

**Past Observations and Future Challenges for Ocean Colour  
Remote Sensing**

*Charles R. McClain*

*Code 616, Ocean Ecology Laboratory  
NASA Goddard Space Flight Center*

**First International Ocean Colour Science Meeting  
Darmstadt, Germany, May 6-8, 2013**

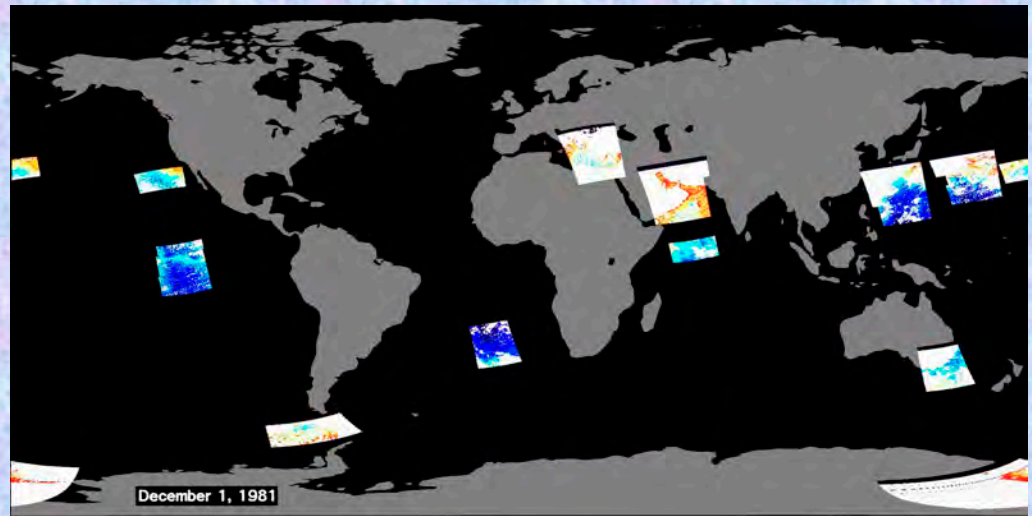
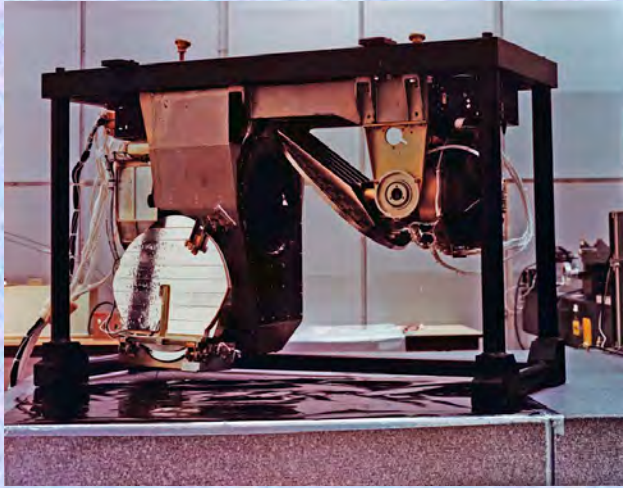
# **Ten Major Steps Forward for Satellite Ocean Biological-Biogeochemical Science**

- **Nimbus-7/CZCS demonstration & experiment team**
- **Global CZCS reprocessing**
- **SeaWiFS Project Office**
- **SeaDAS**
- **MOBY & vicarious calibration methodology**
- **Atlantic Meridional Transect**
- **International Ocean Colour Coordinating Group**
- **SIMBIOS Project**
- **Bio-optical algorithms: empirical to semi-analytic**
- **Chlorophyll-a multi-sensor Climate Data Record**



# Coastal Zone Color Scanner Demonstration

(1978-1986)



## Nimbus-7 CZCS Experiment Team (NET)

•Warren Hovis (PI)

•Howard Gordon

•Ross Austin

•Dennis Clark

•Charlie Yentsch

•Jim Mueller

•Boris Sturm

•Sayed El-Sayed

•Bob Wrigley

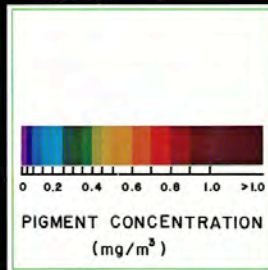
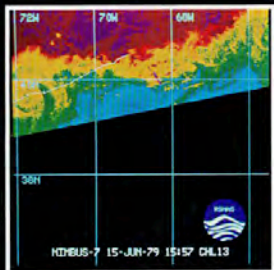
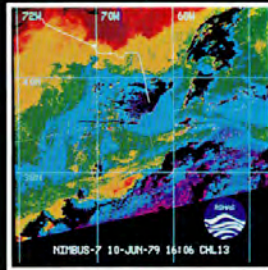
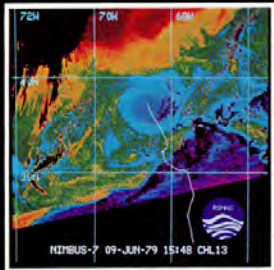
•Frank Anderson

•Ed Baker

•John Apel

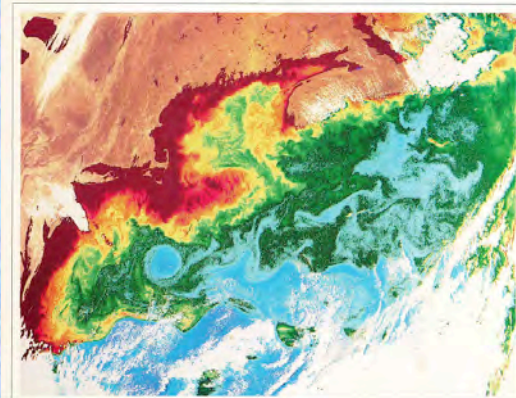
## Applied Optics

1 JANUARY  
1983



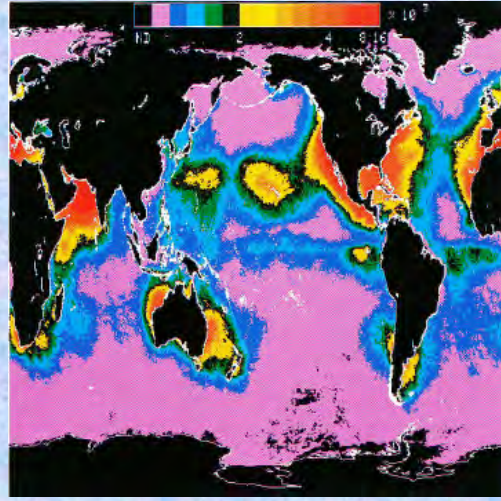
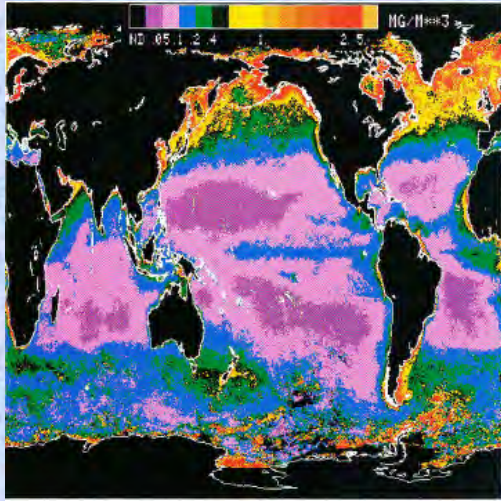
NASA  
Goddard Space Flight Center

NIMBUS-7 CZCS  
COASTAL ZONE  
COLOR SCANNER IMAGERY  
*for Selected Coastal Regions*





# Coastal Zone Color Scanner Reprocessing (1985-1989)



**EOS**  
Transactions, American Geophysical Union  
Vol. 57 No. 44 November 4, 1986

**OCEAN PHYTOPLANKTON CONC. (mg m<sup>-3</sup>)**  
NASA  
GFSC

**LAND VEGETATION INDEX**  
DESERT SENSE VEGETATION

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 90, NO. 44, PAGES 7501-7507, APRIL 15, 1985

**Coastal zone color scanner "system calibration": A retrospective examination**

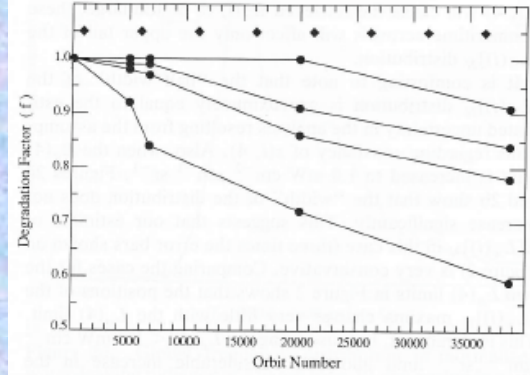
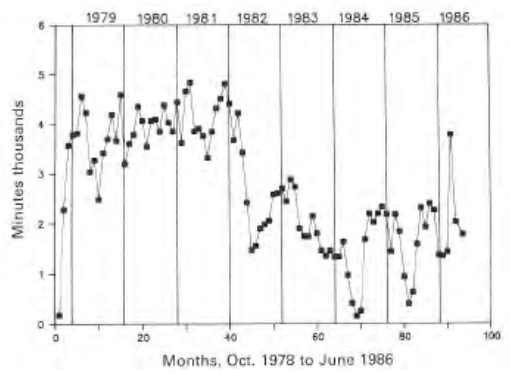
Robert H. Evans  
Assistant Chief of Mission and Atmospheric Sciences, University of Miami, Miami, Florida

Howard R. Gordon  
University of Miami, Coral Gables, Florida

**Abstract.** During its lifetime the coastal zone color scanner (CZCS) produced approximately 60,000 images. These have been placed in an archive of "raw" radiance (scene radiance in a subpixel format that is easily accessible). They have also been processed to form global, 1-monthly composites of oceanic water-leaving radiances, and global composites of vegetation indices. Using these data, we have tried to characterize some aspects of the "system calibration" for the CZCS. Specifically, we have examined the consistency of the radiance band decalibration by a simple manner similar to the well-known long-term degradation of the oceanic water-leaving radiances, and we examined the consistency of the green and red bands by comparing the globally averaged water-leaving radiances, over 15-day periods, for all of the sensors. The results provide evidence that in addition to the long-term degradation, short-term (2 weeks to 1 month) variations in the radiometric sensitivity of these bands existed in early fall 1985 and continued to the end of the mission. In contrast, the data suggest the absence of such variations prior to August 1981. It is concluded to believe that the sensitivity of the blue band probably varied throughout the mission, and that radiometric variations in the other bands. Thus after these fluctuations begin, the actual values of CZCS oceanic radiance concentrations (as a function of distance) should be scaled. Had an extensive set of surface measurements of water-leaving radiances been available during the CZCS mission, these fluctuations could have been revealed from the data set, and they would have greatly increased its value. The lessons learned from CZCS, that is, the requirement of good radiometric calibration and stability and the necessity of "raw radiance" radiance to monitor the performance of the system (scene plus algorithm), are being applied to the same-viewing wide-field-of-view sensor (SeaWiFS) scheduled for launch in August 1995.

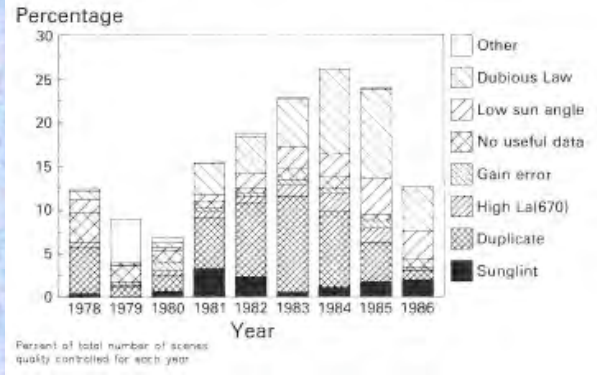
**Introduction**

The coastal zone color scanner (CZCS) on Nimbus II was a scanning radiometer that used the ocean as an integral spectral band. The radiance measured at 415, 510, 555, and 670 nm, bandwidths selected on the basis of 1, 2, 3, and 4 wavelengths, provided information on the concentration of phytoplankton in the near-surface water of the ocean (Morel et al., 1981; Morel and Chluminar, 1982). The CZCS was the first satellite instrument to provide global coverage of phytoplankton in the near-surface water of the ocean. The CZCS was the first satellite instrument to provide global coverage of phytoplankton in the near-surface water of the ocean. The CZCS was the first satellite instrument to provide global coverage of phytoplankton in the near-surface water of the ocean.



## Reprocessing Team

- Wayne Esaias (PI)
- Chuck McClain (QC)
- Gene Feldman (Production)
- Bob Evans (Calibration)



**EOS**  
Transactions, American Geophysical Union  
Vol. 70 No. 23 June 6, 1989

**Oceanic biological productivity**

CHARLES R. SICKLAND, GENE FELDMAN AND WAYNE ESAIAS

**Abstract.** Oceanic primary productivity is a critical element of the global carbon cycle and the distribution of biological productivity. The oceanic primary productivity is a critical element of the global carbon cycle and the distribution of biological productivity. The oceanic primary productivity is a critical element of the global carbon cycle and the distribution of biological productivity.

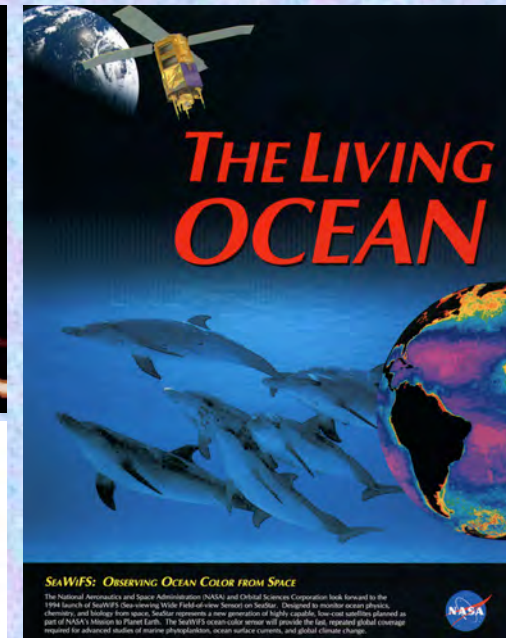
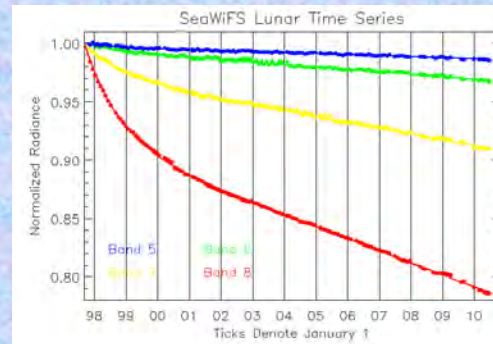
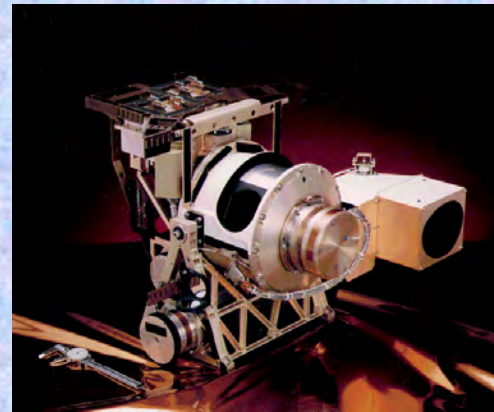
- ~ 5 years
- ~ 30,000
- 9-track tapes
- ~ 90,000 scenes



# The SeaWiFS Project (1991-2010)

## Notable Achievements

- Data-buy “insight, not oversight”
- “First-day” data access & graphical data ordering interface
- Lunar calibration method
- Technical Memorandum Series
- Open community participation
- SeaDAS
- SeaBASS
- In situ measurement protocols
- 1<sup>st</sup> OC climate quality data time series
- HRPT station support
- Calibration round-robins
- HPLC pigment analysis round-robins
- Data analysis round-robins
- NIR aerosol correction method (Gordon & Wang, 1993)
- Real-time field campaign support
- Community-based algorithms (e.g., chl-a, O’Reilly et al., 1999)
- Instrument development (e.g., SeaWiFS transfer radiometer)



OceanColor WEB

Home | Data | Downloads | Analysis | Search | Forum | Services | Links

**Data Access**

This Distribution Station

All systems normal (last updated 11/01/2010 12:00:00)

NOTE: FTP connections must be made to the main site.

**Level 1 and 2 Browser**

Visually search the ocean color data archive. Query downloaded or color data from a single file to an entire mission. Data from the Aquatic mission is also available.

**Level 3 Browser**

Access the entire global satellite sea surface temperature and sea surface salinity data sets for long time periods and time periods and download POC images of digital data in PDF format.

**Data Archive**

Access to the complete data archive. Retrieval of data in bulk is possible.

**Ocean Productivity**

Ocean Net Primary Productivity data products derived from MODIS and SeaWiFS data are available from Oregon State University.

**Global**

An easy-to-use, web-based interface for the acquisition and analysis of Earth Science data provided by the SeaWiFS Data Center. The SeaWiFS Ocean Color Project

This project creates a variety of distributed and raw ocean color products for evaluation and applications to improve Earth Science Data Records.

**Ocean Color Feature**

Two Views from VIIRS

Four articles of the recently launched Suomi NPP satellite provided the 19th anniversary check for the data acquisition instrument. Central and North America resulted between the Pacific and Atlantic oceans.

Our group is processing ocean color data from the mission for environmental and oceanographic measurements available to the broader community for environmental purposes.

The above composite is collected on January 4, 2012 - it was available as an 800 x 800 pixel image.

The narrow-angle view at right is showing the Earth as seen from one Earth diameter above the southernmost tip of South America - was downloaded from VIIRS one year a period of time response on February 3, 2012. Click on the image to enlarge a larger view, at 1600 x 1600 or 32,000 pixel, 32 megabyte version.

**Image Gallery**

NOTE: All SeaWiFS images presented here are for research purposes only. The use of the data for any other purpose is prohibited without the permission of the SeaWiFS Data Center.

**SeaWiFS Data Center**

**Support Services**

SeaDAS

A comprehensive image analysis package for use in acquisition, development and substitute data product visualization.

SeaBASS

An archive of in situ oceanographic and atmospheric data for use in acquisition, development and substitute data product visualization.

Registration for support services

- Data access and Subscriptions
- Program download
- Data Center
- SeaWiFS Access Authorization

Near Real-Time (NRT) Services

- Sea Data Subscriptions
- Subscriptions give users to notify for new data or to set flags on our first near the satellite.

Information Services

- Ocean Color Forum
- Ocean Color Mailing List
- Ocean Color Data Downloading

Other Services

- SeaWiFS Oversight Protocols
- Data Submission Status
- L1/L2 Browser
- SeaWiFS Search Utility
- Search for general and auxiliary data archived by the ocean color data product system.

Current: OceanColor Webmaster  
Authorized by: Gene Carl Feldner

Privacy Policy and Statement of Intent  
Issued: 27 February 2012

NASA

Volume 51 Numbers 1-3 2004 ISSN 0967-0645

ELSEVIER

## DEEP-SEA RESEARCH

Editor: John D. Milliman

### PART II

Topical Studies in Oceanography

Guest Editors:  
D. A. Siegel  
A. C. Thomas  
J. Marra

Views of Ocean Processes from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Mission: Volume 1

[www.elsevier.com/locate/dsr2](http://www.elsevier.com/locate/dsr2)







# SeaDAS (1992-present)



**OceanColor SeaDAS**

Download - Help - Forum - News - Data - Documents - OceanColor - Contact

GUI Functions

Sea Command Functions

Processing Programs

Unix Utility Programs

Ocean Color - SeaDAS Tutorials

Ocean Mailin - SeaDAS FAQ

Download and Installation

Linux and Mac:

- Online Auto-Installation
- Manual Download
- Manual Installation

Windows:

- SeaDAS Virtual Appliance

Satellite Data Info

Data Product Specifications

Data Format Specifications

Satellite Data Access

Level 1 and 2 Browser

Level 3 Browser

Ancillary data

Data Subscriptions

Data File Search Utility

**What is SeaDAS**

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

Supported satellite sensors are MODIS, SeaWiFS, MERIS, OCTS, and CZCS.

- Features
- Requirements
- Online Help
- SeaDAS FAQ
- User Contributed Software
- History of Events
- Training Materials

Thank you to our SeaDAS download mirrors!

SeaDAS Software Usage Policy

**What's New**

**SeaDAS 6.4 Released**

- Includes support for the latest MODIS Aqua reprocessing (V2012.0)
- Includes several bug fixes for both the GUI and processing code
- Drops support for OSX10.5 (Tiger) Mac systems

**SeaDAS 7.0-beta Released**

SeaDAS 7.0-beta is our first release of the new interface for SeaDAS. As this is a beta release, there are a few known (and likely a few unknown) issues. We are actively working on the issues listed below. Please give the program a test drive and do not hesitate to report any issues to use via the OceanColor Forum.

**MODISL1DB 1.8 released**

**User Contributed Software**

Do you have programs to share?

Curator: OceanColor Webmaster  
Authorized by: gene.carl.feldman

Privacy Policy and Important Notices  
Updated: 29 June 2012

## Sensors Supported:

- CZCS (1978-1986)
- OCTS (1996-1997)
- SeaWiFS (1997-2010)
- MODIS/Terra (2001-present)
- MODIS/Aqua (2002- present)
- MERIS (2002-2012)
- Missions under evaluation/development  
– ViIRS, OCM, HICO, and GOCI

NASA Technical Memorandum 104557

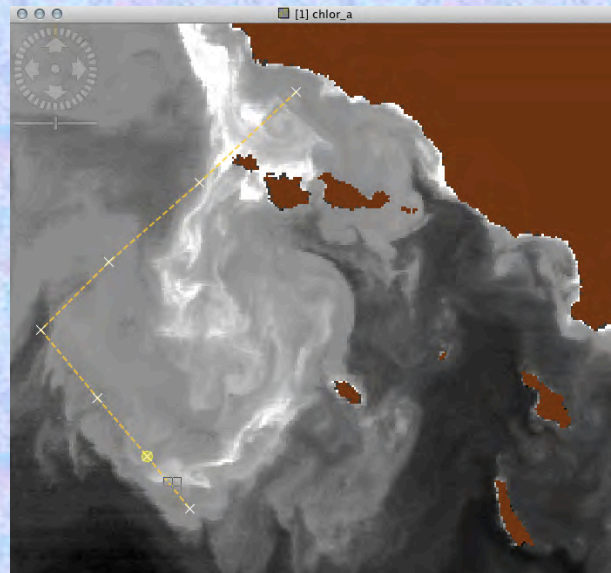
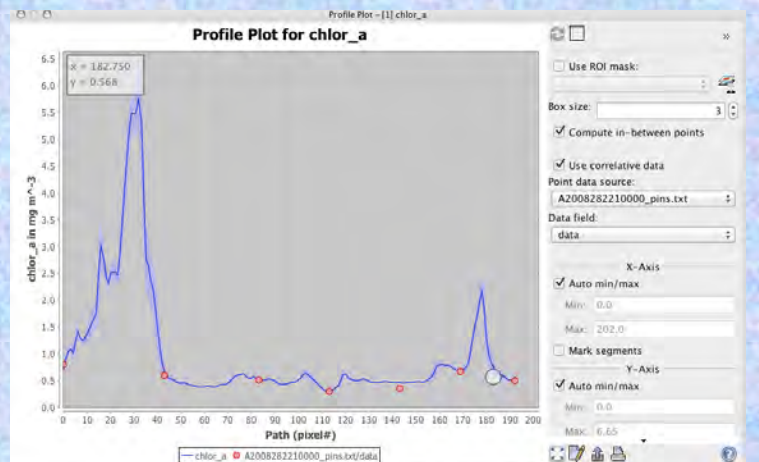
**PC-SEAPAK User's Guide**

Version 4.0

Charles R. McClain, Gary Fu, Michael Darzi, and James K. Firestone

JANUARY 1992

NASA  
National Aeronautics and Space Administration  
Goddard Space Flight Center  
Greenbelt, MD

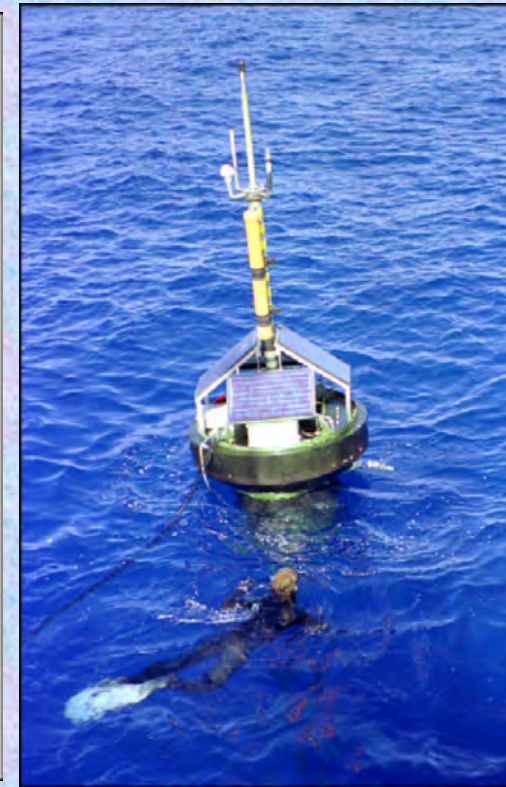
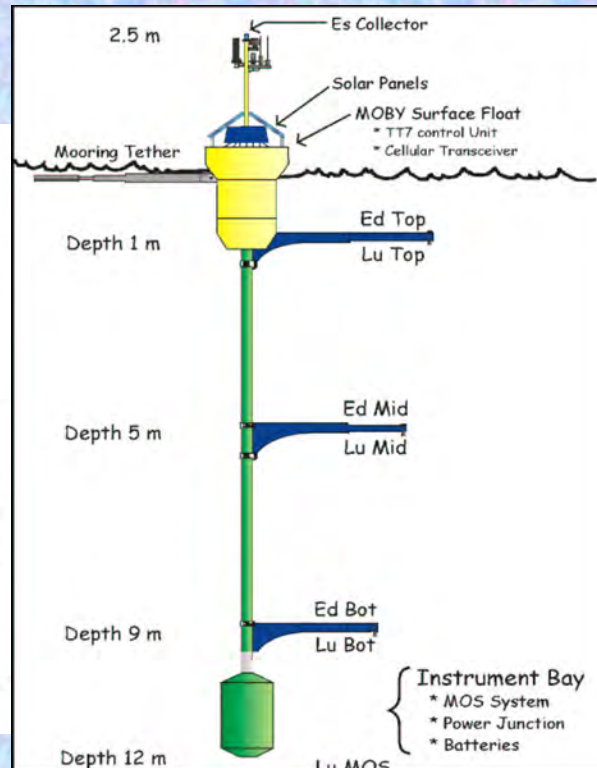
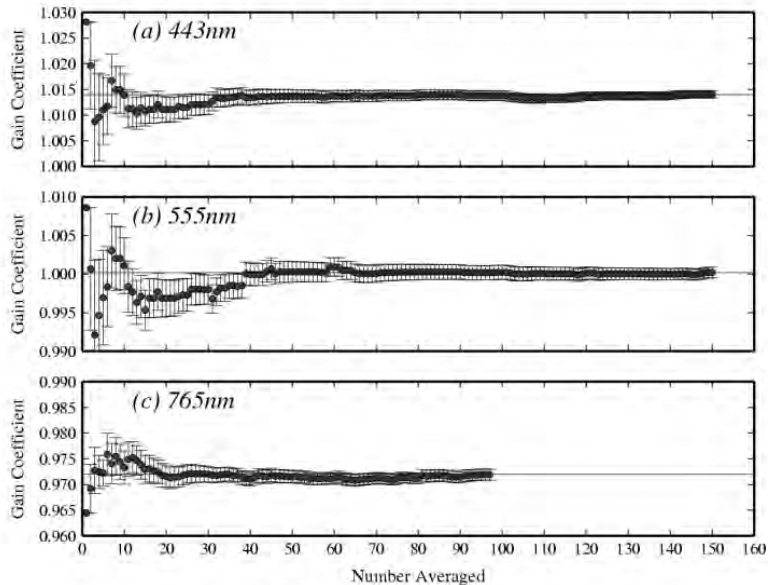
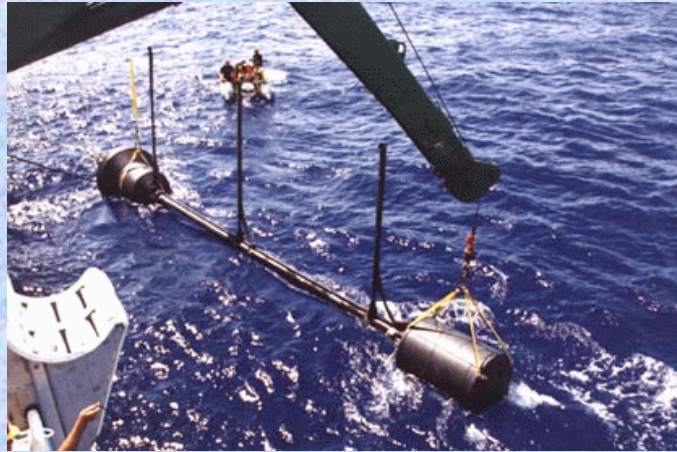




# Marine Optical Buoy (MOBY)

deployed 1996-present

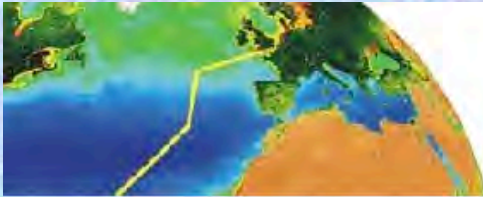
Dennis Clark  
Mark Yarbrough  
Bill Broenkow  
Carol Johnson  
Mark Feinholz  
Stephanie Flora  
Chuck Trees  
Ken Voss  
Steve Brown





# Atlantic Meridional Transect (1995-present)

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## Atlantic Meridional Transect

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You are in : [AMT - Atlantic Meridional Transect - Oceanographic research cruise](#)

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- ▶ [AMT research data](#)
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**The annual AMT voyage undertakes biological, chemical and physical oceanographic research in the Atlantic Ocean**

The Atlantic Meridional Transect (AMT) is a multidisciplinary programme which undertakes biological, chemical and physical oceanographic research during an annual voyage between the UK and destinations in the South Atlantic - previously the Falkland Islands, South Africa and Chile, a distance of up to 13,500km. This transect crosses a range of ecosystems from sub-polar to tropical and from euphotic shelf seas and upwelling systems to oligotrophic mid-ocean gyres.

The programme was established in 1995 and since then has included 23 research cruises involving 223 scientists from 18 countries. AMT has proved to be a long-term multidisciplinary ocean observation programme, which is a platform for national and international scientific collaboration, a training arena for the next generation of oceanographers and an ideal facility for validation of novel technology.

The most recent AMT cruise departed from Southampton, UK on 10 October 2012 and arrived in Punta Arenas on 24 November 2012.

Expressions of interest are now invited for participation in AMT cruises in 2013 and beyond, please contact Andy Rees, [apre@pml.ac.uk](mailto:apre@pml.ac.uk), for further details.

### Latest news

- ▶ [IMBER endorses AMT](#)  
08 Nov 2012 | [News](#)
- ▶ [AMT22 sails on 10 October](#)  
28 Sep 2012 | [News](#)
- ▶ [05 Oct 2011 | Latest location](#)  
[Web news](#)

Hosted at Plymouth Marine Laboratory in conjunction with the National Oceanography Centre.

**PML** | Plymouth Marine Laboratory



**National Oceanography Centre**  
NATURAL ENVIRONMENT RESEARCH COUNCIL



# International Ocean Colour Coordinating Group

## 1996-present

### Chairs:

Trevor Platt

Jim Yoder

David Antoine

### Project Coordinator:

Venetia Stuart

13 topical reports  
published to date.

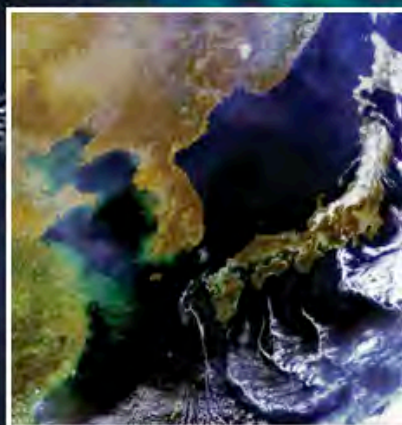


International Ocean-Colour Coordinating Group

An Affiliated Program of [SCOR](#)

[Contact Us](#)

#### Feature Image



GOCI/COMS image showing Yangtze River discharge near South Korea (click on image for larger view)

*Promoting the application of remotely-sensed ocean-colour data through coordination, training, liaison between providers and users, advocacy and provision of expert advice*

[About IOCCG](#)

[Ocean-Colour News](#)

[IOCCG Working Groups](#)

[Training & Education](#)

[Publications & Reports](#)

[Ocean-Colour Bibliography](#)

[Ocean-Colour Sensors](#)

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[Programs & Institutions](#)

[Ocean-Colour Images](#)

Image provided by the SeaWiFS Project, NASA/Goddard Space Flight Centre and OrbImage



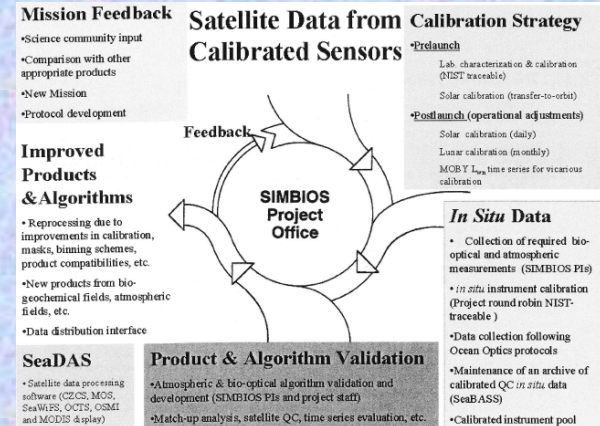
# SIMBIOS (1997-2003)

## (Sensor Intercalibration & Merger for Biological & Interdisciplinary Oceanic Studies)



### Objectives:

- Ensure development of internally consistent research products & time series from multiple satellite ocean color data sources
- Develop methodologies for cross-calibration of satellite ocean color sensors
- Develop methodologies for merging data from multiple ocean color missions
- Promote cooperation between international ocean color projects



### Organization

- SIMBIOS Project Office
- International Science Team

### Activities

- Sensor evaluations (MOS, OCI, OSMI, OCTS, POLDER, MODIS)
- Calibration round robins (SIRREX)
- Coastal/Island AERONET sites (~12)
- Annual science team meetings
- In situ measurement protocols
- Annual project reports (Technical Memos)
- Instrument pool (Microtops, SIMBAD, etc.)
- SeaBASS support
- HPLC round robin
- Data merging methodologies

NASA/TM—2002-210008



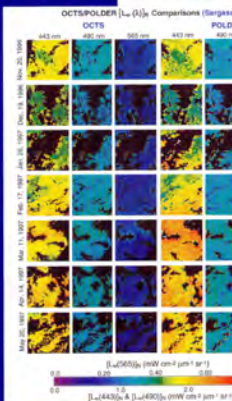
The Proposal for the NASA Merger for Biological and (SIMBIOS) Program, 1997

C. McClain, W. Esaias, G. Feldman, R.

National Aeronautics and Space Administration  
Goddard Space Flight Center  
Greenbelt, Maryland 20771

### Applied Optics

Lasers, Photonics, and Environment



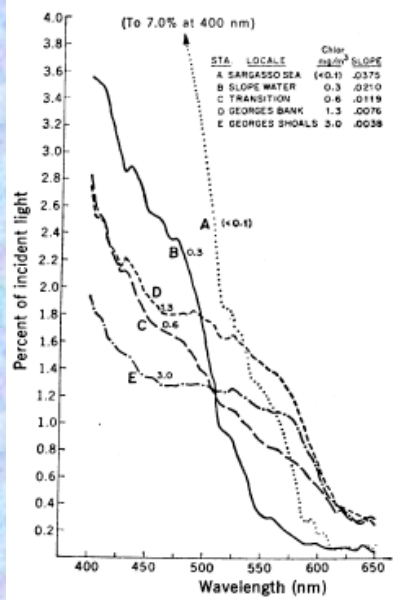


# SIMBIOS International Science Team (#2)





# Bio-optical Algorithms: Empirical to Semi-analytical



Clarke, Ewing, & Lorenzen, *Science*, 1970

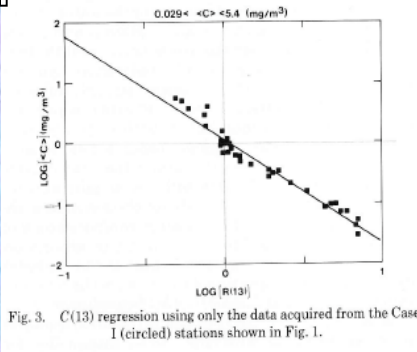


Fig. 3. C(13) regression using only the data acquired from the Case 1 (circled) stations shown in Fig. 1.

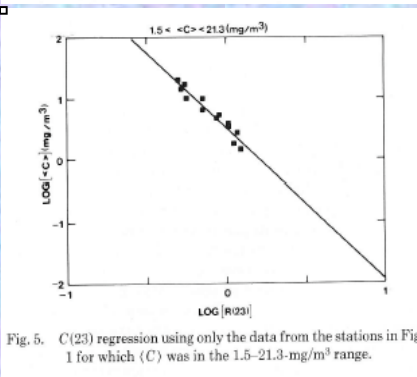
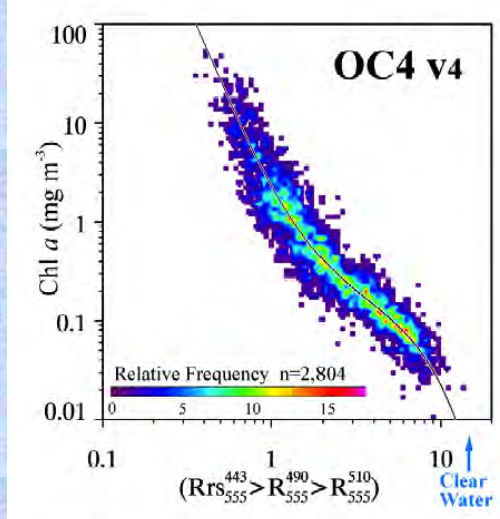
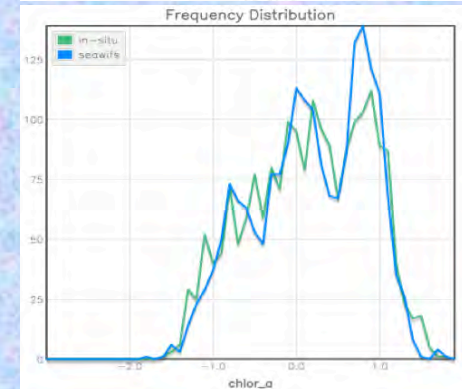
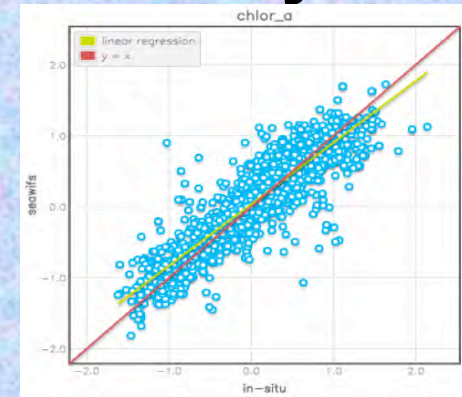


Fig. 5. C(23) regression using only the data from the stations in Fig. 1 for which (C) was in the 1.5-21.3-mg/m<sup>3</sup> range.

Gordon et al., *Appl. Opt.* 1983



O' Reilly et al., *Appl. Opt.*, 1998



SeaWiFS chl-a retrievals

IOCCG Rept #5, 2006

Remote Sensing of Inherent Optical Properties: Fundamentals, Tests of Algorithms and Applications

Reports of the International Ocean-Colour Coordinating Group

REPORT NUMBER 5

CCG  
An Affiliated Program of SCOR  
An Associate Member of CEOS

## Present Validated Products

- Chlorophyll-a
- Diffuse attenuation coefficient (490 nm)

## Current Unvalidated Research Products

- Inherent optical properties
- Spectral diffuse attenuation
- Euphotic depth
- Spectral remote sensing reflectance
- Particulate organic carbon concentration
- Primary production
- Calcite concentration
- Colored dissolved organic matter
- Photosynthetically available radiation
- Fluorescence line height
- Total suspended matter
- Trichodesmium concentration

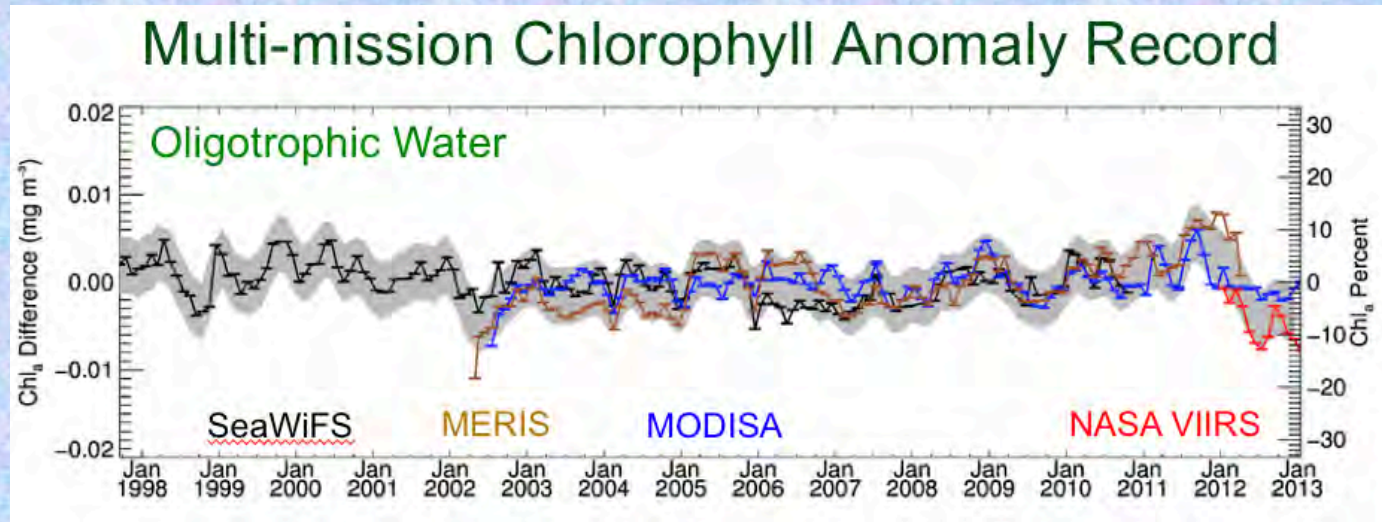
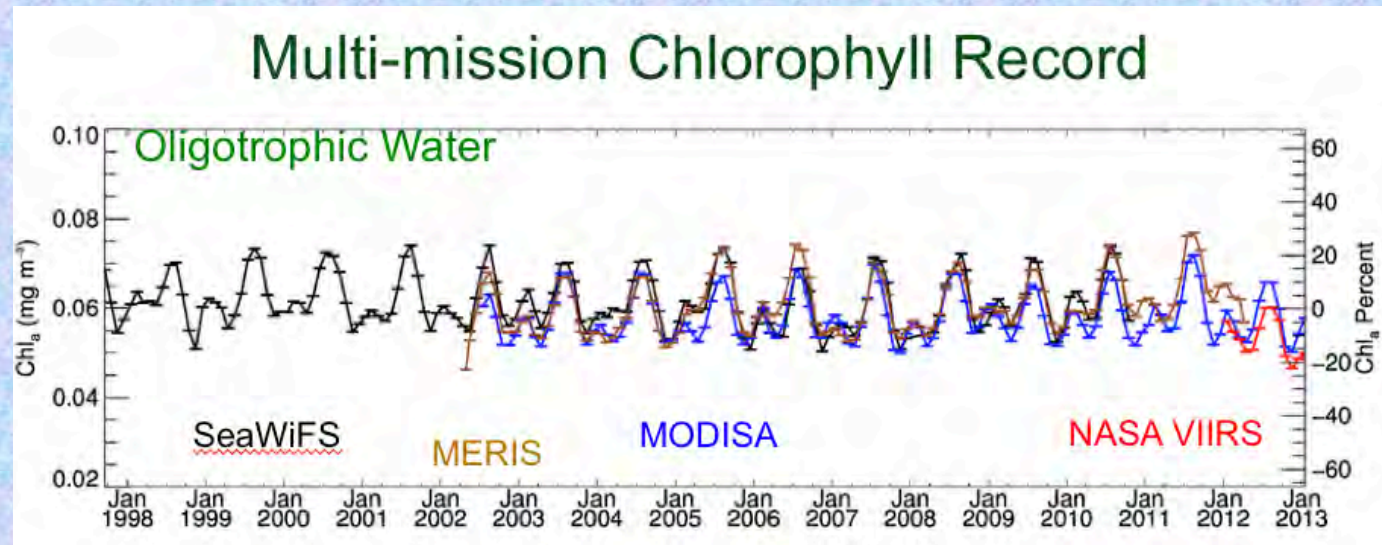
## Future Research Products

- Particle size distributions & composition
- Phytoplankton carbon
- Dissolved organic matter/carbon
- Physiological properties (e.g., growth rates)
- Fluorescence quantum yield
- Phytoplankton pigment absorption spectra
- Export production
- Functional/Taxonomic groups



# Chlorophyll-a Multi-sensor Climate Data Record

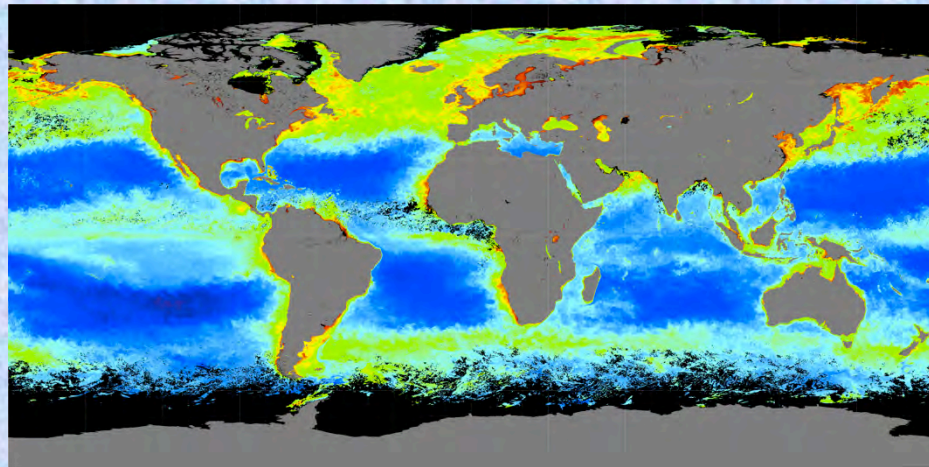
- Multiple sensors of different design
- Different degradation modes
- Common data processing algorithms & methodologies
  - Calibration\*
  - Atmospheric correction
  - Bio-optical
  - Masks & Flags



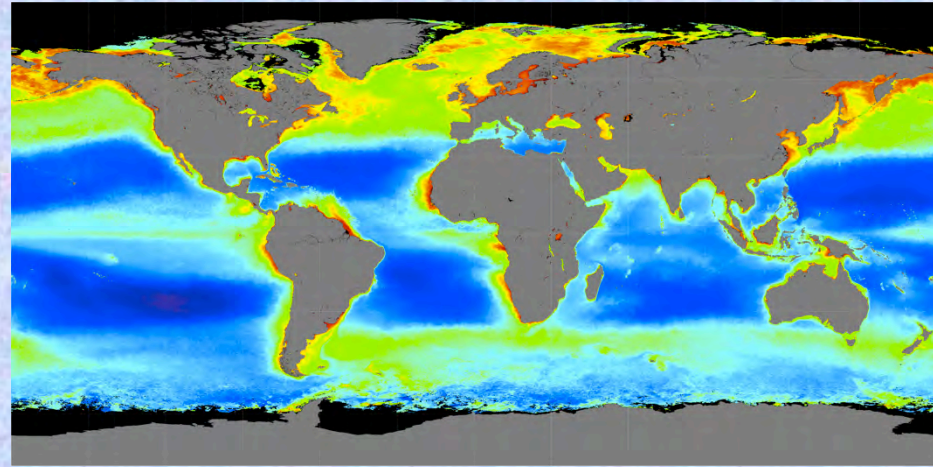
\* MERIS on-orbit calibration is not lunar-based.



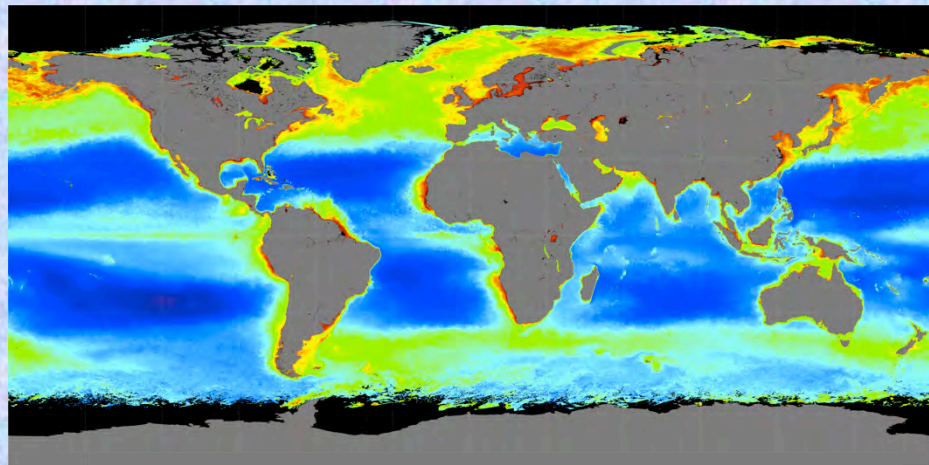
# Data Product Consistency Across Global OC Sensors



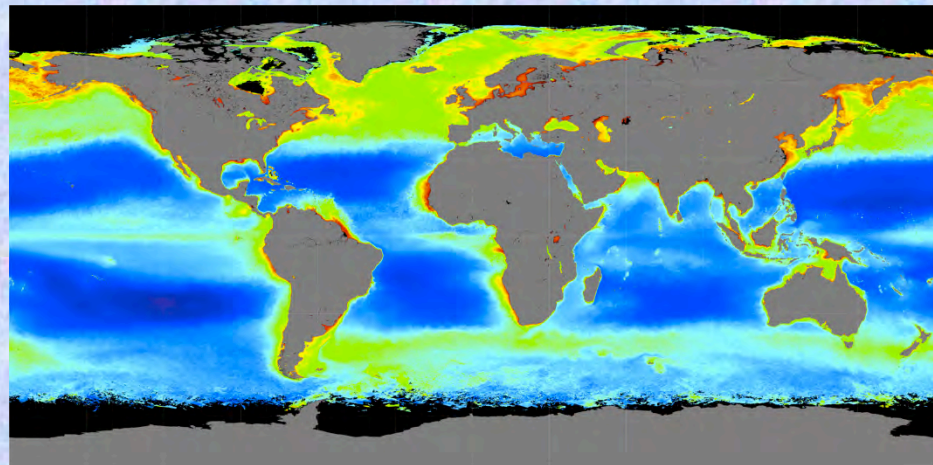
Spring 2012 - VIIRS



Spring Climatology - SeaWiFS

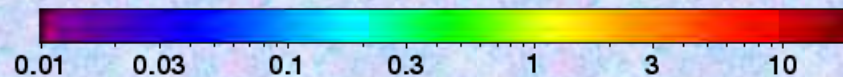


Spring Climatology - Aqua/MODIS



Spring Climatology - Terra/MODIS

Chlorophyll a concentration ( mg / m<sup>3</sup> )





# Honorable Mention

(in no specific order)

- **Field programs**

- Venice tower time series
- BATS optical time series
- AERONET-OC/SeaPRISM
- Boussolle optical mooring time series

- **International cooperative activities**

- Oceanography from Space conferences
- Japan US Working group in Ocean Color (JUWOC)
- NASDA-NASA OCTS reprocessing collaboration
- HPLC Round-Robins (SeaHARRE)

- **Algorithms**

- Gordon & Clark clear water radiance concept
- Gordon-Wang atmospheric correction scheme
- Behrenfeld-Falkowski primary production algorithm

- **OC Sensor Engineering**

- LEO (Global): OCTS, POLDER, SeaWiFS, MODIS, MERIS, GLI
- Geostationary: GOCI



# Future Science: How do we get there?

## Present Validated Products

- Chlorophyll-a
- Diffuse attenuation coefficient (490 nm)

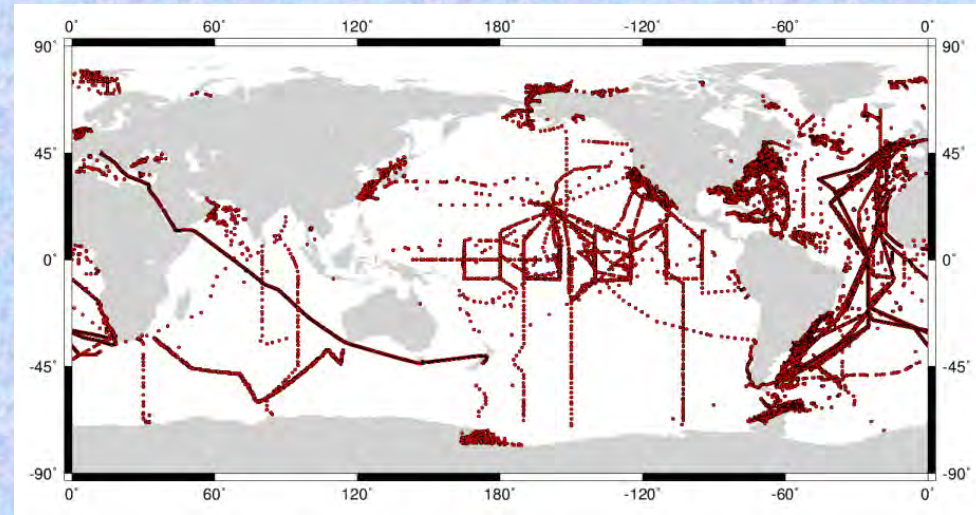
## Current Unvalidated Research Products

- Inherent optical properties
- Spectral diffuse attenuation
- Euphotic depth
- Spectral remote sensing reflectance
- Particulate organic carbon concentration
- Primary production
- Calcite concentration
- Colored dissolved organic matter
- Photosynthetically available radiation
- Fluorescence line height
- Total suspended matter
- Trichodesmium concentration

## Future Research Products

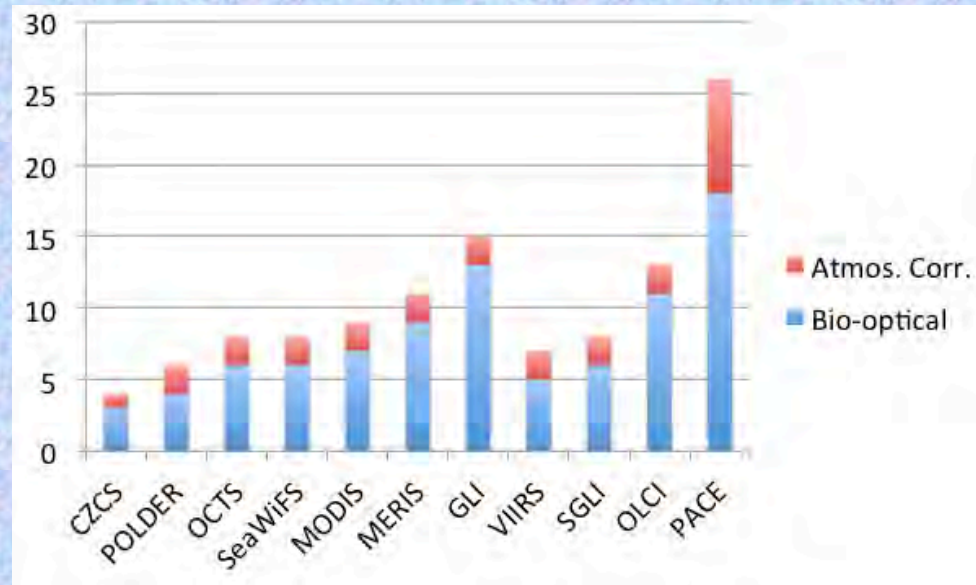
- Particle size distributions & composition
- Phytoplankton carbon
- Dissolved organic matter/carbon
- Physiological properties (e.g., growth rates)
- Fluorescence quantum yield
- Phytoplankton pigment absorption spectra
- Export production
- Functional/Taxonomic groups

## SeaBASS Chl-a: most sampled biogeochemical parameter



## OC sensor spectral bands

Note: PACE/OES is hyperspectral (350-800nm)





# Present & Future Challenges

- **Mission opportunities & space agency budgets & priorities**
  - Increasing requirements for more capable sensors
    - Technology not an issue, but cost & complexity can be
  - Competition for resources between science disciplines (Earth & space)
- **Field measurements and related technology**
  - In situ measurement requirements (increasing product suite/ diversity, consistent well-defined measurement protocols)
    - Need much more in situ data for most current & future derived products
  - Limited instrument development funding through present programs
- **International cooperation**
  - Coordination to minimize mission redundancies & optimize constellation to satisfy diverse science requirements
    - Global science vs. regional management
    - Combination of Low Earth Orbit (LEO) and Geostationary
  - Differing national policies on data and S/W sharing (field & satellite)
  - Collaboration on common infrastructure support (e.g., an international vicarious calibration strategy/system)
  - Joint Cal/Val cruise/field campaign program
  - Sponsorship of round-robin & protocol development activities



# Some Suggestions

- **International strategy on OC missions and science objectives**
  - **Low earth orbit: global, infrequent temporal**
    - IOCCG Report #13
  - **Geostationary: regional, high frequency temporal**
  - **Other ? (asynchronous, ocean-aerosol lidar, etc.)**
- **Pursue joint missions & partnerships**
  - **Defray launch, spacecraft, sensor, ground system, data processing, calibration/validation, science costs**
- **Coordinate joint international field campaigns for calibration/validation & algorithm development and mission science**
  - **Cruises of opportunity (significant science complement), e.g., AMT**
  - **Dedicated experiments**
    - Sequence of targeted regions of interest
    - “Host nation” vessels, multiple nation vessels, etc. scenarios
  - **Predefined measurement suite with internationally assigned &/or competed participation**
  - **Common in situ data archive with QC, e.g., SeaBASS**
- **Implement the International Network for Sensor InTercomparison & Uncertainty assessment for Ocean-colour Radiometry (INSITU-OCR)**