SeaWiFS, MODIS
and a Multi-Decadal Time Series

Watson Gregg,
Chuck McClain, Gene Feldman
and the Ocean Biology Processing Group
NASA Goddard Space Flight Center
Ocean Color Time Series Project
NASA REASoN CAN

Goal:

Provide consistent time series of Level-3 ocean color data from 1979, with a 9-year gap (1987-1996)

Emphasize consistent algorithms and calibration methodologies

Produce Climate/Earth Science Data Records (CDR/ESDR) of ocean color
Ocean Color Time Series

REASoN CAN Team:

Jim Acker, NASA/GES-DAAC
Wayne Esaias, NASA/Oceans and Ice Branch
Gene Feldman, NASA/Ocean Color Processing
Watson Gregg, NASA/Global Modeling and Assimilation
Steve Kempler, NASA/GES-DAAC
Greg Leptoukh, NASA/GES-DAAC
Chuck McClain, NASA/Ocean Color Processing

Data Merging:
Jim Frew, Stephane Maritorena, David Siegel, UCSB
Ocean Color Satellite Missions: 1978-2010 and Beyond

“Missions to Measurements”

1980 1990 2000 2010

CZCS

OCTS/POLDER

SeaWiFS

MODIS-Terra

MODIS-Aqua

VIIRS-NPP

VIIRS-2
<table>
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<tr>
<th></th>
<th>CZCS</th>
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Consistent Ocean Color Time Series Requires Similar

1) Calibration

2) Algorithms

3) Spatial and Temporal Resolution (Level-3)

4) Data Format

5) Access

6) Analysis Tools
Monthly Means/Anom: Global

Linear least squares fit line for 1997 - 2004 annual means (Oct-Sep) N = 7

- **SeaWIFS V4.1** 2.07%
- **Aqua** 16.76% *
- **Terra** -10.32%

Chlorophyll (mg m⁻²)

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</table>
Results from Reprocessing 1
Deep-water AOT and Chlorophyll Comparison to SeaWiFS

AOT (865)

Chlorophyll

\[
\text{<C}_{\text{modis}} = 0.174 \text{ mg m}^{-3} \\
\text{<C}_{\text{seawifs}} = 0.171 \text{ mg m}^{-3}
\]

Solid Line: MODIS/Aqua R1
Dashed Line: SeaWiFS R5
Seasonal Chlorophyll Images

MODIS/Aqua R1

SeaWiFS R5

Winter 2004

Summer 2004

0.01-64 mg m$^{-3}$
SeaWiFS-MODIS/Aqua Global Comparisons

MODIS Reprocessing 1.1 & SeaWiFS Reprocessing 5.1

Clear Water

Normalized Lw

Coastal

MODIS/SeaWiFS Ratio
Ocean Color Time Series: Challenges

CZCS

Data merging algorithm selection

How to determine uncertainty, especially between/among sensors

Atmospheric algorithm selection

Bio-optical algorithm selection
CZCS Science Algorithm Deficiencies

1) calibration  
2) navigation  
3) constant aerosol type  
4) single-scattering approximation for aerosols and no Rayleigh-aerosol interaction  
5) production of pigment rather than chlorophyll  
6) lack of whitecap/foam reflectance  
7) lack of accounting for pressure variability in Rayleigh scattering  
8) lack of accounting for increased water-leaving radiance at 670 nm at high chlorophyll

SeaWiFS Version 5.1, Aqua Version 1.1:  
9) new Rayleigh scattering tables  
10) BRDF  
11) Thuillier extraterrestrial irradiance
Reconstruct historical ocean color record using modern methodologies, Coarse resolution (seasonal, 1-deg.)

Historical CZCS
Reanalyzed CZCS
Modern SeaWiFS

Watson Gregg, NASA/GSFC
Margarita Conkright, NODC (in situ data)
Jay O’Reilly, NMFS (bio-optical algorithm)
Fred Patt, NASA/GSFC/SAIC (navigation)
Menghua Wang, UMBC (atmo correction)
Jim Yoder, URI (analysis, overall guidance)
Nancy Casey, NASA/GSFC (analysis)
### CZCS AI/SeaWiFS Algorithm Compatibility

**SeaWiFS Reprocessing 4 -- Aug 2002**

<table>
<thead>
<tr>
<th>CZCS Algorithm Improvement</th>
<th>SeaWiFS</th>
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<tbody>
<tr>
<td><strong>Calibration</strong></td>
<td>Evans &amp; Gordon 1994 retrospective reanalysis</td>
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<tr>
<td><strong>Navigation</strong></td>
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<td><strong>Rayleigh Scattering</strong></td>
<td>Exact multiple scattering pressure-corrected</td>
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<td><strong>L_w (NIR)</strong></td>
<td>Corrected at 670 nm</td>
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<td><strong>Aerosol Type</strong></td>
<td>Characterized in clear water using 550 and 670 nm Objectively analyzed in high chl</td>
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<td>SeaWiFS Multiple scattering/ Rayleigh-aerosol tables</td>
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<td><strong>Foam Correction</strong></td>
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<td><strong>Bio-Optical Algorithm</strong></td>
<td>Maximum band ratio OC3C</td>
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<td></td>
<td>O’Reilly et al. (2000)</td>
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Ocean Color Time Series Plans

OCTS  Adapt new NIR algorithm and new calibration gains
reprocess by Summer 2005
Begin analysis and validation
Archive validated late 2005

CZCS  Create clean L1A data archive
Obtain precision orbit ephemerides
Upgrade Rayleigh scattering
Re-calibrate Band 1 (443nm)
Begin processing of data using SeaWiFS/Aqua-like algorithms
Produce consistent data set end 2005/early 2006

First version consistent time series early 2006

Community evaluation, re-evaluate algorithms in context of new developments, new applications to SeaWiFS and MODIS

Workshop to define time series standard processing 2007
Ocean Color Data Merging

Workshop held May 2005, sponsored by IOCCG and NASA

Watson Gregg and Paula Bontempi, Co-Chairs

Objectives: To define
1) data and knowledge requirements
2) assessment methodology
3) possible approaches, with strengths and weaknesses

for merging coincident ocean color data from multiple sensors.

Members:
1) Jim Aiken, PML, UK
2) Ewa Kwiatkowska, NASA/OBPG, USA
3) Stephane Maritorena, UCSB, USA
4) Fredric Melin, JSC, Italy
5) Hiroshi Murakami, JAXA, Japan
6) Simon Pinnock, ESA, Italy
7) Claire Pottier, CNES, France
Data Merging Algorithms

Combining data from concurrent missions

Approaches Reviewed:
1) Binning
2) Averaging
3) Subjective Analysis
4) Error-weighted averaging
5) Blended Analysis
6) Optimal Interpolation
7) Objective Analysis
8) Wavelet Analysis
9) Neural Network Analysis
10) Spectral Bio-Optical Modeling
11) Data Assimilation into a Numerical Model
Data Merger Recommendations (draft)

-- Data set knowledge more important than data set quality
Missions should report performance. Minimum RMS and bias
(log-transformed for chl and IOP/AOP), using common in situ
data base (NOMAD)
-- One of biggest impediments to data merging is mission reanalysis
-- Most efforts use L3 data; L3 data production required
-- Emphasize global missions for merging
-- IOCCG should provide links to international in situ ocean color data
bases
-- Should merge chlorophyll, and all other common L3 data products
except aerosol products
-- Merging methodology intercomparison is encouraged, using
frozen mission data set versions, and 4 global mission
data sets (SeaWiFS, Aqua, GLI, MERIS)
Ocean Color Satellite Missions: 1978-2010 and Beyond

- CZCS
- OCTS/POLDER
- SeaWiFS
- MODIS-Terra
- MODIS-Aqua
- MERIS
- GLI/POLDER
- S-GLI
- VIIRS-1
- VIIRS-2

Timeline:
- 1980
- 1990
- 2000
- 2010
Reanalysis of Ocean Color Data

Reanalysis: start from new scientific or technical approach
Time required: 6-12 months for a single mission data set

Reprocessing: start from established and validated methodology, simply a computer-execution event
Time required: 1-30 days for a single mission data set

SeaWiFS: 4 reanalyses in 7 years (6 if count “mini-reprocessings”)

V1 (09/1997): pre-launch calibration and algorithms
V2 (01/1998): 1st estimated observed calibration
V3 (05/2000): high chlorophyll errors corrected, negative LwN’s reduced
V4 (08/2003): in situ calibration errors corrected, new high chl algorithm
  V4.1 (05/2004): new temporal trend
V5 (04/2005): BRDF – compatibility with Aqua
  V5.1 (07/2005): Thuillier constants and new L3 data format
Advantages:

Necessary to provide accuracy, improvements, correct errors

Climate trends can be very small, requiring latest understanding of scientific and technical issues

May correct false trends

Disadvantages:

Impacts ongoing scientific analysis

In a CDR context, a reanalysis may apply to all related missions, increasing the complexity of the effort and increasing the chance of mismatches

Can affect previous understanding of data quality
Data set accuracy must be weighed against stability

Can we set criteria a priori or must it be settled on a case-by-case basis?
Ocean Biology Processing System:
Transition from “Missions to Measurements”

**MAIN PROCESSING SYSTEM**
- Data from multiple satellite and instrument types
- In-situ, ancillary, and other data

- Reconfigurable & Scalable
- Science Community Interactive
  - Knowledgeable Staff
  - Enabling Activities (SeaBASS, SeaDAS, Calibration RR, etc.)
- Flexible Processing
  - Multiple Missions
  - Rapid Reprocessing
  - Parallel Processing Streams (operational, algorithm & calibration testing, evaluation products)

**OBPG Management & Staff**
- MCST*
- NASA HQ Program Management
- NASA Flight Projects
- Science Community

**Community Agreed Standards and Protocols**

**Data**
- GSFC
d- DAAC
- Users

**L1 DATA**
**L1-L3 DATA**

**Data Set Category:**
- Historical (REASoN-CAN)
- Present (EOS, other)
- Future (NPP: EDR Evaluation)

* MODIS Characterization Support Team (NASA/GSFC)
# Terra MODIS OC processing suspended in Jan. 2004
Data Access and Community Support

- **SeaDAS enhancement**
  - Full OCTS, SeaWiFS, MODIS ocean processing support starting with level-0 (direct broadcast users). CZCS processing to be updated.

- **Research campaign support**
  - Global ocean color and sst data available for distribution within 3-4 hours of acquisition by the spacecraft.

- **Web/FTP-based data access and distribution**
  - web/ftp-based browse, order, subscription and extract tool that allows everything from a single file to the entire multi-mission data set to be downloaded. Doing this within the discipline group adds flexibility and quick response for new products prior to them being designated as “CDR’s”
Aqua Reprocessing Results

- New LUT
- Straylight rejection
- RSR and pressure corrections
- Fresnel
- \( f/Q \)
- New MOBY vicarious cal

Also applied in SeaWiFS Reprocessing 5
Results from Reprocessing 1
nLw Comparison to SeaWiFS R5

- Sensor agreement to within 7% for global mean deep-water nLw retrieval. Better for clear water.
- Some bias & trend is still evident between instruments.
Results from Reprocessing 1
nLw Ratio to SeaWiFS R5, Zonal Pacific, 150W-170W

Initial Processing

Reprocessing

Latitude (Solar Zenith)

+/- 20%
35 North

+/- 10%
25 North

+/- 5%
15 North
SeaWiFS Data Quality:
Global Consistency & In Situ Verification

Field Validation: Lwn’s

Temporal Consistency

Field Validation: Chl-a

* Lwn: Normalized Water-leaving Radiance
MODIS/Aqua Data Quality:
Global Consistency & In Situ Verification

Field Validation: Lwn’s

Field Validation: Chl-a

* Lwn: Normalized Water-leaving Radiance
Recent Reprocessing: SeaWiFS 5.1 & MODIS/Aqua 1.1

- TOMS V8 ozone product
  - TOMS V7 previously used
- Thuillier solar irradiance spectrum
  - Neckel & Labs previously used
- Updated MODIS calibration LUT from MCST
- Improved MODIS detector-to-detector calibration for striping reduction
- Revised K(490) algorithm

SeaWiFS V5.1 now available, Aqua 1.1 due shortly

http://oceancolor.gsfc.nasa.gov/REPROCESSING/Aqua/R1.1/
http://oceancolor.gsfc.nasa.gov/REPROCESSING/SeaWiFS/R5.1
Relative Detector Sensitivities: Striping

Solid & Open Circles: 2 mirror sides

Processing 1

Processing 1.1
Effect of OBPG Striping Correction
nLw 412 nm

Before Correction

After Correction
Ocean Color Web

Consolidated data access, information and services

Data Access

Level 1 and 2 Browser
Visually search the ocean color data archive and directly download and/or order data from single files to the entire mission. Extensive online HELP and tutorials available.

Level 2 Browser
Browse the entire Level 3 global ocean color data set for many parameters and time periods and download either JPEG images or digital data in HDF format.

Data Subscriptions
Request a subscription for Aqua data to be staged on an FTP site. You can check the status of an existing subscription.

Data by FTP
The project maintains several FTP sites containing the most popular data products including the complete Level 3 data archive.

GES DAAC
The GES DAAC hosts the recently reprocessed MODIS/Terra ocean color data, the SeaWiFS, OCTS, and CZCS data sets and Terra and Aqua SST data.

Ocean Color Web Feature
Recent topics and imagery of interest to the OceanColor community.

A tropical cyclone named Willy tracked across the eastern Indian Ocean between the 9th and 19th of March, 2005. On March 16th, MODIS measured increased chlorophyll concentrations in the waters that the storm had passed over. Either the storm increased phytoplankton production by mixing colder, nutrient-bearing water to the surface, or the water mixed to the surface contained colored dissolved organic material which looked like chlorophyll to the sensor. Other storms such as Hurricane Isabel have resulted in similar phenomena.

Image Gallery
NOTES: All SeaWiFS images presented here are for research and educational use only. All commercial use of SeaWiFS data must be coordinated with the SeaWiFS Ocean Color Distribution Statistics.