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On behalf of Shubha
Sathyendranath, PML

Ocean Colour Climate Change Initiative

European Space Agency

Climate Change Overview

First Stage of a 6 year programme

– First Stage divided into 3 Phases (1 year each)

– One of 11 CCI Essential Climate Variables

  – Atmospheric Group: Cloud, Ozone, Aerosol, GHG
  – Ocean Group: Sea Level, Sea Ice (TBC) SST, **Ocean Colour**
  – Land Group: Glaciers, Landcover, Fire

Scope of First Stage:

– Requirements Analysis

– Algorithm Specification

– Algorithm Development

– Essential Climate Variable Prototyping

– Essential Climate Variable Validation

Why Ocean Colour? Climate-Change Context

Identified as essential climate variable by GCOS

Amenable to remote sensing: global perspective

Targets a key property of marine ecosystem

The Green component of the Blue Planet (the only marine ECV that probes the "Living" part of the Living Planet)

Phytoplankton bloom in the North Sea off the coast of Scotland. Image captured by ESA's MERIS sensor on 7 May 2008.

Team Composition

ESA ESRIN — Peter Regner

PML Plymouth Marine Laboratory — S Sathyendranath, S Groom, T Platt, M Grant, I Allen, D Loynes

NERSC — L Bertino

HYGEOS — D Ramon, P-Y Deschamps, F Steinmetz

Brockmann Consult — C. Brockmann, O Krûger, M Peters, N Fomferra

VEGA — J Swinton

Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research — R Doerffer, H Krasemann, H Von Storch

JRC European Commission — F Mélin, M Dowell

Additional Collaborators: Italy (Lia Santoleri), USA (Watson Gregg, Zhongping Lee, Bryan Franz, Menghua Wang), Japan (Takafumi Hirata), Canada (Emmanuel Devred)

Organised into: EO Science, Climate Model and System Engineering Teams

External Interfaces: NASA, JAXA, CSA, IOCCG, ESA's CoastColour Project

Team Structure

- Peter Regner, ESA
  - Dr. Shubha Sathyendranath, Scientific Leader (PML)
    - David Loynes, Contracts Officer (PML)
    - John Swinton, Project Manager (VEGA)
    - EO Science Team
      - Steve Groom (PML)
      - Prof Trevor Platt (PML)
      - Roland Doerffer (HZG)
      - Hajo Krasemann (HZG)
      - Fred Melin (JRC)
      - Mark Dowell (JRC)
      - Zhongping Lee (Consultant)
      - Gene Feldman (NASA)
      - Bryan Franz (NASA)
      - Francois Steinmetz (HYGEOS)
      - Menghhua Wang (NOAA)
      - Pierre-Yves Deschamps (HYGEOS)
      - Carsten Brockmann (BC)
      - Olaf Krüger (BC)
      - Lia Santoleri (CNR, Italy)
      - Marco Peters (BC)
      - Takafumi Hirata (Hokkaido Uni)
      - Didier Ramon (HYGEOS)
      - Emmanuel Devred (Dalhousie Uni)
    - Climate Research Group
      - Prof Le Quere : Dynamic Green Ocean (UEA)
      - Prof Hans Von Storch (HZG)
      - Laurent Bertino (NERSC)
      - Icarus Allen (PML)
      - Takafumi Hirata (Hokkaido Uni)
      - Watson Gregg (NASA)
    - System Engineering
      - Norman Fomferra (BC)
      - John Swinton (VEGA)
      - Mike Grant (PML)

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Work Breakdown

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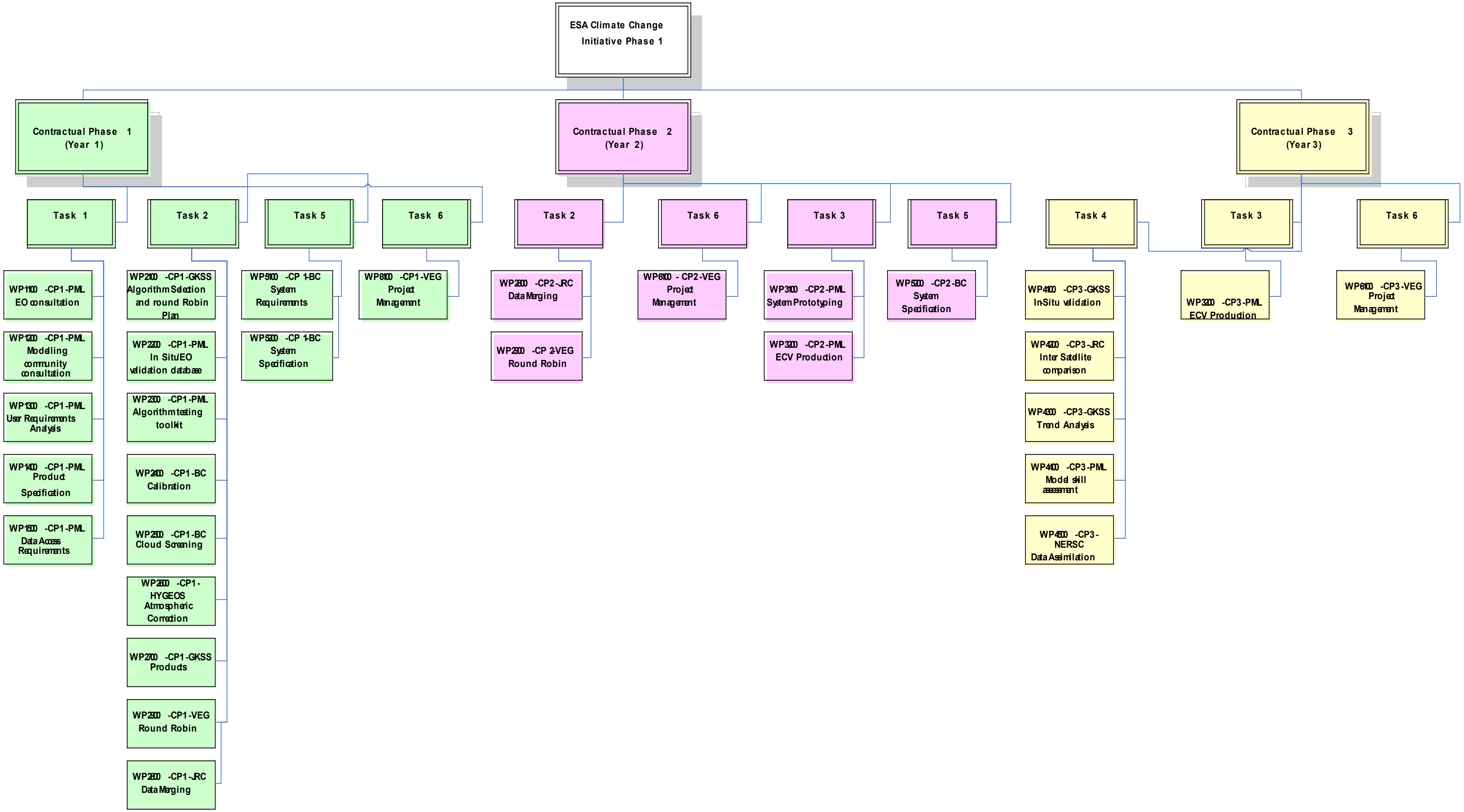

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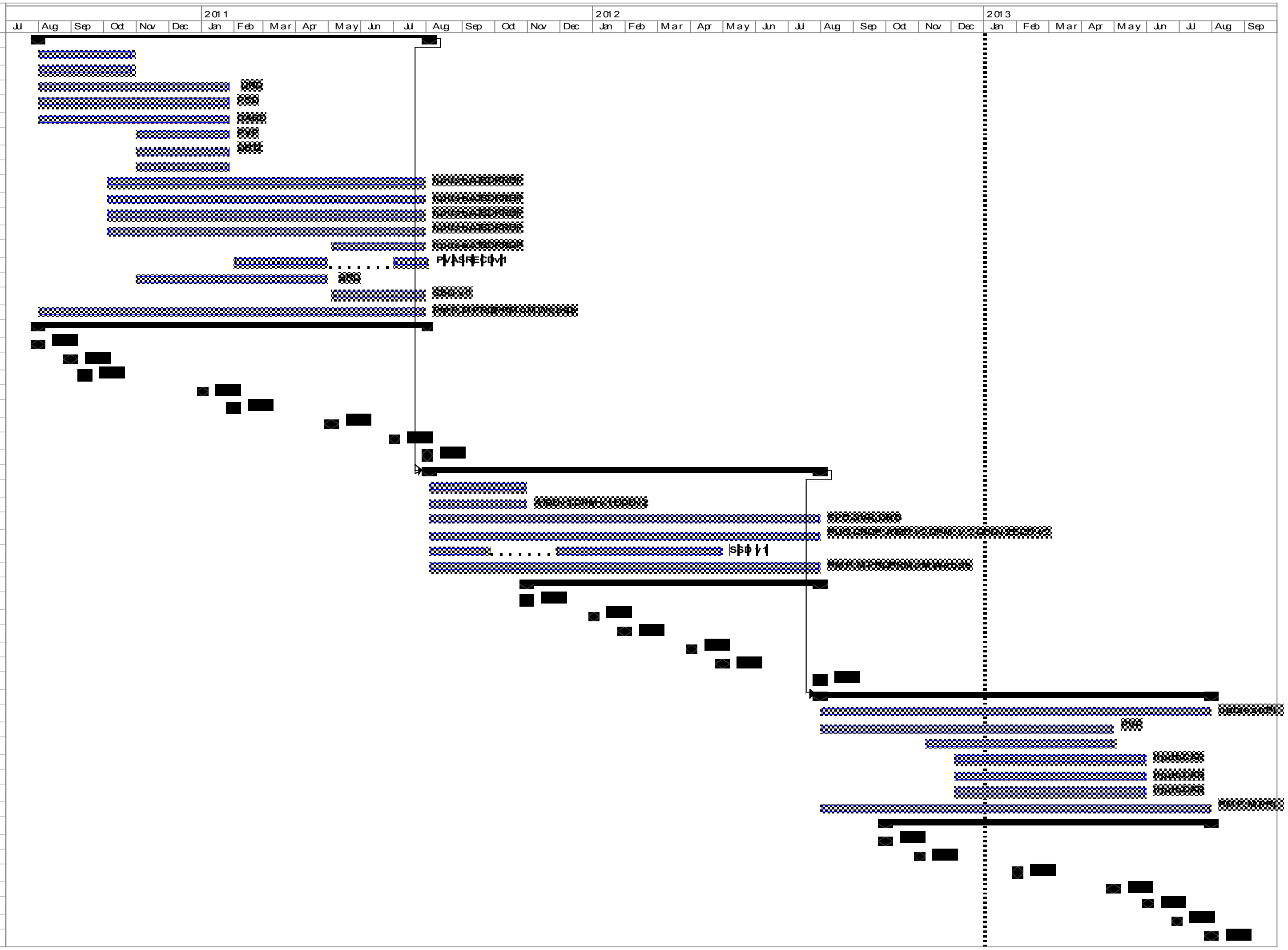
Schedule

ID	Task Name
1	Ocean Colour CCI - Phase 1
2	WP1100-CP1-PML-EO Consultation
3	WP1200-CP1-PML-Modelling community Consultation
4	WP1300-CP1-PML-Requirements Analysis
5	WP1400-CP1-PML-Product Specification
6	WP1500-CP1-PML-Data Access Requirements
7	WP2100-CP1-GKSS- Algorithm Selection and Round Robin Plan
8	WP2200-CP1-PML-In-situ/EO Validation Database
9	WP2300-CP1-PML-Algorithm Testing Toolkit
10	WP2400-CP1-BC-Calibration
11	WP2500-CP1-BC-Cloud Screening
12	WP2600-CP1-HYGEOS-Atmospheric Correction
13	WP2700-CP1-GKSS- Products
14	WP2800-CP1-JRC-Data Merging
15	WP2900-CP1-VEG-Round Robin Selection
16	WP5100-CP1-BC-System Engineering
17	WP5200-CP2-BC-System Specification
18	WP6100-CP1-VEG-Project Management
19	Meetings
20	Contractual Kick Off
21	Team Kick Off
22	Co-location 1 (Progress Meeting 1)
23	Progress Meeting 2
24	CM UG1
25	Progress Meeting 3
26	CM UG2
27	First Annual Review
28	Ocean Colour CCI - Phase 2
29	WP2800-CP2-JRC-Data Merging
30	WP2900-CP2-VEG-Round Robin Selection
31	WP3100-CP2-PML-System Prototyping
32	WP3200-CP2-PML-ECV Production
33	WP5200-CP2-BC-System Specification
34	WP6100-CP1-VEG-Project Management
35	Meetings
36	Co-location 2 (Progress Meeting 4)
37	Progress Meeting 5
38	CM UG3
39	Progress Meeting 6
40	CM UG4
41	Second Annual Review
42	Ocean Colour CCI - Phase 3
43	WP3200-CP3-PML-ECV Production
44	WP4100-CP3-GKSS- In-Situ comparison
45	WP4200-CP3-JRC-Inter Satellite comparison
46	WP4300-CP3-GKSS- Trend Analysis
47	WP4400-CP3-PML-Model Skill Assessment
48	WP4500-CP3-PML-Data Assimilation
49	WP6100-CP3-VEG-Project Management
50	Meetings
51	CM UG5
52	Co-location 3 (Progress Meeting 7)
53	Progress Meeting 8
54	Progress Meeting 9
55	Co-location 4
56	CM UG6
57	Final Review



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Major scientific and technical challenges

Need for scientific consensus on detailed ECV Product and performance specifications

The major scientific problems include:

- Satellite calibration (with particular focus on MERIS)
- Pixel classification and masking (to avoid cloud or glint affected pixels, for example)
- Atmospheric correction
- Product algorithms
- Data merging (including merging MERIS with MODIS and SeaWiFS)
- Evaluation of the NASA CZCS mission to extend the ocean colour record back three decades

To work with an under-sampled ocean: despite efforts of the community over many years, the in-situ databases for match-ups are limited in number and also in geographical distribution

GCOS requirements: a major challenge

GCOS target requirements	Current status				
	Band/product	**MERIS**	**SeaWiFS**	**MODIS**	**GlobColour** SeaWifs MODIS MERIS
Accuracy 5% **5%**	**Radiance 412 nm** **Radiance 490 nm**	**28%** **19%**	**13%** **14%**	**24%** **14%**	**21%** **12%**
Temporal resolution: daily		**3d**	**1-2d**	**1-2d**	**1-2 d**
Stability: 1% per decade	**Not specified**				

A major challenge to meet all the GCOS requirements: extremely high requirements for the quality and long term stability of the data

OC-CCI: Strong research component to quantify, and where possible, reduce errors

Implementation Approach

Balance between the need for high accuracy and precision and that for global coverage

Examine a variety of approaches

Keep downstream applications firmly in mind (to maximise user pool)

Consistency and robustness of algorithms in a changing climate

Establish the user community right from the beginning: build on their inputs; inform them of limitations in data

Demonstrate novel products along the way, to expand the range of applications for societal benefit

Ocean Colour and Ocean Models for Climate Research

Ocean-colour observations are a valuable adjunct to models of the marine ecosystem, biogeochemistry and fisheries, serving to test model outputs; providing data to initialise models; contributing to data assimilation to constrain model parameters or to improve predictions

Modelling Community:

- Corinne Lequéré – Dynamic Green Ocean Models; Input requirements
- Icarus Allen – Model skill assment, EC FP7 MEECE
- Laurent Bertino – Data Assimilation; Input requirements; Arctic
- Watson Gregg – General Circulation model, Data Assimilation
- Hans von Storch – Time Series, Trend Analysis
- Takafumi Hirata – Global and North Pacific Modelling

Links to Earth Observation Community

- IOCCG
  - Report on OC-CCI at IOCCG Annual Meeting in Plymouth (Feb 2011)
  - Prepare news item on OC-CCI for IOCCG Newsletter
  - Propose an IOCCG Report on Ocean Colour and Climate Change (?)
- ESA EO Community
  - Presentation at ESA Living Planet Symposium
  - Participation in ESA Carbon from Space Workshop
  - CCI co-location meeting
- ChloroGIN and SAFARI networks
  - Use websites of networks to inform community of OC-CCI activities
- EAMNET (Europe – Africa Marine NETwork)
  - Use website and/or newsletter

Status of data assimilation in Europe

- State estimation in 3D assimilating real OC data
  - Carmillet et al. 2001: HYCOM-NPZD, SEEK filter
  - Natvik and Evensen 2003: MICOM-NPZD, EnKF
  - C. Fontana (LEGI, Grenoble), presentation at EGU 2011
    - 9 years of assimilation with NEMO-LOBSTER (N. Atlantic)
    - Dynamic SEEK filter, with Gaussian anamorphosis

- Joint state-parameter estimation (twin experiments)
  - Loza et al. 2003: 0-D model and SIR filter
  - Loza et al. 2004: 1-D model and 4D-var
  - Simon and Bertino (in press):
    - 1-D model and EnKF with Gaussian anamorphosis.

Status and plans in the MyOcean project

- Med MFC (INGV)
  - Real-time assimilation of OC data from CNR is operational
  - 3D Var approach used
  - Some problems with multivariate updates
- North-West Shelf MFC (UK Metoffice)
  - Real-time forecast in free run
  - Reanalysis planned for 2012.
- Global MFC (Mercator Océan)
  - Real-time forecasts planned for 2012
  - Reanalysis is planned for 2012
- Arctic MFC (NERSC)
  - Real-time forecasts planned for 2012 (in free-run)
  - Reanalysis is planned for 2012 (assimilation with EnKF)
- Baltic MFC (DMI)
  - Real-time forecasts planned for 2012
  - Reanalysis planned for 2012 (both in free run).

Anticipated Achievements

Quantification of uncertainties with details of the processing chain:

- different sensors
- calibration of sensor
- atmospheric correction and cloud detection
- retrieval of IOPs and concentrations of water constituents
- vertical distribution

Quantification of these uncertainties for different regions / provinces

Quantification of the relationship between uncertainties and changes in water properties/ trends for different provinces

Analysis of annual cycles and seasonal variability for different regions compared with expected and observed decadal trends

Quantify the effect of quality filters with respect to reduction in number of data, possible bias and data quality for the time series, e.g. by comparing trends derived from time series of the same area but with different quality filters regarding clouds coverage, aerosol concentration etc.

Ocean Ecosystem as Thermodynamic System

The pelagic ecosystem is an open, dissipative system sustained by regular energy supply from sun, to which it is coupled through the pigment molecules contained in phytoplankton. The light penetrating into the ocean allows biogeochemistry, where otherwise only geochemistry would be possible.

Furthermore, the light that escapes from the ocean (the basis of the ocean-colour signal), carries coded information on ocean biology and biogeochemistry.

Emil Nolde

Some properties of phytoplankton

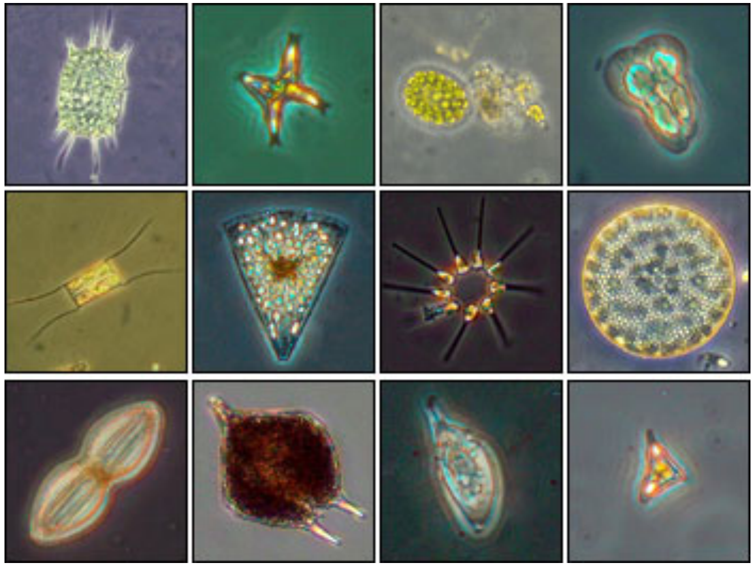
Predominantly single-celled and microscopic (0.5 to 250µm)
Green plants (chlorophyll pigments, photosynthesis)

Mostly confined to the surface (illuminated) layer

Ubiquitous and abundant (up to 10^5 cells ml^{-1})

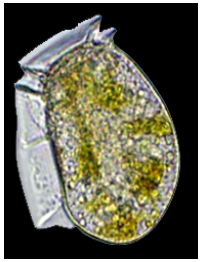
Control colour of water (detectable from space)

Consume carbon dioxide
(ocean carbon cycle, climate change



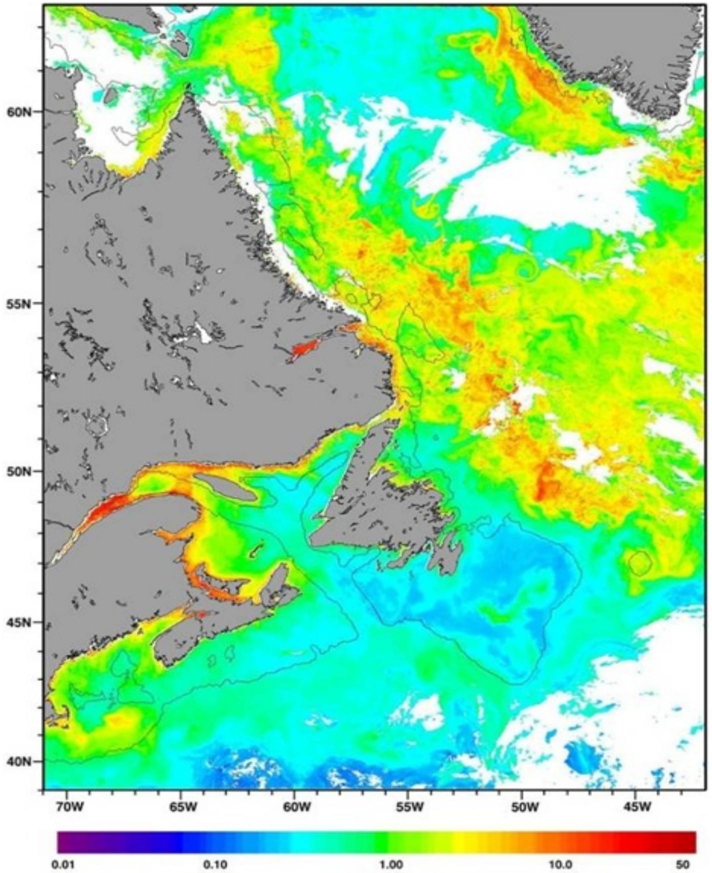
Collective metabolism enormous

(50×10^9 tonnes per annum)



Slightly negatively buoyant

Chlorophyll maps from Ocean Colour



Chlorophyll-a (mg m^{-3})

SeaWiFS composite image
1-15 June 1998

A major product of ocean-colour remote sensing is distribution of chlorophyll concentration, the most fundamental property of the ocean ecosystem.

The maps are strikingly beautiful, but that ought not to conceal their basis in strict radiative transfer theory. They contain a wealth of information, with many present and potential applications.

The technique exploits the absorption of light by the pigment. It probes the interface between the physical forcing field (light) and the biological building blocks (phytoplankton pigments).

What happens to the absorbed light?

Principal Fate of Light Absorbed by Phytoplankton

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Thermal dissipation is the principal fate of energy absorbed by pigments, with a corresponding effect on the heat budget of ocean's upper layer

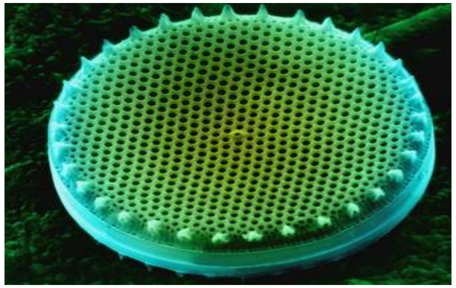
Dual Role for Light Absorbed by Phytoplankton

Photosynthesis

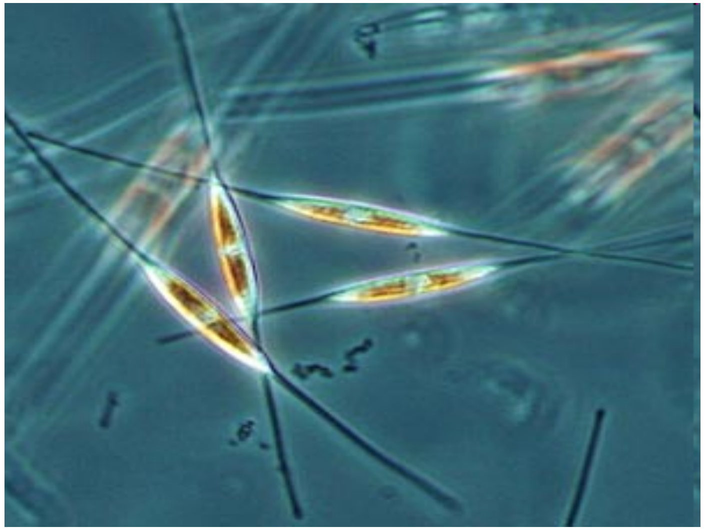
Heating of photic layer

Light absorbed by phytoplankton influences upper ocean dynamics, introduces feed-back mechanisms between biological and physical processes. Central to understanding Earth as an interconnected system in climate-change context.

What is the Relevance of Ocean Colour?



- Physical oceanography
- Biogeochemistry (carbon cycle, functional types)
- Ecosystem indicators
- Marine resources

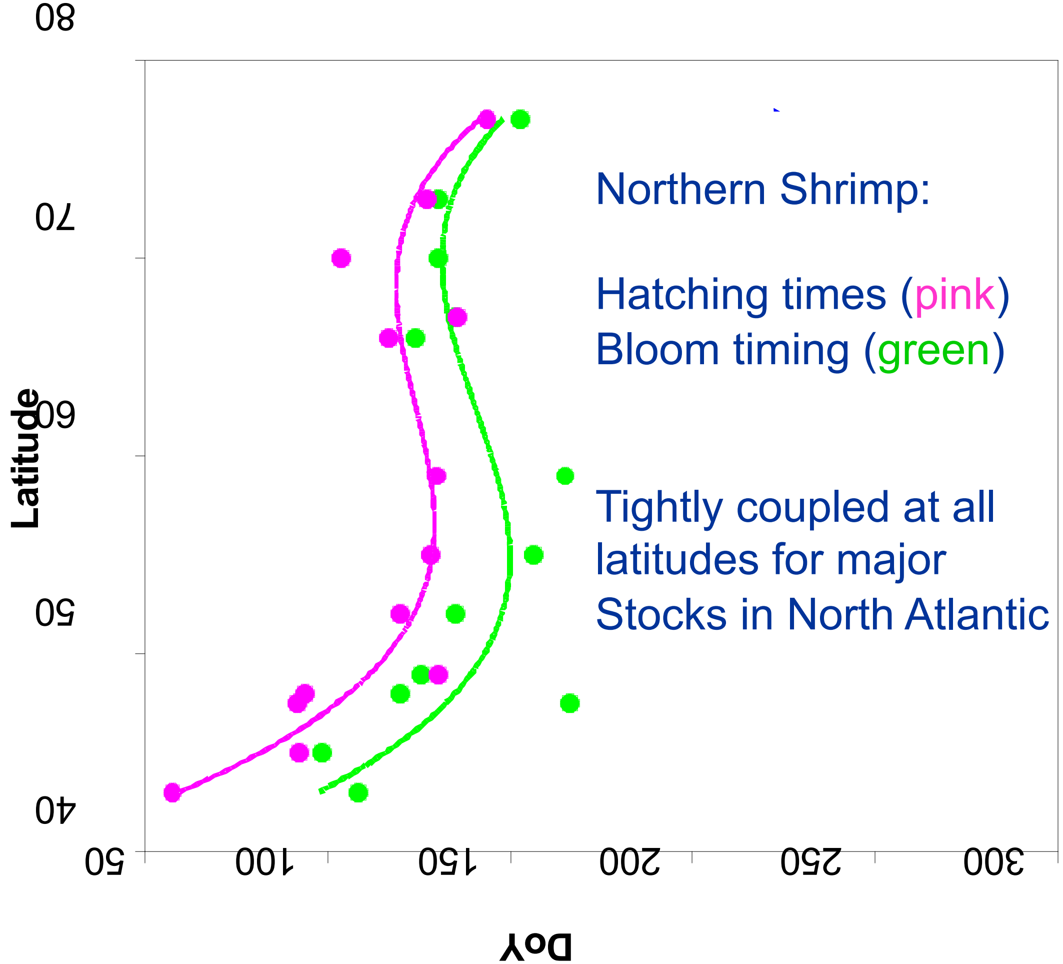


Some Ecological Indicators from Remote Sensing

Indicator	Label	Dimensions
Initiation of spring bloom	b_i	[T]
Amplitude of spring bloom	b_a	$[ML^{-3}]$
Timing of spring maximum	b_t	[T]
Duration of spring bloom	b_d	[T]
Total production in spring bloom	b_p	$[ML^{-2}]$
Annual phytoplankton production	P_Y	$[ML^{-2}]$
Initial slope of light-saturation curve	α^B	$[L^2]$
Assimilation number	$P^B{}_m$	$[T^{-1}]$
Particulate organic carbon	C_T	$[ML^{-3}]$
Phytoplankton carbon	C_p	$[ML^{-3}]$
Carbon-to-chlorophyll ratio	χ	dimensionless
Phytoplankton growth rate	μ	$[T^{-1}]$
Generalised phytoplankton loss rate	L	$[ML^{-3}T^{-1}]$
Integrated phytoplankton loss	L_T	$[ML^{-3}]$
Spatial variance in biomass field	$\sigma_B{}^2$	$[M^2L^{-6}]$
Spatial variance in production field	$\sigma_P{}^2$	$[M^2L^{-4}]$
Phytoplankton functional types	NA	NA
Delineation of biogeochemical provinces	NA	NA

Platt & Sathyendranath (2008)

Some Indicators Closely Related to Marine Resources:



Basin-scale coherence of North Atlantic shrimp stocks.

Coupling vulnerable to climate change.

Koeller, Fuentes-Yaco, Platt, Sathyendranath and others (2009)

The Algorithm Suite

Consists of different parts, including:

- filters
- atmospheric correction
- inherent optical properties
- chlorophyll concentration

For each of the elements of the suite, a number of candidate algorithms will be tested before final selection is made

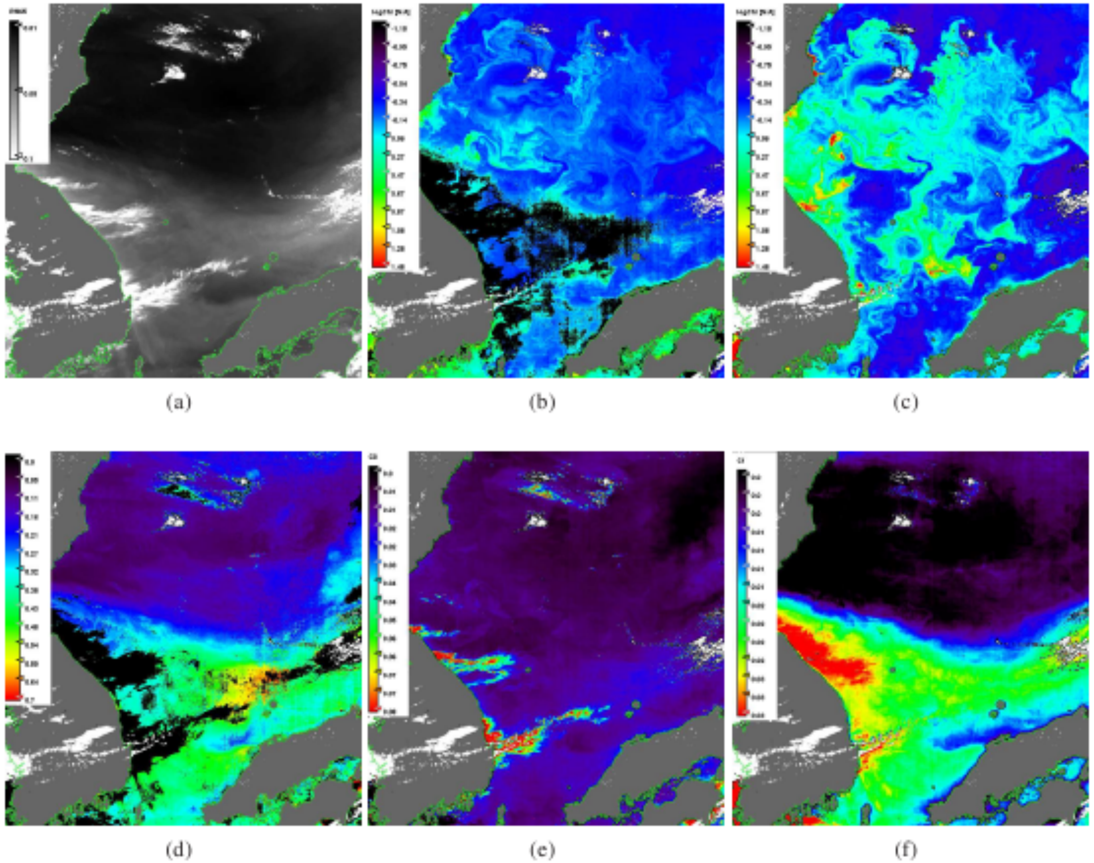
Atmospheric Correction

In OC-CCI we will investigate two types of AC algorithms:

1. Gordon and Wang type: Estimation of an aerosol model from the radiances in the NIR
   a. ESA MEGS (MERIS)
   b. NASA MSL12 included in SeaDAS (MERIS, MODIS, SeaWiFS & CZCS)
2. Neural Net and Spectral matching: a direct model with varied geophysical parameters used to train a NN or to spectrally fit the TOA radiances
   a. GAC (Glint and atmosphere correction Processor), which has been developed for MERIS at HZG under contract to ESA (MERIS, MODIS, SeaWiFS & CZCS)
   b. POLYMER developed at HYGEOS (MERIS, MODIS, SeaWiFS & CZCS)

Both use not only NIR bands but also the blue-green spectral range as input, and both are able to determine RLw even in sun glint contaminated parts of an image.

POLYMER



MERIS image 31 March 2004 off Japan sea. (a) An aerosol event can be seen on 865 nm reflectance and (d) on AOT at 865 nm retrieved with MEGS 7.4. (b) and (c) show chlorophyll concentration estimated by algorithms MEGS 7.4 and POLYMER respectively. (e) and (f) show the spectral dependency coefficients of POLYMER polynomial fit , respectively flat and in l^{-1} . (from Steinmetz et al., 2010)

In Water Algorithm Development: Our approach

Explore generality (ideally applicable in Case 1 and Case 2 algorithms)

Include a variety of approaches (empirical, model-based)

Examine applicability of models to climate-change studies (e.g., robust in a changing climate; consistency over a long time series)

Need for error characterisation

Need for merging

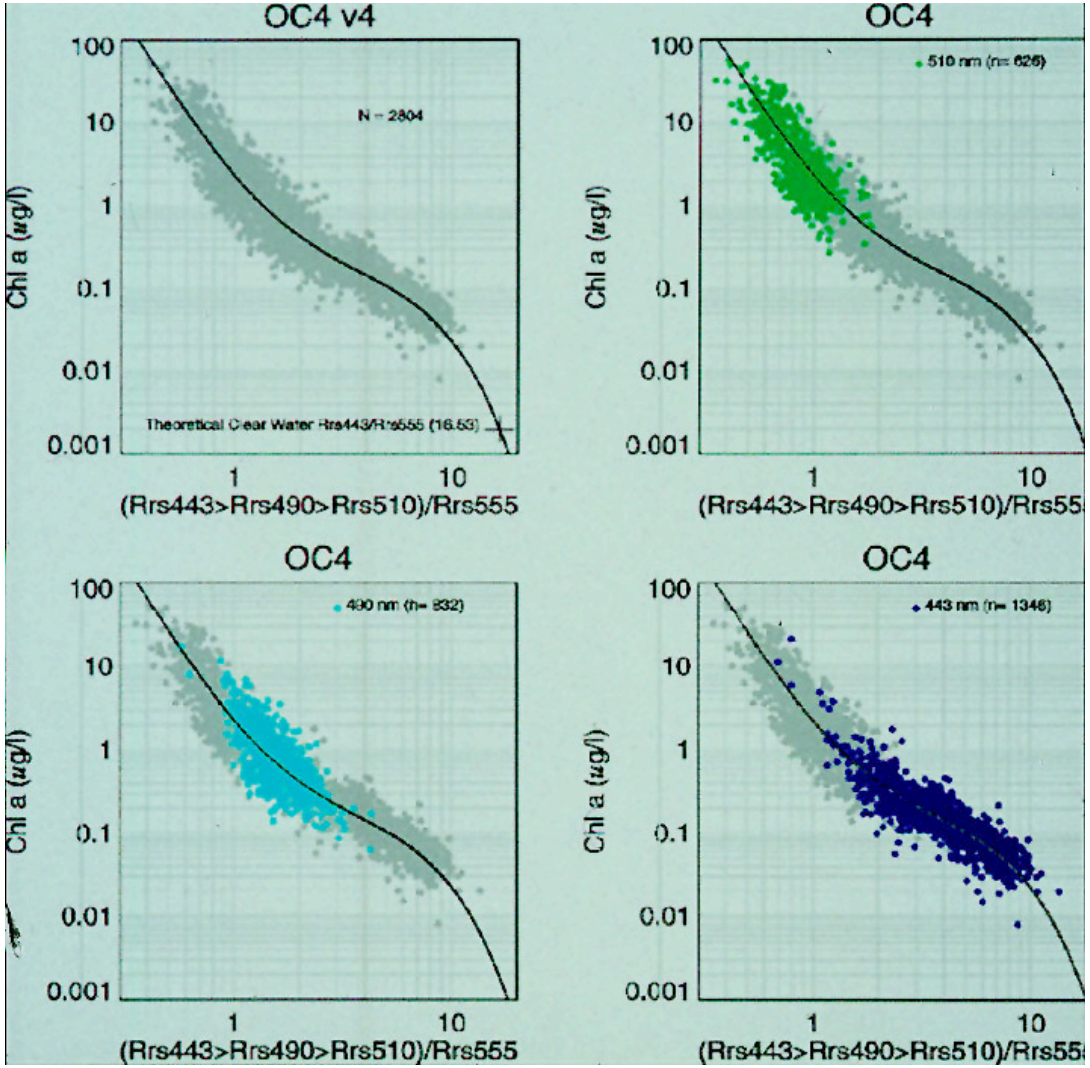
NASA OC4 algorithm

Statistical, empirical relationship between reflectance ratios and chlorophyll concentration

Based on extensive in situ data

Highly successful, globally applicable

But does not by itself provide insight on the underlying causes for the observed relationship.



Ocean Colour and Phytoplankton Community Structure

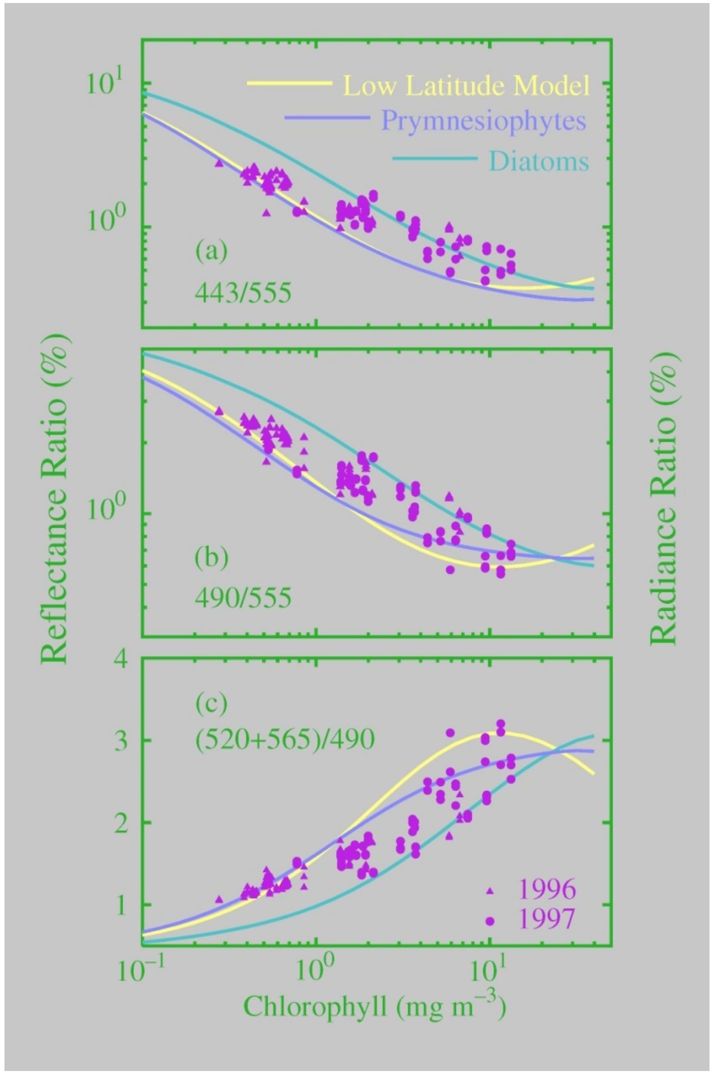
Relationships between reflectance-ratios and chlorophyll concentrations depend on phytoplankton species composition.

Could be an advantage to be exploited if eventual goal is to extract information on phytoplankton type present.

Phytoplankton species composition vulnerable to climate change.

Questions:
Is algorithm robust to changes in phytoplankton community structure?

Is algorithm robust regionally?



OC4 Algorithm by Year

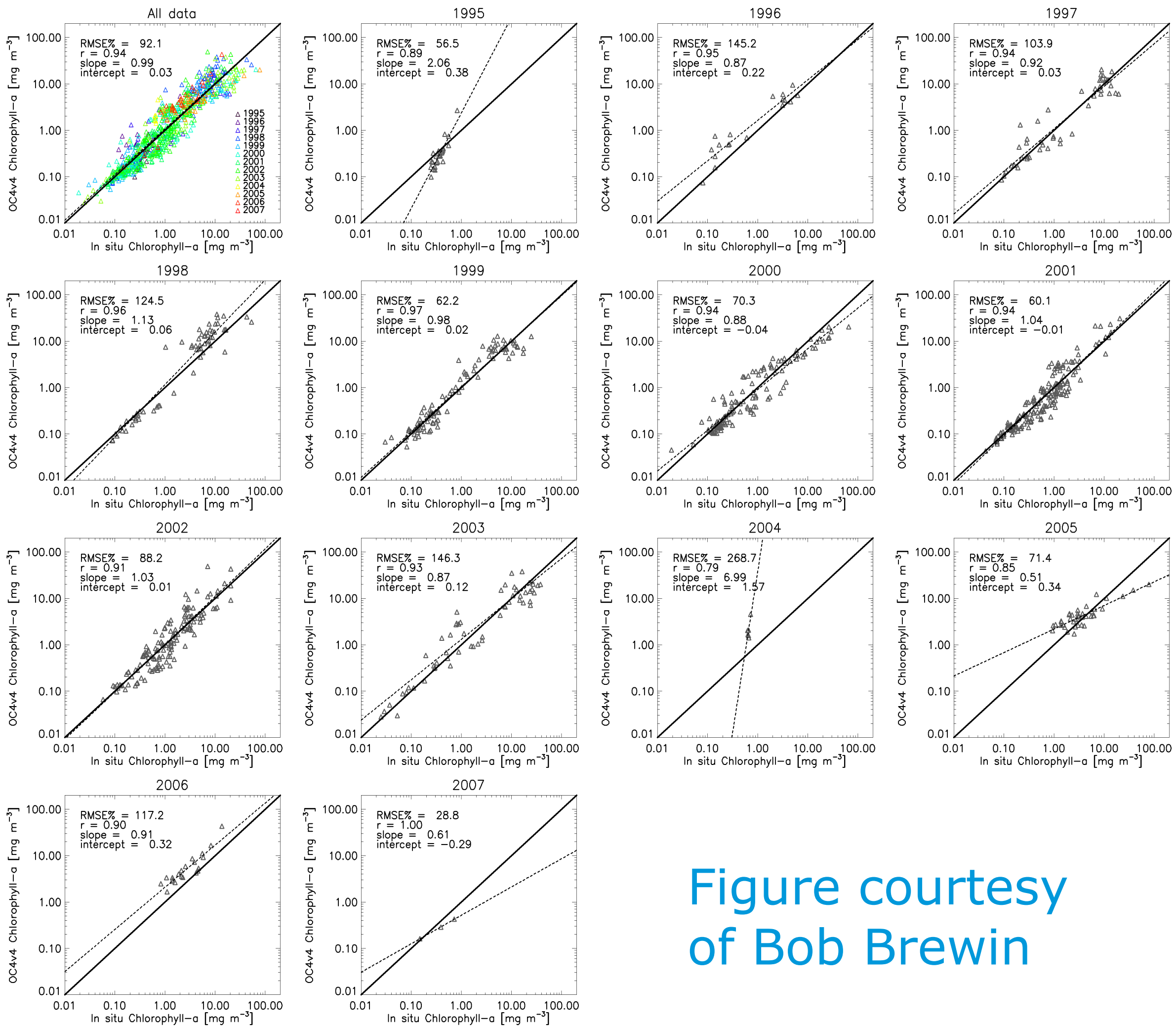


Figure courtesy of Bob Brewin

Are inter-annual changes in performance of algorithm significant?

Are they likely to become significant in a changing ocean?

OC-CCI algorithm should be stable in a changing climate

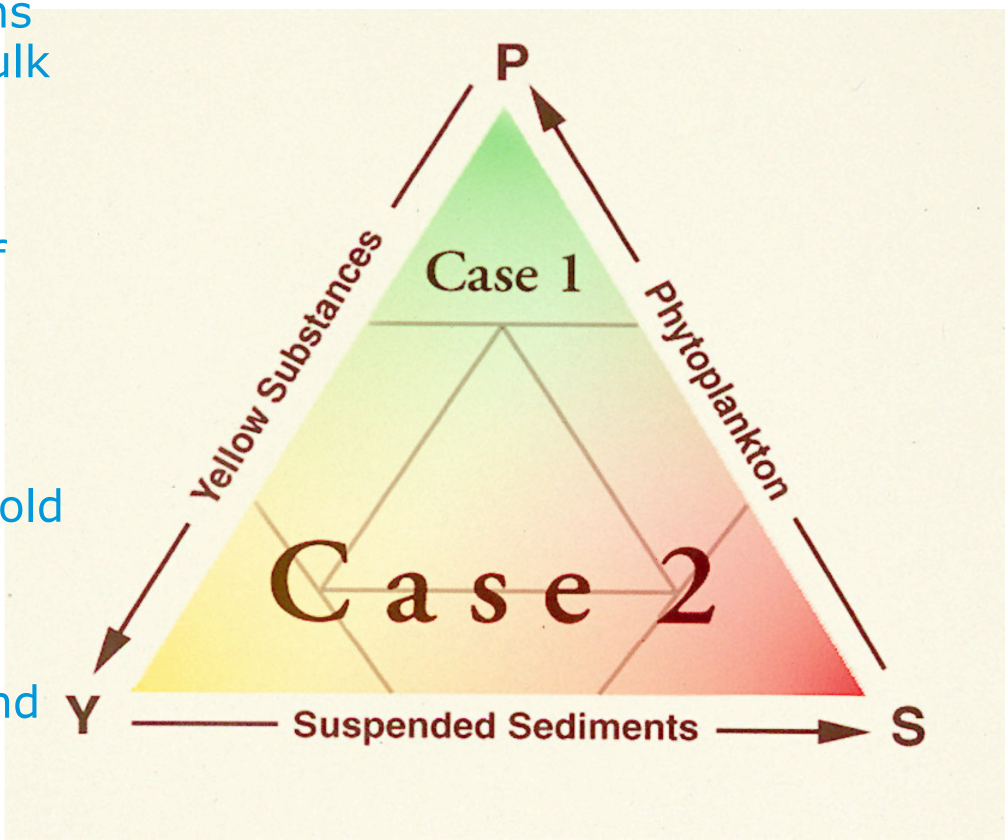
Case 1 and Case 2 Waters

Classification of ocean waters into Cases 1 and 2 is based on the relative contributions of optically-relevant constituents to the bulk optical properties of the sea

Case 1 waters may be seen as a subset of Case 2 waters

A robust Case 2 algorithm should work in Case 1 waters, but the inverse does not hold true

Note: Natural synergy between OC-CCI and ESA's CoastColour Project



Error Characterisation, Reduction

Requires meticulous analyses of the various sources of error in ocean-colour products:

1. instrument specifications
2. instrument calibration procedure
3. atmospheric correction
4. in-water algorithms

Approaches to error characterisation include:

1. Neural Network
2. Formal error analysis
3. Fuzzy logic

Data Merging

Considerations:

1. Main sensors in addition to MERIS: NASA sensors SeaWiFS, MODIS Aqua and possibly CZCS
2. Primary requirement for climate records: consistency
3. Error propagation on merging
4. Suitability for downstream applications
5. GCOS requirements

Impetus: shift from mission-oriented to ECV-oriented products

1. Tightly linked to to calibration, algorithm development, validation and inter-comparison

Methods:

1. statistical techniques; optically-based techniques; numerical (model-based) methods
2. Note: bias-correction is important

Success Criteria:

1. Validation; Improvement to temporal and spatial coverage; Computationally efficient

Product Validation

Three-step process:

- Algorithm inter-comparison
- Round-robin exercise
- Validation with in situ data

Approach:

- Test a variety of approaches at each step
- Improvement to temporal and spatial coverage
- Computationally efficient

Project Websites

1. **ocean colour** – http://www.esa-oceancolour-cci.org
2. **cmug** – http://www.esa-cmug-cci.org
3. **cloud** – http://www.esa-cloud-cci.org
4. **fire** – http://www.esa-fire-cci.org
5. **ghg** – http://www.esa-ghg-cci.org
6. **glaciers** – http://www.esa-glaciers-cci.org
7. **land cover** – http://www.esa-landcover-cci.org
8. **aerosol** – http://www.esa-aerosol-cci.org
9. **ozone** – http://www.esa-ozone-cci.org
10. **sea level** – http://www.esa-sealevel-cci.org
11. **sst** – http://sst-cci.org/

Example of parameter estimation
Simon and Bertino (JMS 2011, in revision)