Toward Long-Term Consistency in Ocean Color Measurements

Bryan Franz
Ocean Discipline Processing Group
the project formerly known as SeaWiFS/SIMBIOS/SeaDAS/SeaBASS

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SeaWiFS Annual Repeatability in nLw  
Deep-Water Subset, 8-Day Bins

Long-term temporal stability is a fundamental requirement for climate data records.
Demonstrated sensor stability, and ultimately **mission to mission consistency**, allows for geophysical interpretation of long-term changes.
Changes in SeaWiFS response over time are tracked and corrected exclusively through monthly observations of the moon. Degradation is well behaved and predictable. **No need for routine updates.**
MODIS/Terra Solar Diffuser Trends
412 nm, 2 Mirror Sides, 10 Detectors

MODIS/Terra temporal calibration has not been predictable, thus requiring routine calibration updates to maintain long-term stability. Degradation of mirror + state changes + SD measurement error.
MODIS response varies significantly across the scan (different mirror AOI). Mirror is degrading => RVS is changing => polarization sensitivity is changing. Effects vary by detector and mirror-side.
Sensor-to-Sensor Comparative Analysis

<table>
<thead>
<tr>
<th>SeaWiFS Band</th>
<th>MODIS Band</th>
<th>SeaWiFS $\lambda$ (nm)</th>
<th>MODIS $\lambda$ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>412</td>
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<tr>
<td>8</td>
<td>16</td>
<td>865</td>
<td>869</td>
</tr>
</tbody>
</table>

Water-Leaving Radiance Products

- 8-Day mean Level-3 products binned at 9 km resolution
- common bins selected between sensors (equal area bins)
- means computed and trended with time

Deep Water Subset

- all bins deeper than 1000 meters
MODIS/Terra Collection 4.1

comparison with

SeaWiFS 4th Reprocessing
MODIS and SeaWiFS Annual Repeatability

MODIS/Terra Collection 4.1 vs SeaWiFS 4th Reprocessing

Deep-Water Subset, 8-Day Means

The annual repeatability of MODIS/Terra Collection 4.1 is not at the level observed with SeaWiFS. Variability may not be geophysical.
SeaWiFS radiances are relatively stable with time, while MODIS/Terra Collection 4.1 shows long-term increases at 488 and 551-nm and large deviations from SeaWiFS over shorter time-scales.
Variability in MODIS/Terra radiances translates to +/- 20% differences in global-averaged deep-water chlorophyll retrievals between sensors. Note that the agreement is good when averaged over years.
Both sensors show a similar level of agreement with *in situ* data.
However, match-up distribution is heavily biased to mid-latitude NH,
and differences between the two sensors vary geographically with a strong seasonality that increases with latitude (solar zenith angle). This may be uncorrected polarization, BRDF, other …..
What about Aqua?
MODIS and SeaWiFS nLw Trends

MODIS/Aqua Collection 3.0 vs SeaWiFS 4th Reprocessing
Deep-Water Subset, 8-Day Means

**MODIS & SeaWiFS**

**MODIS / SeaWiFS**

MODIS radiances are 10-40% higher than SeaWiFS, and increasing with time in all bands. Few resources have been focused on characterization of MODIS/Aqua, due to difficulties with Terra.
MODIS/Aqua Reprocessing

within the

Ocean Discipline Processing System (ODPS)
Differences from MODAPS Processing

File Formats and Standard Product Suite

• SeaWiFS-like file formats for Level-2 and higher.

• SeaWiFS-like product suite + 11um SST.

  nLw_412          normalize water-leaving radiance at 412 nm
  nLw_443          normalize water-leaving radiance at 443 nm
  nLw_488          normalize water-leaving radiance at 488 nm
  nLw_531          normalize water-leaving radiance at 531 nm
  nLw_551          normalize water-leaving radiance at 551 nm
  nLw_667          normalize water-leaving radiance at 667 nm
  chlor_a          OC3M chlorophyll (MODAPS chlor_a_2)
  sst              11um sea surface temperature
  eps_78           750/869 SS aerosol reflectance ratio
  angstrom_531     Angstrom exponent 531/869
  tau_869          aerosol optical thickness at 869

• Reduced Level-2 file size of 80MB (5-30MB compressed).
Differences from MODAPS Processing
Calibration

• Instrument Calibration (MCST)
  – Revised temporal calibration based on smoothed solar diffuser measurements and OBC-determined RVS corrections.

• Vicarious Calibration (ODPS)
  – No time dependence.
  – NIR ratio fixed at Tahiti (well characterized AERONET site, chosen for consistency of aerosol type over time).
  – Visible calibration determined at MOBY (6-point average).

\[
\begin{array}{cccccccc}
412 & 443 & 488 & 531 & 551 & 667 & 749 & 869 \\
0.9801 & 0.9846 & 0.9875 & 1.0003 & 0.9984 & 0.9913 & 0.9915 & 1.0000
\end{array}
\]
After ODPS reprocessing, MODIS/Aqua radiances are at most 5-10% higher than SeaWiFS, but with seasonal variability in differences.
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MODIS/SeaWiFS nLw Ratios

MODIS/Aqua ODPS Reprocessing vs SeaWiFS 4th Reprocessing
Zonal Pacific Subsets (150-170W), 8-Day Means

Seasonality in high-latitudinal differences is clear. Magnitude and phase are very similar to comparisons with MODIS/Terra 4.1. This results in high-lat chlorophylls which are 30-50% higher than SeaWiFS in winter.
MODIS and SeaWiFS Annual Repetatability

MODIS/Aqua **ODPS** Reprocessing vs SeaWiFS 4th Reprocessing
Deep Water Subset, 8-Day Means

**SeaWiFS**

**MODIS/Aqua**

Additional algorithm development and/or characterization work is needed to achieve the level of stability observed with SeaWiFS.
ODPS Data Distribution

• Currently MODIS/Aqua only
• Aqua data available within 2-4 hrs of observation
• Level-1A + ancillary files for processing in SeaDAS
• Level-2 standard product suite
• Level-3 mapped (chlorophyll, K490, tau_869, nLw_551)
• Web-based browse, search and order + point and click direct access.
• Direct ftp access to most recent L1A, L1B, Geolocation, L2, and entire mission archive of L3 maps at 4 and 9-km.
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 3 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.

**Oceans FTP Site**
The Oceans FTP site contains the most recent 10 days worth of all MODIS/Aqua data and products, as well as the complete Level 3 mapped 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 (in conventional MODIS format).

Latest News

Welcome to the new OceanColor Web. This site is intended to serve as the entry point into all of NASA's ocean color-related activities as part of the evolution of the individual ocean mission-based activities into an integrated ocean measurement-based program.

We have just begun the process of integrating the various mission-specific services, information, and documentation that have been developed over a number of years, so we expect that this website will be evolving quite rapidly. We encourage everyone to use the online forum, which is linked through the Questions button above, to provide feedback, ask questions and offer suggestions.

Support Services

**SeaDAS**
SeaDAS is a comprehensive image analysis package for the processing, display, analysis, and quality control of ocean color data.

**SeaBASS**
SeaBASS is an archive of in situ oceanographic and atmospheric data used for algorithm development and satellite validation.

**Cruise Support Services**
Overflight predictions; Near real-time imagery and data for cruise support.

**MQABI**
MODIS (Ocean) Quality Assurance Browse Imagery Tool that allows access to MODIS Sea Surface Temperature products and statistics.

Subscribe: Ocean Mailing List
online repository for anonymous ftp downloads containing:
1- the most recent 10 days of ALL MODIS/AQUA products
2- the complete Level-3 mission archive at multiple time/space resolutions
3- the complete ancillary met/ozone data and attitude and ephemeris

MODIS/Aqua data available within hours of observation

oceans.gsfc.nasa.gov

Anonymous access granted, restrictions apply.

Path: [oceans.gsfc.nasa.gov]

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<td>Folder</td>
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Multi-Mission Browse and Order Page - Showing navigation tools

Selection = Full MODIS/Aqua Mission - Chlorophyll

Sunday, 23 June 2002 through Monday, 9 February 2004

Chlorophyll

Display results at a time.
Selection = Single Day MODIS/Aqua Mission - Sea Surface Temperature
For next screen, click on map near Central America

Saturday, 7 February 2004
(2004038)

Sea Surface Temperature

<table>
<thead>
<tr>
<th>December 2003</th>
<th>January 2004</th>
<th>February 2004</th>
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<tbody>
<tr>
<td>S  M  T  W  T  F  S</td>
<td>S  M  T  W  T  F  S</td>
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</table>
Single file (level-1 or level-2) browse and download page

From this page one can directly download the compressed data.
Files in either level-1 or level-2 format as well as the supporting documentation.

The next example shows how to order all the files acquired over a week covering a given geographic region.

A2004038191500.L1A_LAC
50,998,234 bytes
A2004038191500.L2_LAC
20,472,527 bytes
(The above hyperlinks point to bzip2-compressed HDF files. Documentation on these prototype products can be found HERE.)

Search Criteria
Time Period: Saturday, 7 February 2004
Sensors: MODIS(Aqua)
Area of Interest: Within 36 km of 16.5N, 90.4W
Percentage of AOI that swaths must include: Any part

Number of swaths: 1 swath found
Selection = Eight Day MODIS/Aqua Mission
Next Screen: select ALL the Aqua files that cover east coast of the United States during this period by clicking on the map.
These are all the Aqua files that covered the geographic region you chose during the first 8 day period in February 2004. You can individually select which files you may want to order by clicking on the little box above the image (based on coverage, cloud cover, etc.) or just order them all.

<table>
<thead>
<tr>
<th>Date</th>
<th>File Name</th>
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<tbody>
<tr>
<td>8Feb2004</td>
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<td>7Feb2004</td>
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<td>6Feb2004</td>
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<tr>
<td>1Feb2004</td>
<td>A2004034181000.L2 LAC</td>
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</tbody>
</table>

**Search Criteria**

- **Time Period:** 8-day period beginning Monday, 2 February 2004
- **Sensors:** MODIS(Aqua)
- **Area of Interest:** Within 36 km of 39.7N, 74.2W
- **Percentage of AOI that swaths must include:** Any part

**Number of swaths:** 1st through 9th of 9 swaths
Choose which products you want and what level of interaction with the ordering system you prefer.

Enter your email address.

gene.c.feldman@nasa.gov

Pick which data products you want for your selected scenes.

- Level 1
- Level 2
- Meteorology & Ozone
- Attitude & Ephemeris

- Remind me when my order is about to expire.
- Require my email confirmation for early file deletion.
- Notify me when my data have been deleted from the staging area.

Review order
Review your order and if correct, submit it. In a few minutes after you submit Your order, you will receive an automated confirmation message from the Ordering system that by replying to, will trigger your order to be filled. Currently, orders are staged within 3-5 minutes after confirmation.

You are about to order the following 18 files from the SeaWiFS Data Processing System.

<table>
<thead>
<tr>
<th>A2004039182500.L1A_LAC</th>
<th>A2004037184000.L1A_LAC</th>
<th>A2004036175500.L1A_LAC</th>
<th>A2004035171500.L1A_LAC</th>
<th>A2004034181000.L2_LAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2004038174500.L1A_LAC</td>
<td>A2004037170000.L1A_LAC</td>
<td>A2004035185000.L1A_LAC</td>
<td>A2004034181000.L1A_LAC</td>
<td>A2004033172500.L2_LAC</td>
</tr>
</tbody>
</table>

The total volume of the above files (in the compressed form in which they are stored in our archive) is \textbf{475,250,680} bytes.

You are also about to order the ancillary data (Meteorology & Ozone and Attitude & Ephemeris) that correspond to the scenes in your search results.

You do wish to be reminded by email when your order is about to expire, and you do require email confirmation when you use the Web to request early deletion of your staged order, and you do wish to be notified when your order has been deleted from our staging area.

The email address you have entered is \textbf{gene.c.feldman@nasa.gov}.

If all this information is correct and you wish to submit your order to be filled, then click the "Submit order" button below.
Work in Progress

• Frequent reprocessing for evaluation (80-100x processing capacity)

• Running various sensitivity analyses over temporal subset of MODIS/Aqua mission.
  – Various polarization correction approaches
  – Various BRDF correction options
  – Various Level-1B LUT approaches (working closely with MCST personnel)

• Additional distribution options (parameter and geographic subsetting, subscriptions)
Extra Slides
Some issues raised in recent calibration reviews reflect a difficulty in separating changes in instrument from changes in SD measurements.

Challenging Issues and Concerns

- BRF error’s impact on RSB calibration
- Instrument and focal plane temperature effects
- On-orbit RVS characterization limits
- Polarization (SBRS/MCST/Miami)
- SD screen vignetting effect – observations and simulation results (Xiong/Waluschka)
- Scattering (SBRS/Waluschka)
- Earth shine (Wolfe)
- Calibration (detector’s response) stability
MODIS Oceans Calibration

- **MCST pre-launch calibration**
  - DN to reflectance, temperature corrections, response versus scan angle (RVS)

- **MCST on-orbit calibration (solar, lunar, srca)**
  - time dependent gains
  - RVS adjustments
  - detector normalization (destriping)

- **RSMAS (Univ. of Miami) vicarious calibration**
  - time dependent gains, offsets to match water-leaving radiances from MOBY
  - time dependent RVS correction, detector normalization, mirror-side correction by flat-fielding near Hawaii.
MODIS Calibration Issues

Class 1: Potential Level-1 calibration coefficient sources of error
- Excess radiance on the MODIS solar diffuser (SD) due to Earthshine
- Excess radiance on the MODIS SD due to uncertainties in attenuation screen
- Uncertainty in the SD bi-directional reflectance (BRF) correction
- Uncertainties in the focal plane temperature corrections

Class 2: Maintaining calibration intra-orbit and inter-season
- Stray light in the optical path from Earth view
- Detector-based temperature correction estimates
- Changing polarization sensitivity
- Uncertainties in the focal plane temperature correction
Differences from MODAPS Processing

Processing Algorithms

- SeaWiFS Level-2 and Level-3 processing software applied.
- Updated polarization sensitivity tables.
- Minimal BRDF correction (no f/Q).
- Alternate NIR water-leaving radiance correction (Arnone & Stumpf rather than Seigel).
- Additional correction of nLw for out-of-band response.
- Reduced aerosol model suite (12 models).
- Glint correction (SeaWiFS algorithm + polarization terms).
- Whitecap correction (SeaWiFS algorithm).
- Different solar irradiance model (Thuillier 2003).
- No NIR smoothing.
**Simplified RSMAS Calibration Model (RADCOR)**

*only what is active for ocean color*

\[
L'(b,d,p,t) = [L(b,d,p,t) - O_v(b,t)] \cdot G_v(b,t) \cdot G_d(b,d,t) \cdot G_r(b,m,p,t)
\]

where:

- \(O_v\) is the vicarious offset
- \(G_v\) is the vicarious gain
- \(G_d\) is the detector relative gain (destriping)
- \(G_r\) is the RVS adjustment

\[b=\text{band}, \ d=\text{detector}, \ m=\text{mirror-side}, \ p=\text{scan-pixel}, \ t=\text{time}\]
Magnitude and phase of high-latitude differences are very similar for MODIS/Terra (MODAPS) and MODIS/Aqua (ODPS).