a thermocline develops at 20 – 30 m depth that separates the warmed surface water from a cold, low saline intermediate water layer (Matthäus, 1995).

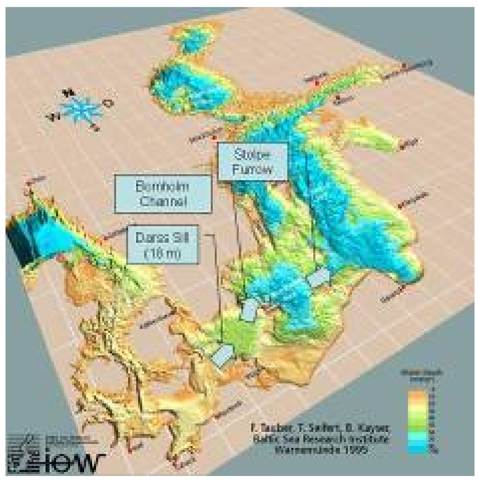


Figure 2: Baltic Sea basin structure and saline bottom water propagation

Saltwater inflow events occur intermittently (Fig. 3), under specific meteorological conditions. The intermittent nature of the inflows has important consequences for the bottom water oxygen budget in the deep basins, further affecting the biogeochemistry of nitrogen and phosphorus. Because the permanent halocline effectively cuts off the bottom water from the atmospheric oxygen supply, degradation of organic matter continually decreases bottom water oxygen concentrations, until anoxic conditions are reached. The oxygen supply is only replenished at the next inflow event (Nehring, 1995).

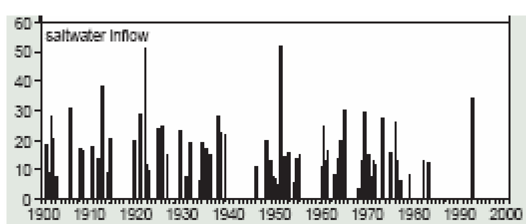


Figure 3: Salt water inflows to the Baltic Sea (HELCOM, 2003)

Bottom water anoxia is a natural phenomena in the Baltic Sea, but its frequency and duration are increased by eutrophication, which has led to a larger supply of organic matter to the sediments (see review by Elmgren, 2001). Anoxia affects not only benthic animals, but also restricts the spawning area for Baltic Cod. Baltic Cod requires salinity > 11 PSU, which is only met below the permanent halocline, and oxygen concentrations > 2 ml/l. As a consequence, while cod spawning has historically been reported from the Gotland Deep, Gdansk Deep and the Bornholm Basin, reproduction is currently only possible in the Bornholm Basin (SGCSA, 2004).

The low surface salinity and the – in an evolutionary context – young age of the Baltic Sea has important consequences for its ecosystem (see review by Elmgren and Hill, 1997). The Baltic Sea is inhabited by those marine and freshwater species, which can tolerate the salinity range of the Baltic, together with relatively few brackish water specialists. The number of marine species decreases with the salinity gradient north/eastward, while the number of freshwater species increases in opposite direction, but the resulting species diversity is generally lower than in fully marine of freshwater areas. The low species richness is most pronounced for macroscopic organisms, compared to microscopic organisms such as phytoplankton. As an ultimate consequence, the Baltic Sea also has relatively few fish species of commercial interest with a lower average value per unit of catch weight as for example the North Sea. Whether the low species richness makes the Baltic Sea more sensitive to disturbances is still debated. Elmgren and Hill (1997) suggest, that trophic interactions are only affected, if major ecological groups are completely eliminated.

Eutrophication

Eutrophication was first considered a problem in the coastal areas of the Baltic Sea and only during the 1980ies open-sea eutrophication was recognized as a major concern (Elmgren, 2001). Compared to the late 1960ies, winter concentrations of nitrogen and phosphorus in the surface layer had increased at least by a factors of 4 and 8 (Fig. 4), respectively, till the mid 1980ies and have stabilized or slightly declined afterwards (see review by Elmgren, 2001).

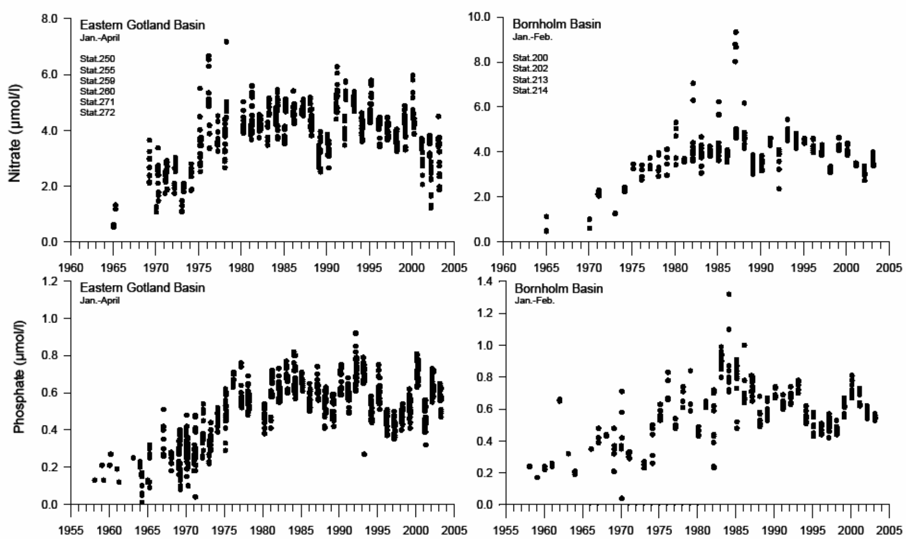


Figure 4: Time series of winter nutrient concentrations in the surface layer (0 – 10 m) of the Baltic Sea (Nausch et al., 2004)

Nutrient inputs to the Baltic Sea are now decreasing, especially with respect to point sources of nitrogen and phosphorus. Nutrient losses from agriculture have also been declining, especially in the regions affected by the economic transition after the breakdown of the Soviet Union (East Germany, Poland, and Baltic Countries). However, this has not yet translated into a reduction of the nutrient loads in rivers, because of the long residence time of nutrients in soils (HELCOM, 2003).

The Baltic Sea is believed to react only slowly to nutrient load reductions. Savchuk and Wulff (1999) suggest that the effects of 50 % nutrient load reduction every 5th year would be seen after 20 years in the Baltic Proper, while in the Gulf of Finland recovery after load reductions would be faster. This is due to the different residence time of water and nutrients in the sub-basins of the Baltic Sea. Fast recovery in coastal areas versus slow response in the Baltic Proper has also been found in a modelling study by Neumann et al. (2002). Because of the longer residence time of phosphorus, there is also growing consensus that cyanobacteria blooms, which benefit from the phosphorus pool unmatched by nitrogen, will increase, while the Baltic Sea recovers from eutrophication (Savchuk and Wulff, 1999, Neumann et al., 2002). The residence time of nutrients, which determine the time-scale of ecosystem recovery, has been estimated at 13 years for phosphorus and 5 – 6 years for nitrogen, while the water residence time is around 22 years (Wulff and Stigebrandt, 1989). Differences to the water residence time are due to geochemical processes – sediment burial of nitrogen and phosphorus, and in the case of nitrogen, denitrification.

The ecosystem effects of eutrophication in the Baltic Sea are site specific (see SGPROD, 2004). There is consensus that major effects of eutrophication are (Elmgren and Larsson, 2001, and references cited):

- Reduced water transparency, affecting submerged vegetation
- Increase of toxic or noxious algal blooms
- Increased areas of oxygen-deficient bottom waters
- Both positive and negative effects on fish stocks

A general pattern of the processes involved (Fig. 5) has been presented by Rönnberg, 2001, after Bernes (1988) and Bonsdorff et al. (1997).

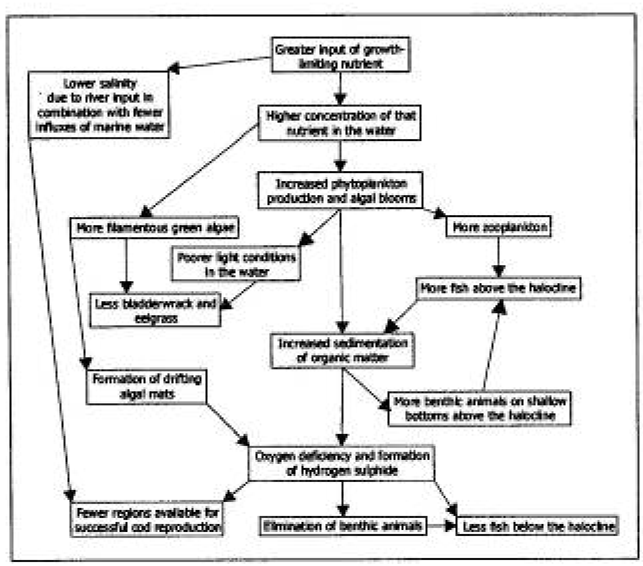


Figure 5: Biological effects of eutrophication

Marine monitoring of eutrophication and its effects

Marine monitoring of eutrophication and its effects is coordinated by HELCOM (see assessment and management). Monitoring is mainly based on ship-board measurements. Variables include hydrographic parameters (temperature, salinity, dissolved oxygen and hydrogen sulphide), nutrients (NO_3, NO_2, NH_4, SiO_4, N_{tot}, P_{tot}), and biological variables (chlorophyll *a*, phytoplankton biomass and species composition, as well as the biomass and species composition of mesozooplankton and macrozoobenthos).

The existing monitoring network is quite dense for hydrography, nutrients and chlorophyll *a*, but monitoring frequency and spatial coverage is lower for the biological parameters (Fig. 6). Buoys and moorings are used by Germany, Denmark, Sweden and Finland to increase the temporal frequency of hydrographic observations. Also three ship-of-opportunity transects provide hydrographic, nutrient and phytoplankton (chlorophyll *a*, biomass and species composition) data from the surface layer. A continuous plankton recorder transect has been started by the Finnish Institute of Marine Research.

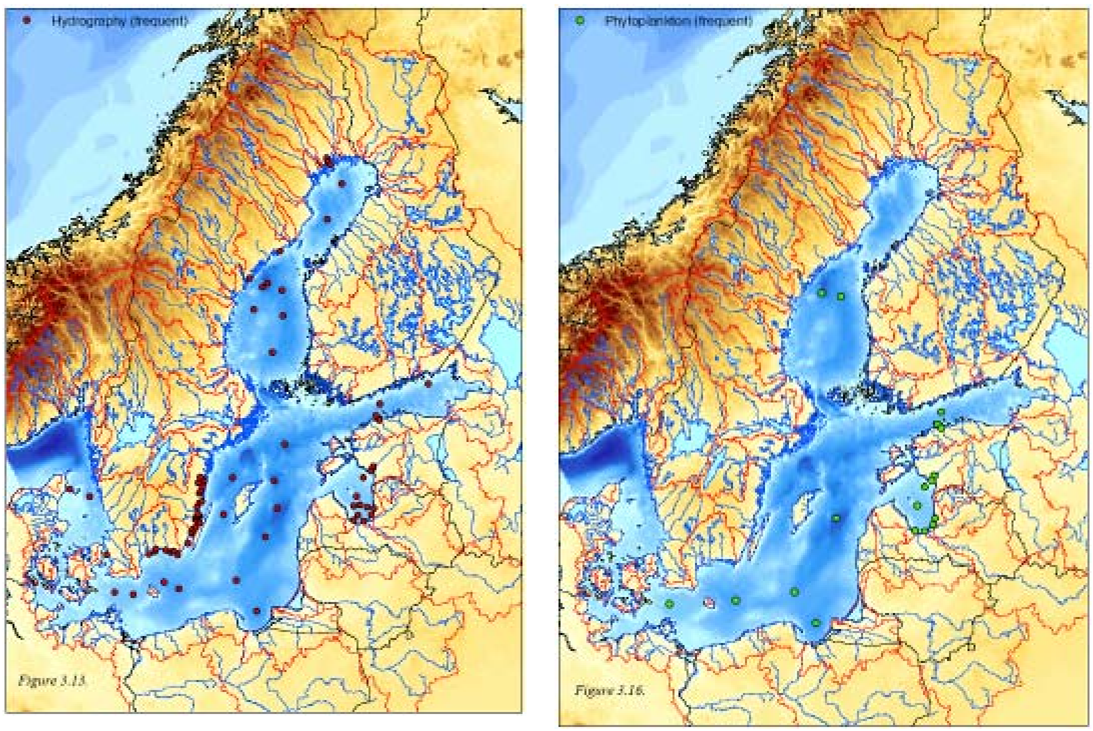


Figure 6: Ship based Baltic Sea monitoring network (Gorringe and Håkansson, 2004) for hydrography (left) and phytoplankton species composition and biomass (right)

Satellite data are mainly used by the oceanographic services in the Baltic Sea area for sea surface temperature fields and by several research and monitoring agencies for synoptic views of chlorophyll *a* concentrations. A special application is the mapping of cyanobacterial blooms (Fig. 7), which form surface scums in parts of the Baltic Proper and the Gulf of Finland in summer. Satellite monitoring of summer chlorophyll *a* has also been used to produce indicator reports on the summer algal situation in the Baltic Sea (Schrimpf et al., 2004).

Assessment and management

In 1974 the then seven Baltic coastal states signed the "Convention on the Protection of the Marine Environment of the Baltic Sea Area" – usually known as the Helsinki Convention and established the Helsinki Commission (HELCOM), which is responsible for implementing the convention. The contracting parties individually or jointly take appropriate legislative, administrative or other measures to prevent and eliminate pollution to the Baltic Sea. HELCOM – in addition to the Baltic Sea itself - covers the entire Baltic Sea catchment area, including inland waters to address pollution at its source.

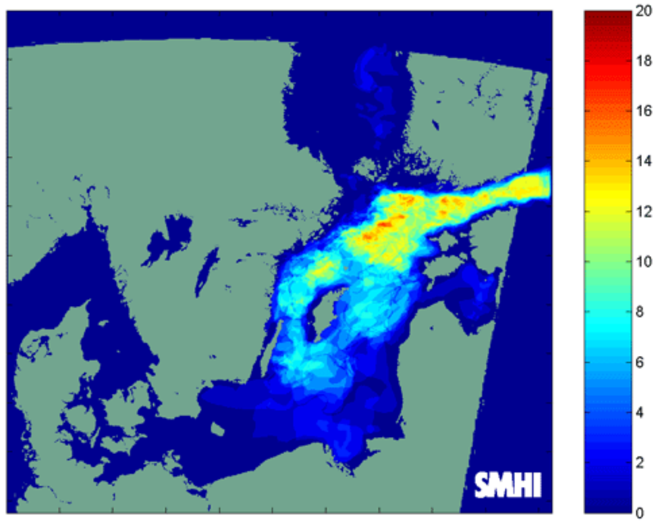


Figure 7: Number of days with cyanobacteria evident in each pixel from NOAA AVHR (Hansson, 2004)

Marine monitoring of eutrophication and hazardous substances in the Baltic Sea is the responsibilities of the contracting parties. Under the auspices of HELCOM the contracting parties have harmonized analytical methods as well as quality assurance procedures and cooperate in assessing the environmental state of the Baltic Sea.

Assessment and monitoring of commercial fish species in the Baltic Sea is organized by several ICES working groups, which produce scientific advice. Total allowable catches (TACs) for the main commercial species – cod, herring, sprat and salmon – were agreed on by the International Baltic Sea Fisheries Commission, which will now be replaced by bi-lateral negotiations between the EU and Russia.

At the end of the 1990ies, the need for more timely assessments of the Baltic Sea and advice that would be easy to comprehend by policy makers, led HELCOM to shift its assessment system to indicator and thematic reports that describe specific features of the Baltic Sea ecosystem, as for example bottom water oxygen, winter nutrient concentrations, summer chlorophyll *a*. These indicator reports are produced annually and replace the series of thematic assessments that described ecosystem changes during assessment periods of four years. Harmonization with assessment systems used in other EU waters, for example the OSPAR assessment of the North Sea and parts of the North Atlantic and the EU Water Framework Directive, led to the adoption of a system of Ecological Quality Objectives and to a first classification of the ecological state of the open waters of the Baltic Sea, currently prepared by the HELCOM EUTRO project. HELCOM and OSPAR have also jointly committed themselves to take a more integrated approach to marine management, adopting an ecosystem approach to management, defined as:

“the comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take action on influences which are critical to the health of marine ecosystems, thereby achieving sustainable use of ecosystem goods and services and maintenance of ecosystem integrity” (HELCOM/OSPAR Bremen declaration, 2003).

Currently, the Baltic Sea Regional Project, a GEF/World Bank funded programme in the Baltic Sea area, supports especially the Eastern Baltic countries Russia, Poland, Lithuania, Latvia, and Estonia, to increase their capacity in implementing the ecosystem approach. The project has so far been especially successful in bridging the gap between the “eutrophication” and “fishery” communities in Baltic Sea monitoring and management.

Future management of the Baltic Sea will significantly be influenced by EU politics. An EU Marine Strategy is in the design phase, and coastal waters are already now governed by the EU Water Framework Directive. The Water Framework Directive provides a definition of “good ecological quality” and requests the EU member states to take appropriate action if good ecological quality is not reached by 2015.

Abstract: Alg@line is a forerunner in the field of monitoring research using commercial ferries. In 1992 the Finnish Institute of Marine Research started systematic measurements on board ferry Finnjet, crossing the Baltic Sea Proper, using unattended recording and sampling system. Alg@line co-operation project uses several approaches to integrate operationally ecological and environmental information of the Baltic Sea such as chlorophyll-a and turbidity observation with flow through system and MODIS satellite monitoring of the water quality.

Alg@line has monitored and reported the phytoplankton community dynamics and the state of the Baltic Sea (www.balticseaportal.fi) for 12 years (Rantajärvi et al. 2003). Nowadays, Alg@line is a co-operation between several research institutes and shipping companies. Alg@line monitors the fluctuations in the Baltic Sea ecosystem in real-time using high-frequency automated sampling on board six merchant ships (ship of opportunity, SOOP). Alg@line participates also in the EU project FERRYBOX (2002-2005) with 10 other partners around the Europe (www.ferrybox.org).
Furthermore, three Finnish Frontier Guard vessels provide SOOP and CTD-data. Annually, 1.5 to 2 million flow-through observations (*in vivo* chlorophyll *a*, salinity and temperature), 7 000 phytoplankton species observations and 1000 nutrient observations are gathered.

The Ship of opportunity (SOOP) monitoring system on board Finnpartner ferry operating across the Baltic Proper from Helsinki to Travemünde forms the backbone for the Alg@line monitoring. The ferry sails every week from Helsinki to Travemünde and back, so the route is monitored twice a week. The *in vivo* chlorophyll-a measurements are carried out in a flow through water system with Turner Scufa fluorimeter. The seawater is taken from the piping system of the ferry. The chlorophyll-a

fluorescence is recorded with a spatial resolution of about 200 m. The data recording has the geo-reference logging from GPS.

The flow-through measurements of *in vivo* chlorophyll *a* fluorescence are validated with the *in vitro* chlorophyll *a* values obtained from the water samples. The detailed description of the unattended algal monitoring system is given in Ruokanen et al. 2003. Besides the water flow-through monitoring, the SOOP system includes an automated refrigerated sequential water sampler, which collects waters samples of 1 litre volume for supplemental analysis of inorganic nutrients, phytoplankton species composition and *in vitro* chlorophyll *a* analysis with extraction method in the laboratory. Waters samples are collected about every 30 nautical miles along the route (24 samples) from Travemünde to Helsinki once a week.

The Alg@line database is an unparalleled dataset for studies on satellite image validation in the Baltic Sea area. For further development feasibility studies have been made to sample CDOM and turbidity records. Phycocyanin is a specific pigment for filamentous cyanobacteria, and thus its fluorescence characteristics can be used to assess cyanobacterial distribution. Alg@line started to detect operationally phycocyanin and turbidity together with chlorophyll *a* fluorescence in the Baltic in the summer 2005.

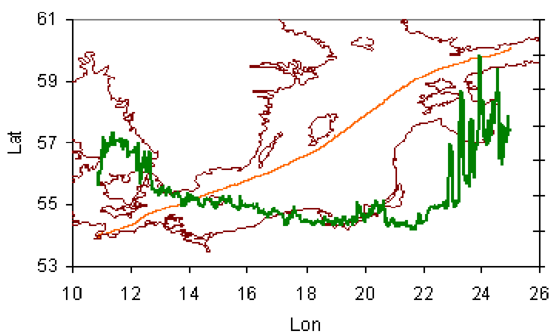


Fig 2. Concentration of chlorophyll-a in the surface layer along the route of the ferry Finnpartner from Travemünde to Helsinki on the 14th March 2005.

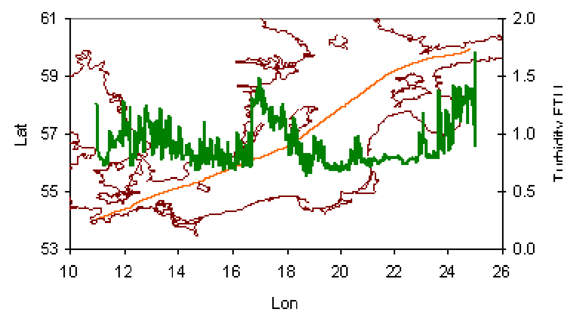


Fig 3. Turbidity (FTU) in the surface layer along the route of the ferry Finnpartner from Travemünde to Helsinki on the 26th March 2005.

Chlorophyll-a observations of have been used to develop a local algorithm for the Baltic Sea (Vepsäläinen et al. 2005) and data assimilation has been applied to improve the spatial accuracy in the regional water quality mapping (Pulliainen et al. 2004). Several attempts have been made to develop empirical algorithm to estimate chlorophyll-a distribution with optical remote sensing data. Conventionally, chlorophyll-a estimates are obtained using empirical reflectance ratios. In the case of the Baltic Sea high concentrations of coloured dissolved organic matter (CDOM) and high turbidity due to high contents of suspended matter make the predictions more difficult. Also specific structure of phytoplankton communities as blue-green algae blooms creates extra challenge for predictions. In these multi-component cases more complex hyperspectral models are needed. For that purpose in this study multivariate calibration was applied to validate Modis satellite data against automated fluorescence records of chlorophyll-a on board the ferry Finnpartner with regular route from Travemünde to Helsinki (Alg@line data).

Partial least square (PLS) regression analysis was used to validate chlorophyll-a records against 1 km resolution bands. Satellite data was received from NASA GES Distributed Active Archive Centre

(DAAC) Data Pool through Internet. For validation the Modis/Terra data on the 28 of July, 2004 at 9:50 UTC was used and the chlorophyll-a records along the route ± 3 hours the satellite recording.

The satellite data was received in HDF-EOS format. Data for each band was extracted with HDFLook-Modis (Louis Gonzalez L and Deroo C 2004) software and further analyzed together with chlorophyll-*a* data with GRASS-GIS software (Neteller and Mitasova 2004). Statistical analysis was done with PLS and PCR analysis (Martens and Naes 1989) with the R statistical software (R core team 2004). PLS analysis showed that only the bands with the wavelengths from 562 to 920 nm (i.e. b11, b12, b13L, b13H, b14L, b14H, b15, b16, b17) had contribution to chlorophyll-a variance. The R^2 reached 72 % with 6 latent variables recommended for the modelling. The chlorophyll-a distribution maps evaluated according to the model are shown for 29 August 2004.

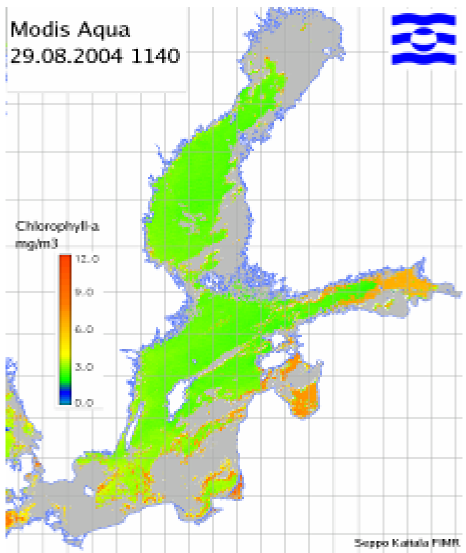


Fig X. Chlorophyll-a distribution in the Baltic Sea according to PLS prediction.

In -the case of high concentrations of coloured dissolved organic matter (CDOM) and high turbidity, e.g., in the Baltic Sea, hyperspectral models are needed for satellite data analysis. For that purpose, multivariate calibration was applied to validate Modis satellite data against automated fluorescence records of chlorophyll *a* on board the ferry Finnpartner having a regular route from Travemünde to Helsinki (Alg@line data). Partial least square (PLS) regression analysis was used to validate chlorophyll *a* records.

Sea Ice Monitoring

Most used operational satellites in the Baltic Sea ice monitoring:
DMSP SSM/I: poor resolution.
NOAA AVHRR: meteorological satellite, visual/infrared channels, large scale monitoring.
ERS SAR: cloud and daylight independent, fine scale ice monitoring, automatic classifications.
RADARSAT SAR: cloud and daylight independent, fine scale ice monitoring, automatic classifications ice drift.

Processed into resolution of 100 m, the SAR image is more accurate then AVHRR, and could be used directly in ice navigation. For instance when the cloud coverage prevents the use of AVHRR, independent SAR data can be available despite thick cloud coverage. RADARSAT SAR data needs processing before the data are in visible format, and the file sizes are large, thus it takes hours before the data are in use of users.

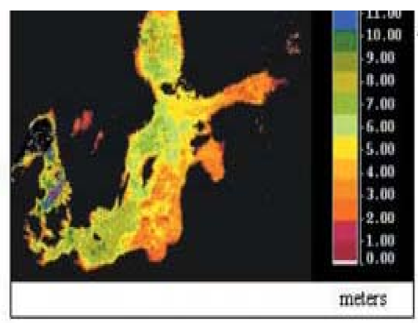
Water Quality Monitoring and Coastal Management

Nicolas Hoepffner
Inland and Marine Waters Unit
Institute for Environment and Sustainability
EC - Joint Research Centre
Ispra, Italia
nicolas.hoepffner@jrc.it

All water systems, inland surface waters, estuaries, coastal waters, are exposed to an increasing external pressure, natural or anthropogenic. These pressures are interconnected in many ways and are acting simultaneously to affect the quality of the waters with loss of habitats and biodiversity, deterioration of the ecosystems, often posing human health at risk.
To reduce, stop, or even reverse such negative trends, national Plans and international Programmes have recently emerged, addressing the urgent need to assess and monitor the present quality status of water bodies, to establish reference conditions and reference sites for inter-calibration network, to specify indicators and criteria for an ecological status classification system, and to implement appropriate measures that would sustain an improvement of the aquatic environment. Over the past decade, several studies have demonstrated the ability of satellite data to provide water quality information through the measurements of 'water colour'.

Water turbidity or water transparency

Identifying water turbidity from space can be made by examining the amount of reflectance in the visible region. The reflectance percentage over two spectral bands can be, in turn, correlated with attenuation, Secchi disk depth and total suspended matter although the relationships will vary regionally and depends on the optical properties of the water.



Secchi depth map of the Baltic Sea (July 1999) simulated from SeaWiFS attenuation coefficient (Kratzer et al. 2003)

Water-mass classification

In addition to a classical view of case 1 and Case 2 waters, sequential satellite images specifically processed to derive the absorption properties of the water can be used to identify changes in the absorption processes with time for a given area, as well as to track water masses based on specific fingerprint of the absorption components (phytoplankton, detritus, dissolved organic matter).

Particles transport and coastal erosion

The total concentration of scattering matter is estimated based on the total scattering coefficient and a scattering efficiency by arbitrary size particle averaged over a given size distribution. This provides new application for using the scattering coefficients derived from ocean colour satellites to understand the variability of the size distribution in coastal waters, to understand how river-born particles are delivered and dispersed in the ocean, to monitor changes in the size distribution of the particles with physical processes.

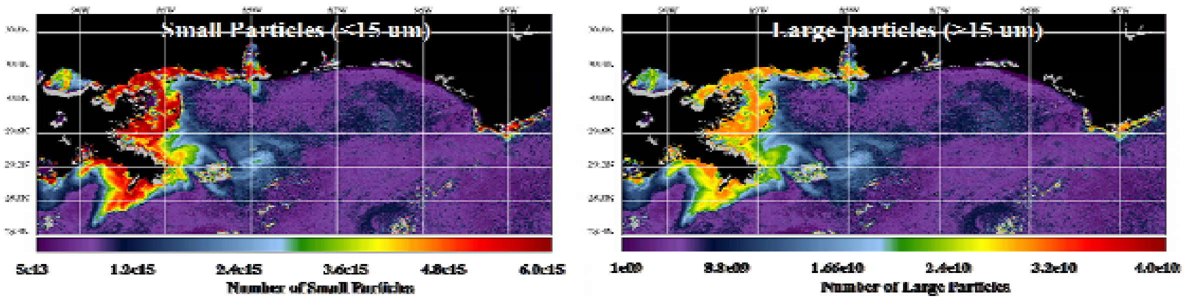
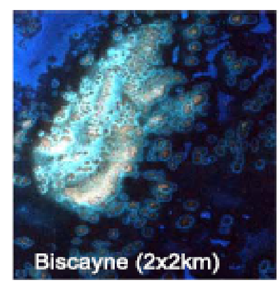


Figure: Dispersion of large and small particles from the Mississippi River. Number of particles is computed from the IOP spectral scattering coefficient for a SeaWiFS *image Haltrin and Arnone 2001)*

Eutrophication

The process of eutrophication is the ecosystem response to an excess of nutrients commonly issued from human activities through river runoff, direct inputs from urban and industrial waste treatment, and atmospheric pollution. It results as some anomalous production of organic material due to an intensification of phytoplankton photosynthesis. This, in turn, can reduce the water transparency and oxygen availability at depth, causing irreversible loss of habitats and species mortality.

Coral reefs



Satellite remote sensing in the visible spectrum has been used successfully to map the global and basin scale distribution of coral reef ecosystems, and to monitor their growth or deterioration. Specific algorithms using high pixel resolution optical sensor (Landsat TM, SPOT, and IKONOS) have developed using radiance contrast difference between coral species and brighter non coral features.

Advanced classification scheme conducted on satellite images can provide a significant distinction of coral habitats with an accuracy higher than 75%.

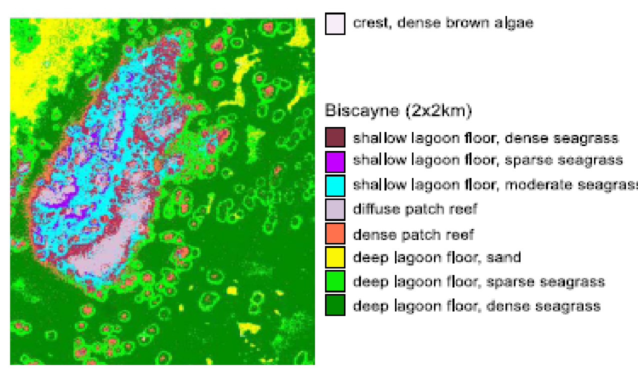


Figure: RGB colour composite based on IKONOS bands and corresponding classification of reefs and other bottom features (Andréfouet et al. 2003)

Hyperspectral remote sensing

A hyperspectral sensor provides continuous spectral coverage over the visible spectrum with better than 10 nm resolution. It opens new doors for optical oceanography and its application in monitoring the water quality in coastal and complex turbid waters.

Mini - Projects

Students will be grouped in teams of 2 or 3 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 2005 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. 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 will give a 5 to 10 minutes 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 07/10/2005 afternoon.