NASA support for ocean color research

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21 January 2010 @ SAC

professional background

NASA Goddard Space Flight Center - Jun 99 to present

oceanographer @ Ocean Biology Processing Group

ocean color from all instruments & SST from MODIS & VIIRS

located in Maryland near Washington D.C.

academic background

biology & environmental science @ University of Virginia - 1996

oceanography @ the University of Connecticut - 1998

oceanography @ the University of Maine - Sep 09 to present

1. why ocean color?
2. ocean color @ NASA
3. the NASA Ocean Biology Processing Group (OBPG)
4. calibrating & reprocessing an ocean color mission
5. international collaborations

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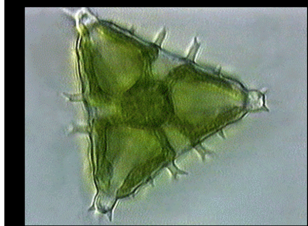
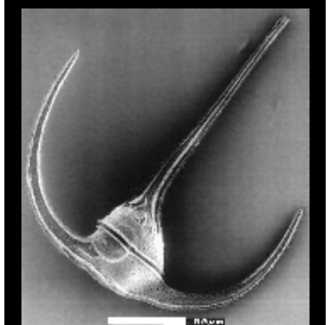
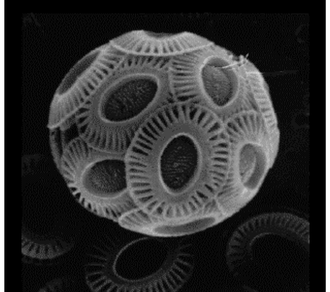
why ocean color?



ocean color:
ocean monitoring in the visible range of the electromagnetic spectrum

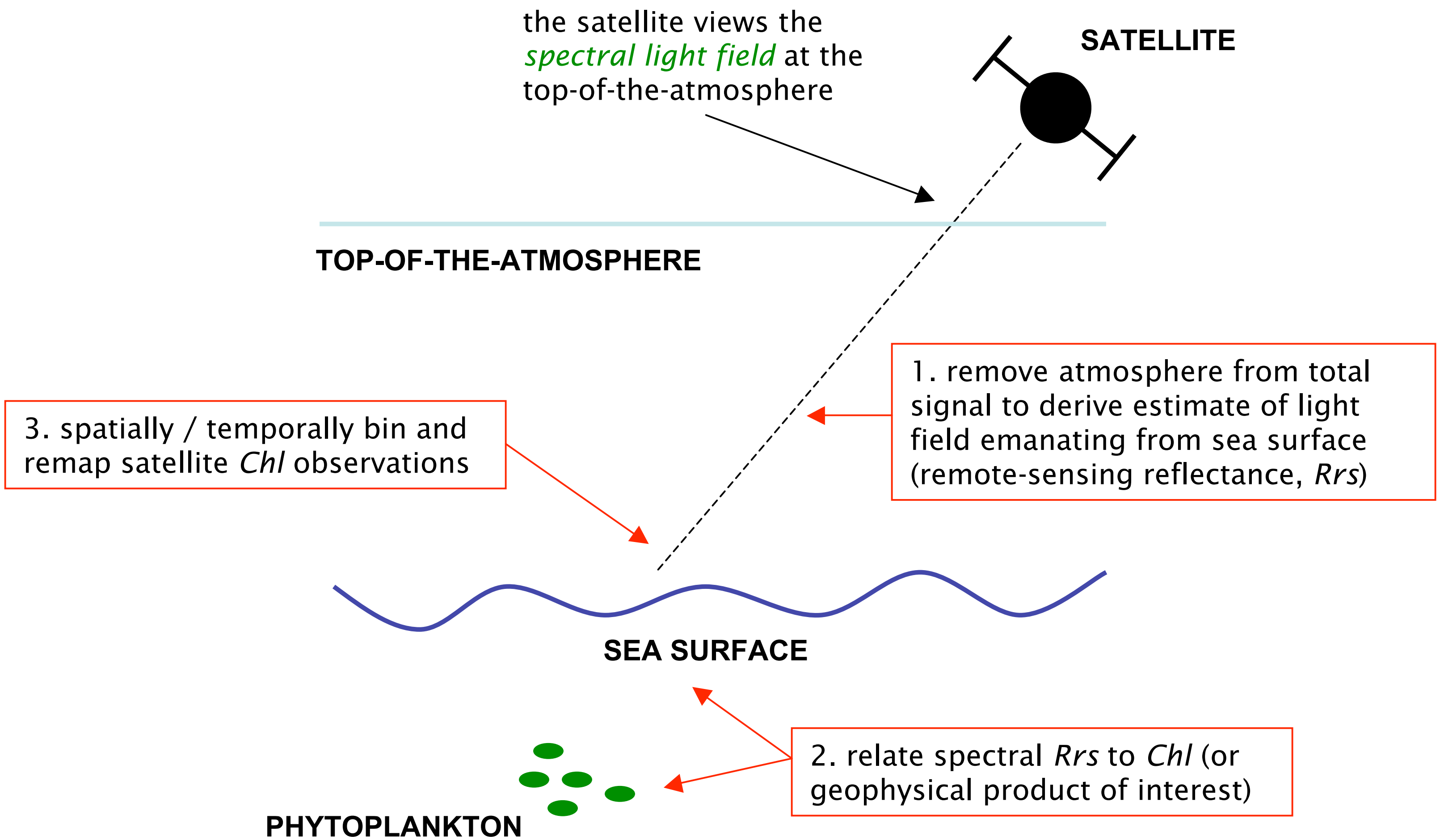
primary (historical) goal:
to extract concentrations of marine phytoplankton

phytoplankton:

- fix carbon dioxide into organic material
- play a profound role in the global carbon cycle and climate
- responsible for ~half of Earth net primary production
- form the basis of the marine food chain
- support various industries, primarily fisheries

secondary (modern) goals:
separate phytoplankton species (e.g. coccolithophore, harmful algae)
monitor coastal environments

why ocean color?

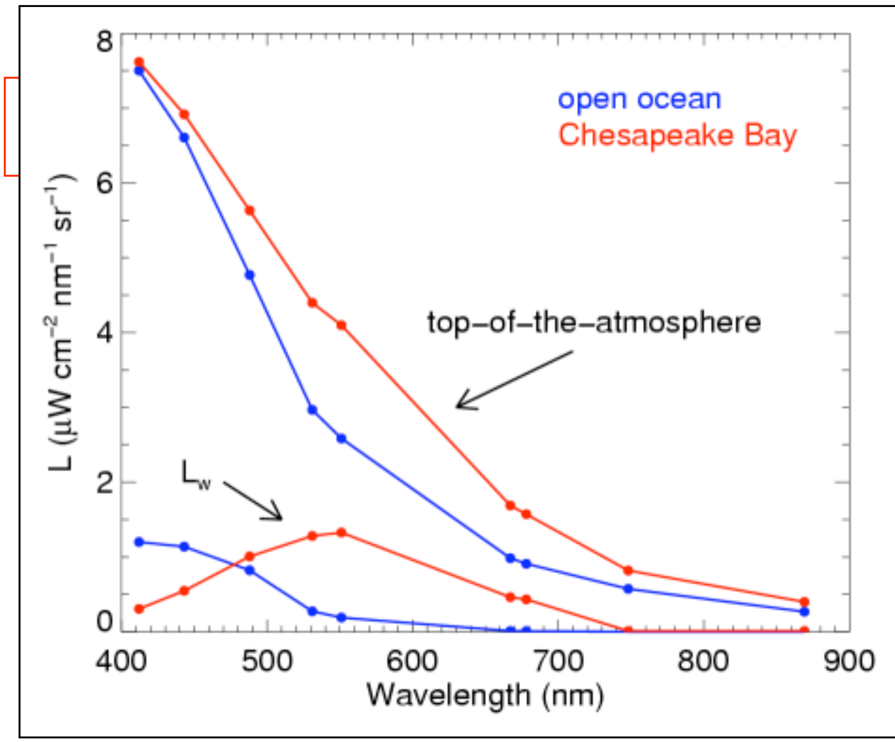


why ocean color?

the satellite views the *spectral light field* at the top-of-the-atmosphere

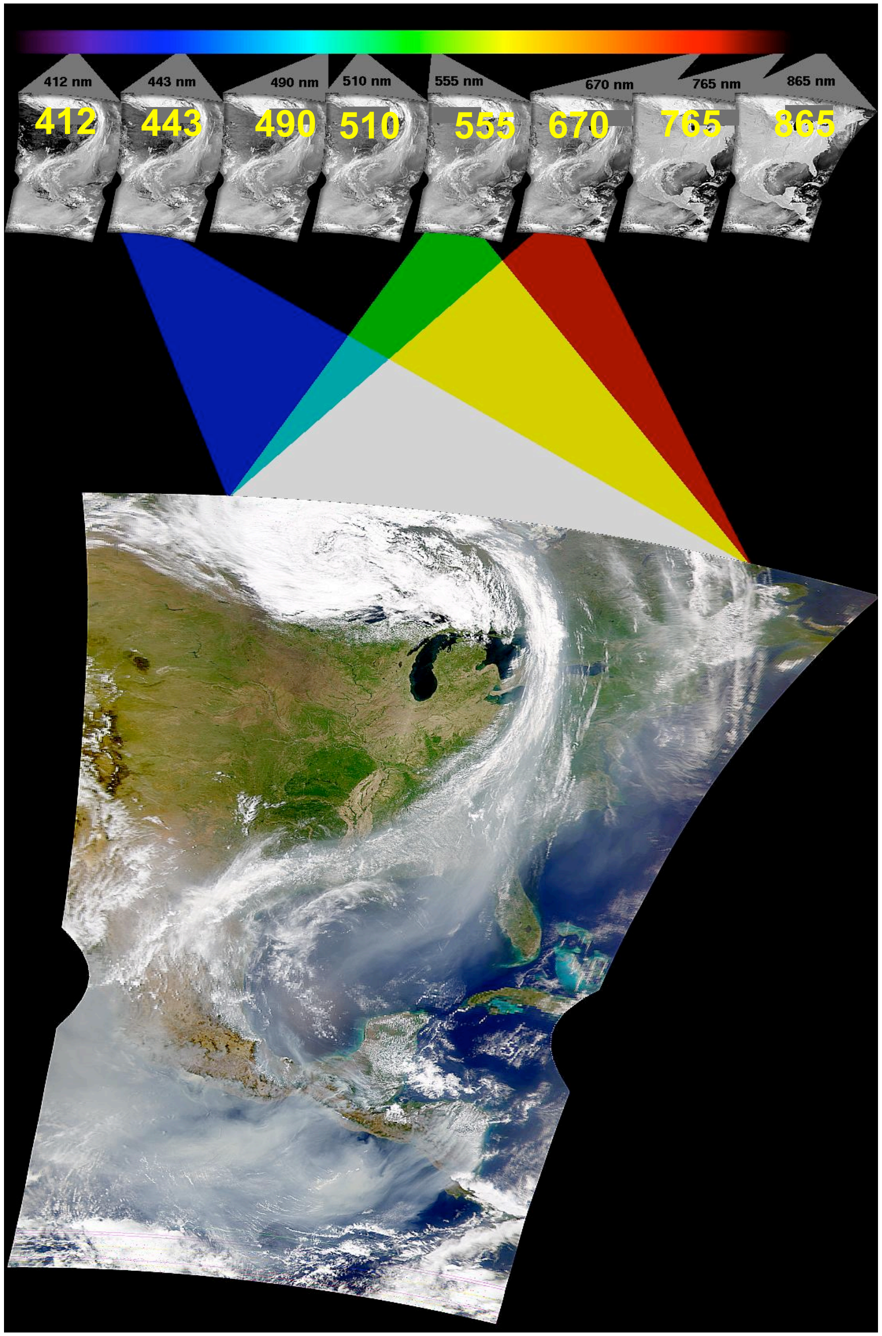
SATELLITE

TOP-OF-THE-ATMOSPHERE



1. remove atmosphere from total signal to derive estimate of light field emanating from sea surface (remote-sensing reflectance, *Rrs*)

2. relate spectral *Rrs* to *Chl* (or geophysical product of interest)



ocean color data products

primary optical variable

remote-sensing reflectance (Rrs; units sr-1);

the subsurface upwelled radiance that propagates through the sea-air interface, normalized by the downwelled irradiance

primary bio-optical variable

chlorophyll-a concentration (Chl; units mg m-3);

main photosynthetic pigment of phytoplankton, used as index of phytoplankton biomass;

other data products

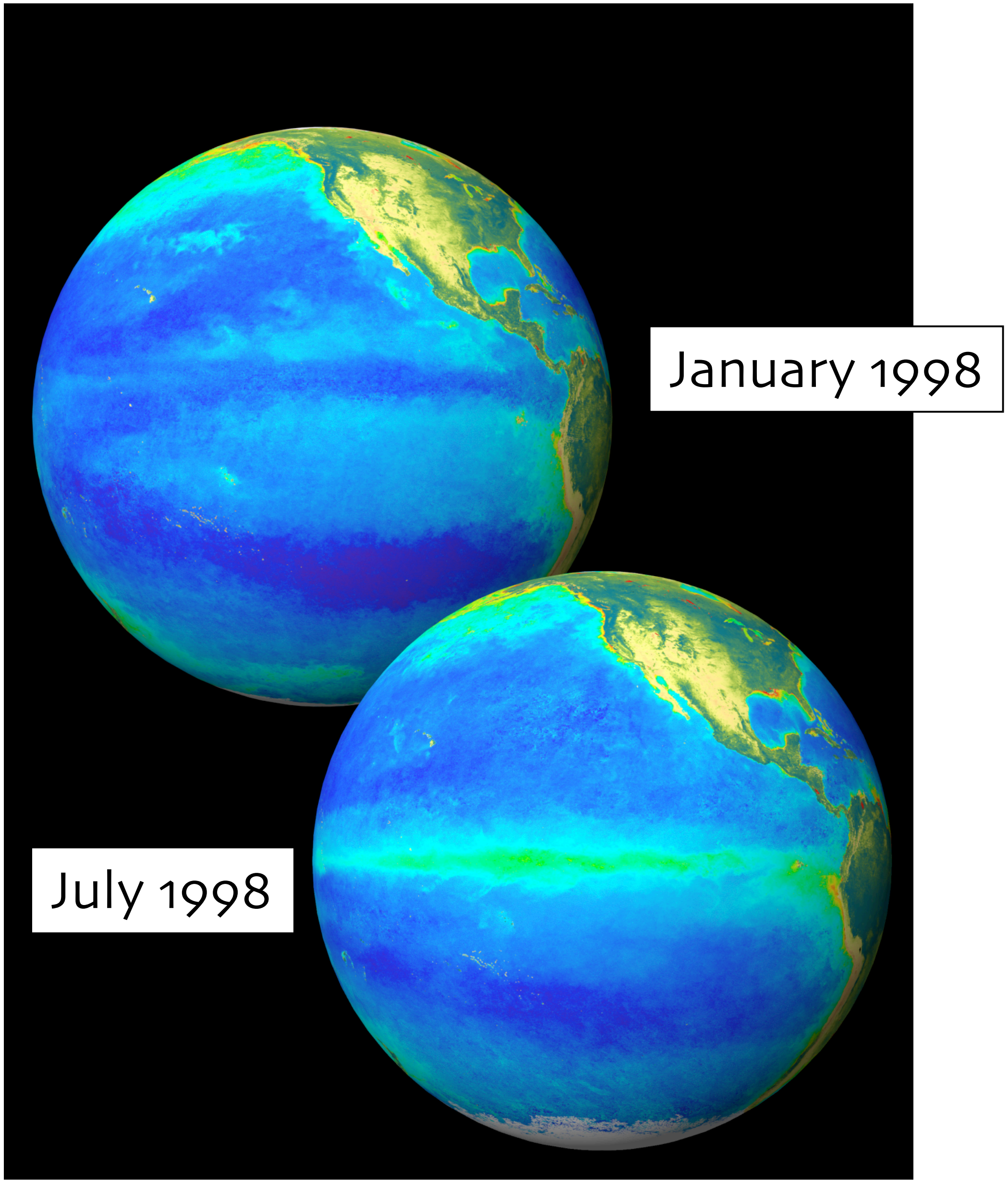
concentrations of water column constituents, e.g., particulate inorganic & organic carbon, &

descriptors of the light field (e.g., PAR, euphotic depth, fluorescence line height & quantum yield)

examples of ocean color applications

SeaWiFS captured the El Nino / La Nina transition

see Behrenfeld et al. "Biospheric primary production during an ENSO transition," Science 30 (2001)



examples of ocean color applications

climate & productivity are related

see Behrenfeld et al. “Climate-driven trends in contemporary ocean productivity,” Nature 444, (2006)

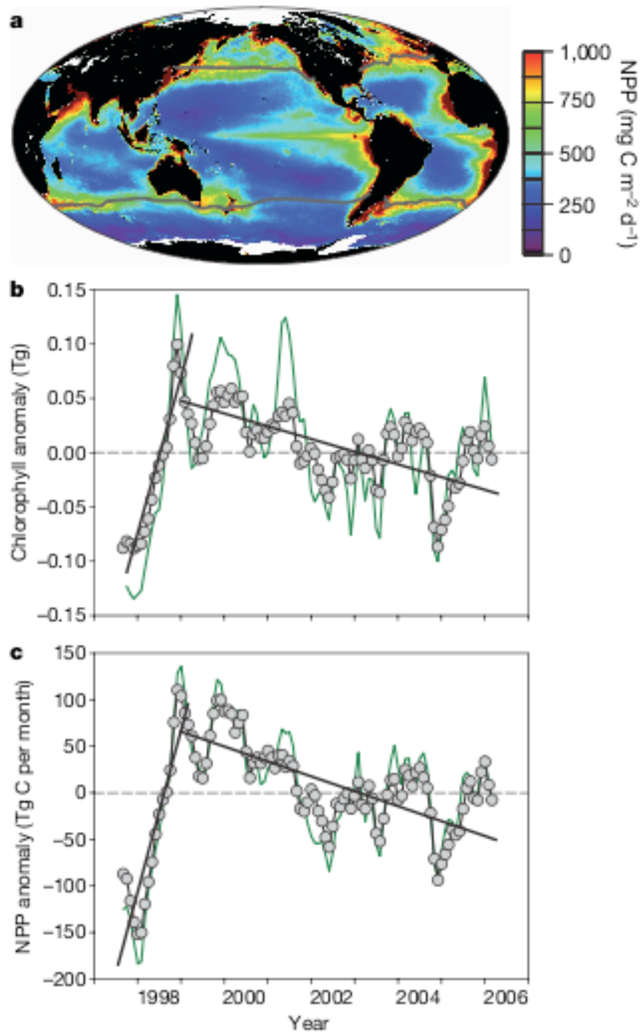


Figure 1 | Distribution and trends in global ocean phytoplankton productivity (NPP) and chlorophyll standing stocks.

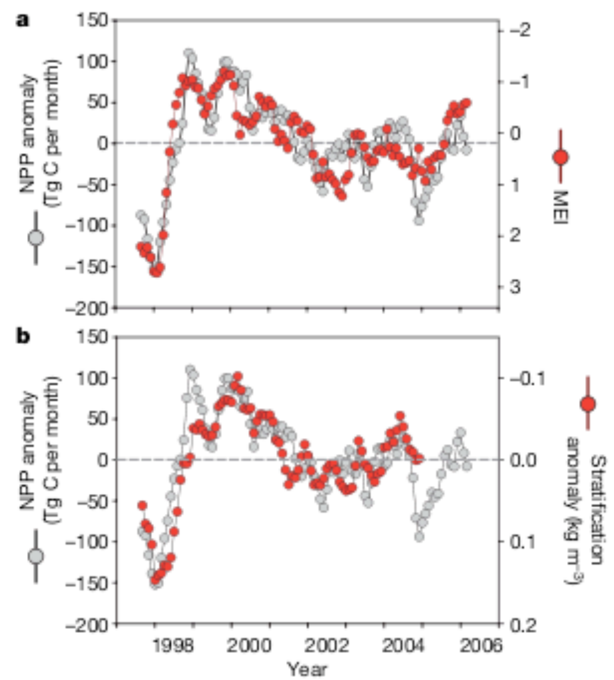


Figure 2 | Ocean productivity is closely coupled to climate variability.

examples of ocean color applications

harmful algal blooms

Gulf of Mexico Harmful Algal Bloom Bulletin

27 October 2005

National Ocean Service

National Environmental Satellite, Data, and Information Service

Last bulletin: October 24, 2005

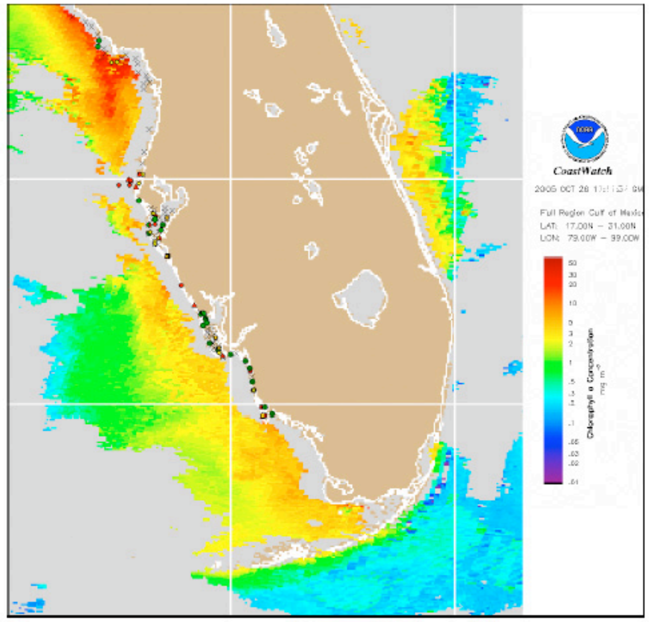
Conditions: Harmful algal blooms have been identified in Pinellas County, Dixie to Levy County and in very small patches from Manatee to Collier County in Florida. A secondary bloom has been identified in patches along Alabama and the Florida Panhandle. No impacts are expected along the coast from Pinellas to Collier County or from Dixie to Levy County today through Sunday. Patchy very low to low impacts are possible from Wakulla to Okaloosa County, FL and Baldwin to Mobile County, AL today through Sunday. Dead fish have been reported in Bay and Okaloosa Counties over the past few days. Dead fish smell, while unpleasant, does not produce the same respiratory irritation as red tide.

Analysis: The harmful algal bloom continues to dissipate along the SW Florida coastline; however very small remnant populations of *K. brevis* may still be present in patches from Pinellas to Collier County. Low *K. brevis* concentrations remain offshore of Bunces Pass in southern Pinellas County. Previous low *K. brevis* concentrations in Sarasota County have decreased to background levels (FWRI 10/20-26). Chlorophyll levels are elevated all along the Florida coast due to resuspension produced by Hurricane Wilma; thus bloom extent analysis is limited. Results of a wind transport model indicate possible bloom movement 20-30km southward since October 24. No recent samples have been reported from Levy to Dixie Counties. Sampling is recommended. Persistent northeasterlies will minimize coastal impacts through Sunday. Continual dissipation of the bloom is expected. Reports of discolored water are likely.

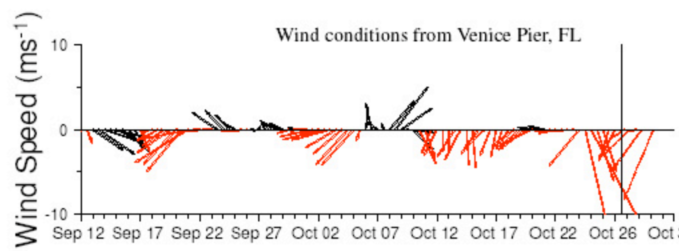
˜Fisher, Bronder

Please note the following restrictions on all SeaWiFS imagery derived from CoastWatch.

1. These data are restricted to civil marine applications only; i.e. federal, state, and local government use/distribution is permitted.
2. Distribution for military, or commercial purposes is NOT permitted.
3. There are restrictions on Internet/Web/public posting of these data.
4. Image products may be published in newspapers. Any other publishing arrangements must receive OrbImage approval via the CoastWatch Program.



Chlorophyll concentration from satellite with HAB areas shown by red polygon(s). Cell concentration sampling data from October 19, 2005 shown as red squares (high), red triangles (medium), red diamonds (low b), red circles (low a), orange circles (very low b), yellow circles (very low a), green circles (present), and black "X" (not present).



Wind speed and direction are averaged over 12 hours from measurements made on buoys. Length of line indicates speed; angle indicates direction. Red indicates that the wind direction favors upwelling near the coast. Values to the left of the dotted vertical line are measured values; values to the right are forecasts.

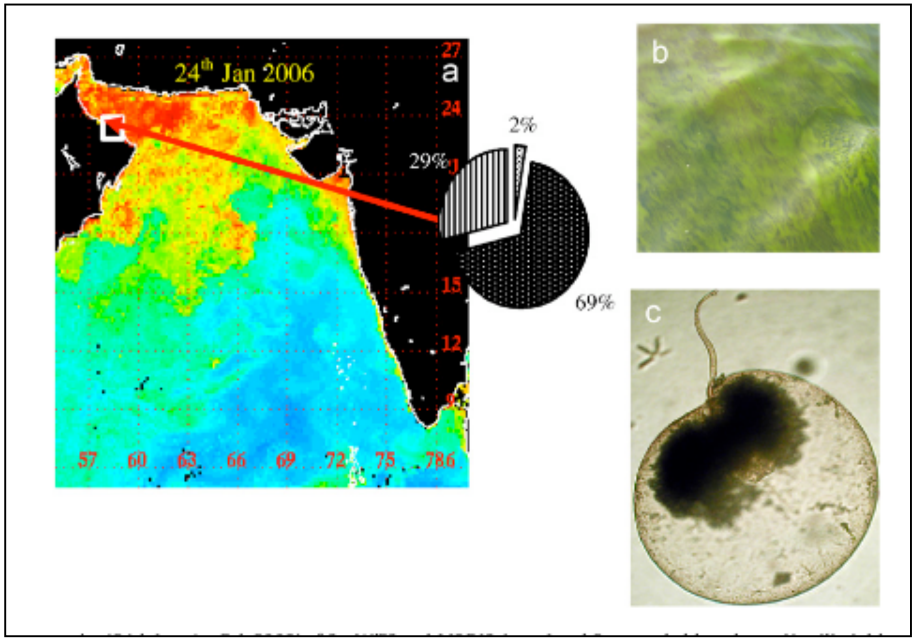
SW Florida: Moderate (10-15kts, 5-8m/s) northeasterly winds today will continue through Sunday; strengthening up to 20kts (10m/s) Saturday and Sunday.

examples of ocean color applications

two (of many) studies of the Arabian Sea that used satellite ocean color

Goes et al., "Warming of the Eurasian landmass is making the Arabian Sea more productive," Science 22 (2005)

Gomes et al., "Blooms of *Noctiluca miliaris* in the Arabian Sea - an *in situ* and satellite study," Deep Sea Research I 55 (2008)



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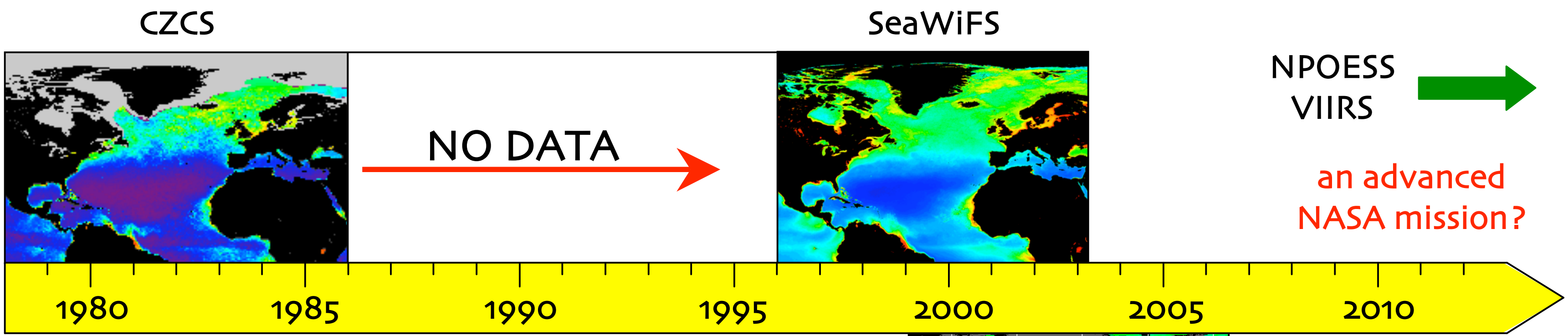
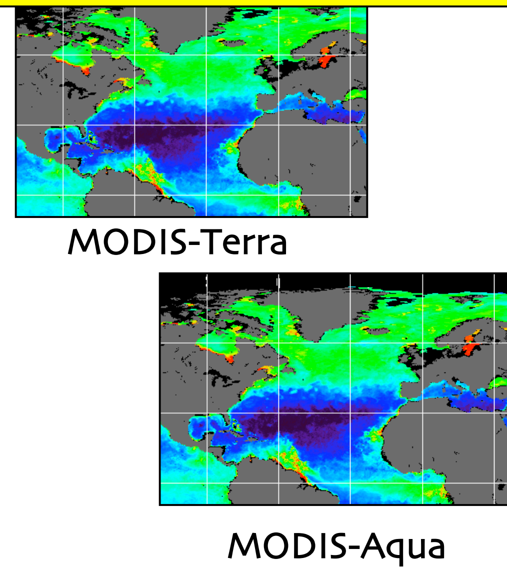
NASA's goals are to:

make available high quality ocean color data to the broadest user community in the most timely & efficient manner possible

facilitate the continuity & consistency of a long-term ocean color data record for climate research through international collaborations on satellite missions and field campaigns





Chronology of NASA's Ocean Color Measurements

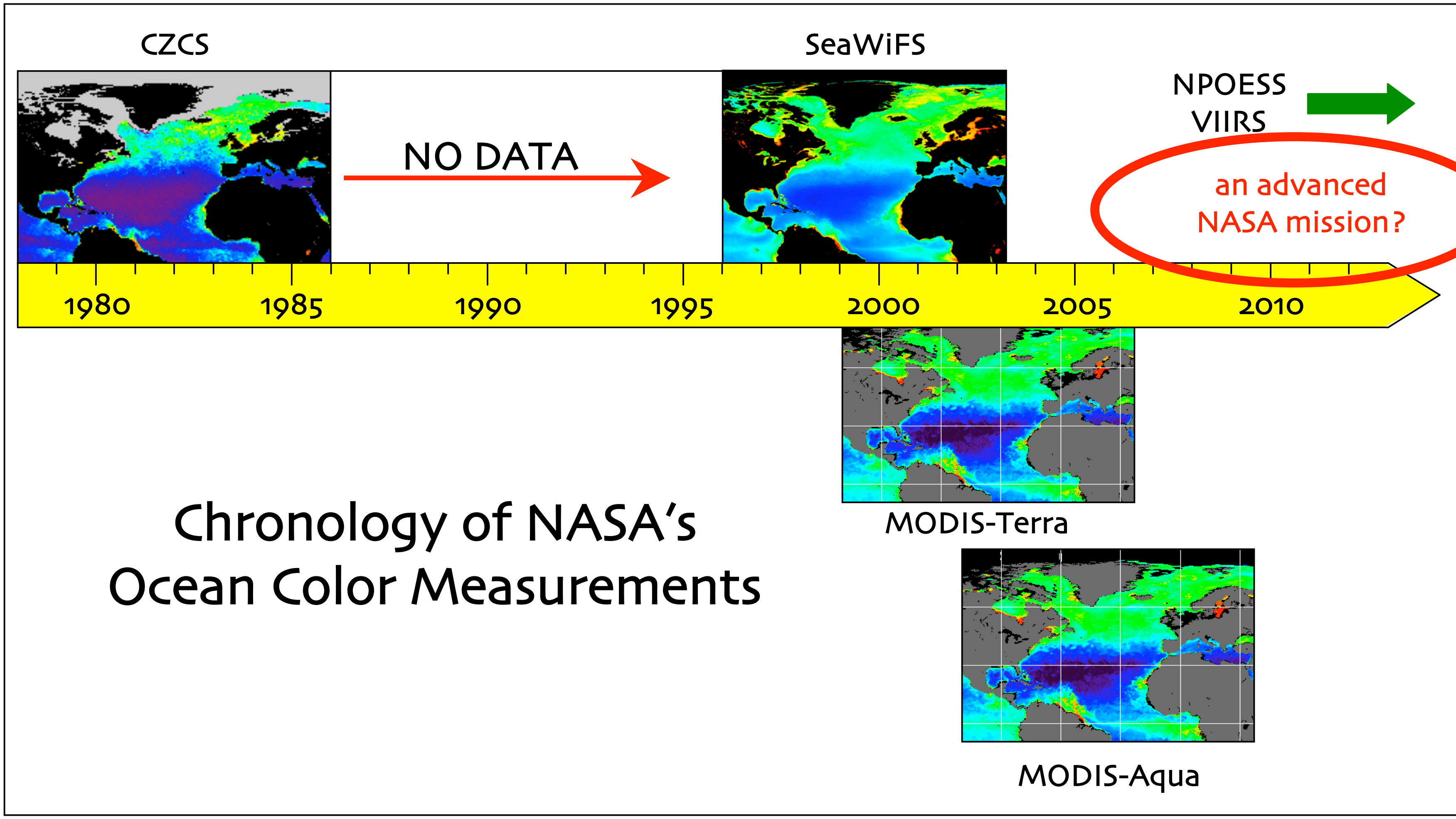
other satellite data

sea surface temperature: AVHRR, MODIS, VIIRS, ...

winds: SSMI, Nscat, Quikscat, SeaWinds, ...

sea surface topography: TOPEX, Jason, Grace, OSTM, ...

salinity: Aquarius



other
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salinity: Aquarius

1. ACE (Aerosols-Clouds-Ecosystems)

mission & payload

low Earth orbit (LEO), polar orbit

sun-synchronous, early-afternoon orbit, with altitude of 500-650 km

instruments and technology

HSR Lidar for assessing the heights of aerosol & cloud properties.

dual frequency Doppler cloud radar for cloud properties & precipitation

multi-angle, swath polarimeter for imaging aerosol & clouds

ocean ecosystem multi-channel spectrometer (OES)

IR multi-channel imager for cloud temperatures & heights

high frequency swath radiometer for cloud ice measurements

low frequency swath radiometer for precipitation measurements

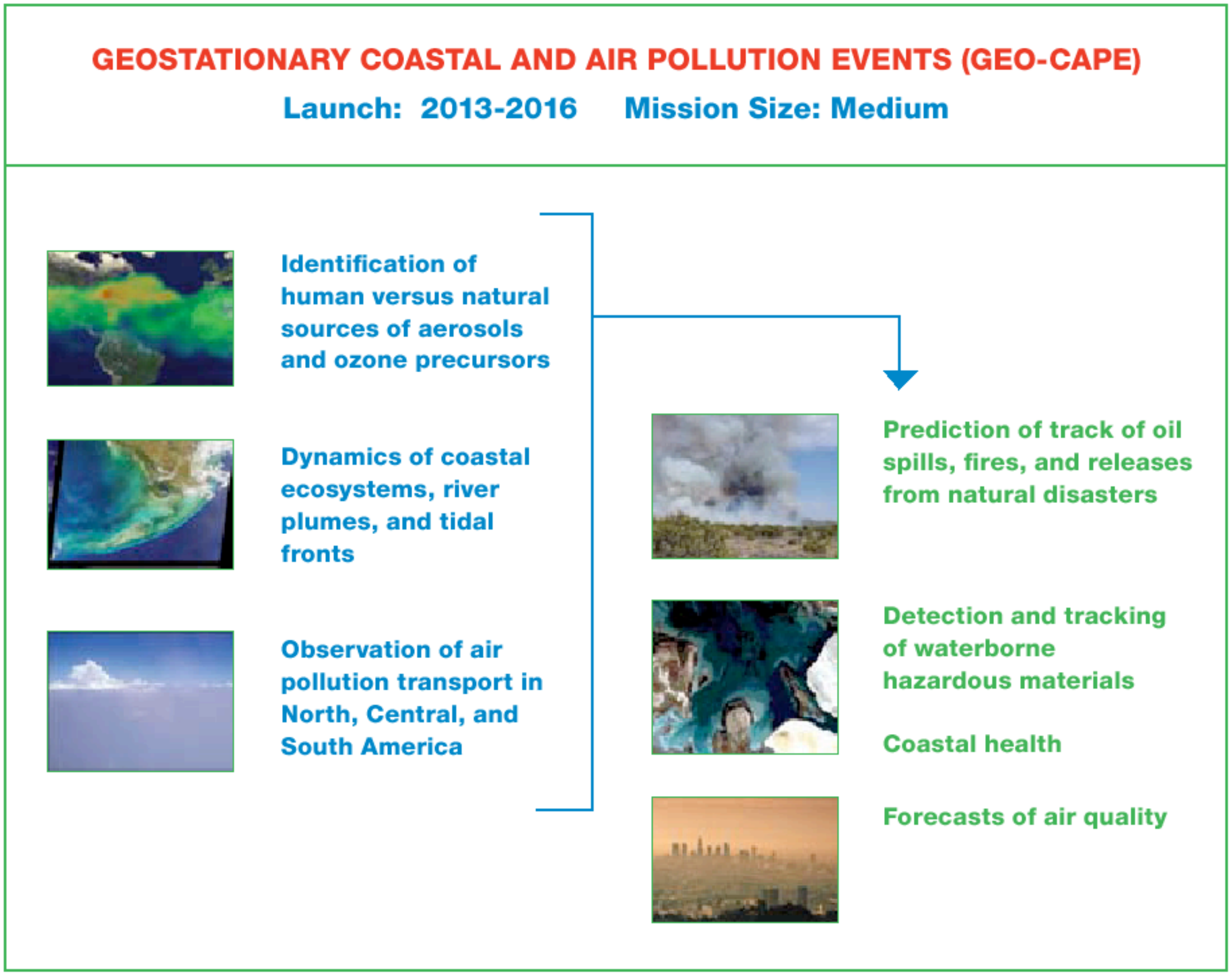
microwave temperature/humidity sounder

the ACE mission – with its advanced instruments – will likely not launch until 2020

black – specified by NAS Decadal Survey & red – Science Definition Team recommendations

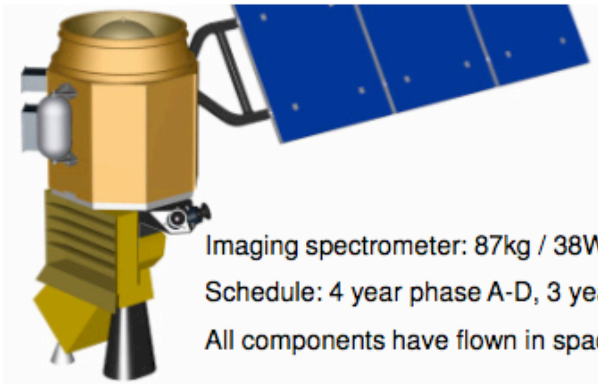
2. GEO-CAPE (Geostationary Coastal & Air Pollution Events)

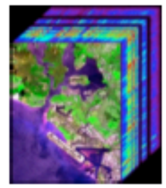
UV-visible-near IR wide area spectrometer covering 45°S to 50°N hourly
steerable, high spatial resolution, event-imaging spectrometer
O3, NO2, CH2O, SO2, aerosols & IR correlation radiometer for CO mapping



3. HyspIRI (Hyperspectral Infrared Imager)

HyspIRI Imaging Spectroscopy Science Measurements





Imaging spectrometer: 87kg / 38W

Schedule: 4 year phase A-D, 3 years operations

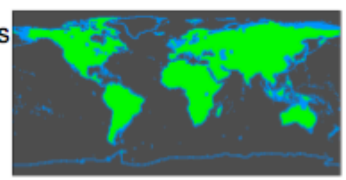
All components have flown in space

Science Questions:

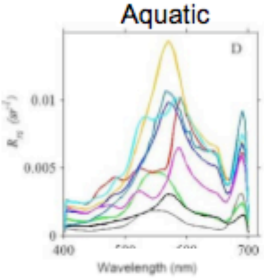
- *What is the composition, function, and health of land and water ecosystems?*
- *How are these ecosystems being altered by human activities and natural causes?*
- *How do these changes affect fundamental ecosystem processes upon which life on Earth depends?*

Measurement:

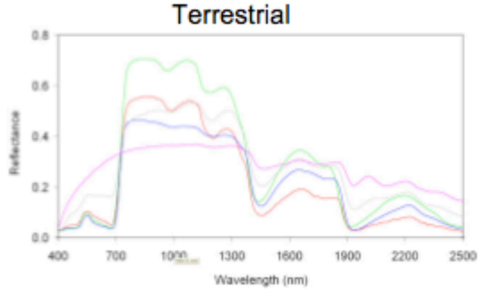
- 380 to 2500 nm in 10nm bands
- Accurate 60 m resolution
- 19 days revisit
- Global land and shallow water



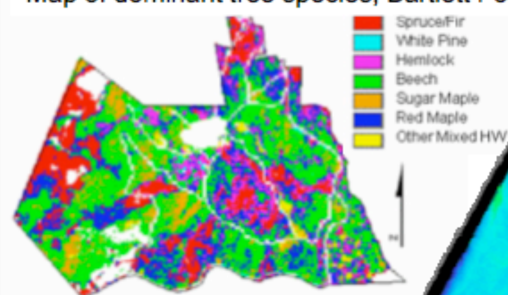
Aquatic

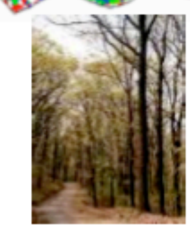


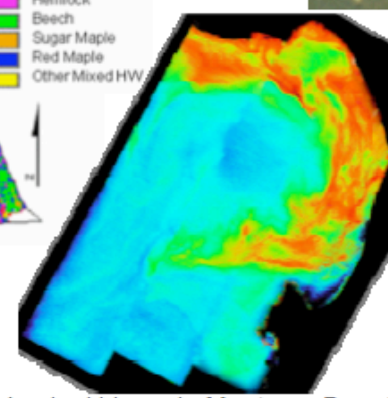
Terrestrial



Map of dominant tree species, Bartlett Forest, NH







Red tide algal bloom in Monterey Bay, CA

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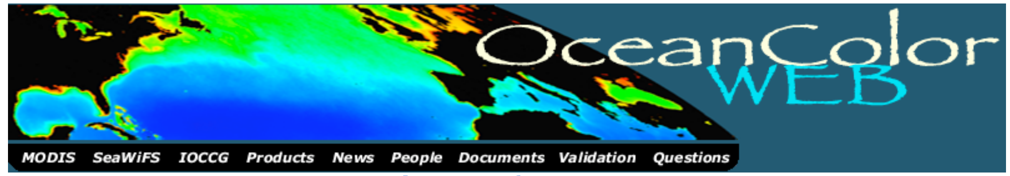
the NASA Ocean Biology Processing Group

- **Ocean Color (OC)**
- SST for MODIS, GHRSST
- Salinity from Aquarius



oceancolor.gsfc.nasa.gov

- End-to-End Shop for Ocean Color
  - –Sensor calibration/characterization
  - –Processing software & algorithms
  - –Product validation (SeaBASS)
  - –Algorithm development (NOMAD)
  - –User processing and display (SeaDAS)
  - –Data archive and distribution
  - –User support (Ocean Color Forum)

Consolidated data access, information services, and community feedback.

- Distributed processing system

  400x global reprocessing for MODIS

  4000x for SeaWiFS

- Data archive and distribution

  ~1 PB online storage (RAID)

  distribution: 34 million files OC

  (2004-) 9 million files SST

Missions Supported

MODIS/Aqua: 2002-present

MODIS/Terra: 1999-present

SeaWiFS/Orbview-2: 1997-present

OCTS/ADEOS: 1996-1997

MOS/IRS-P3: 1996-2004

CZCS/NIMBUS-7: 1978-1986

VIIRS/NPP: 2011 launch

Glory Data System : 2009 launch

Aquarius / SAC-D : May 2010 launch

New Mission Development (ACE)

the NASA Ocean Biology Processing Group

measurement-based organization

consolidated expertise in ocean color measurements

- multi-mission, end-to-end
- sensor calibration/characterization, prelaunch & on-orbit
- product validation (SeaBASS validation data set)
- algorithm development & evaluation (NOMAD)
- data processing and distribution (ODPS, OceanColorWeb)
- user processing and display (SeaDAS)
- user support (Ocean Color Forum)

global processing & distribution

- SeaWiFS
- MODIS (Aqua & Terra)
- CZCS
- OCTS (Japan)

the NASA Ocean Biology Processing Group

http://oceancolor.gsfc.nasa.gov/

- data
- documentation
- analyses
- software
- support services
- public forum

data distribution

free & open data distribution policy

all data available on-line

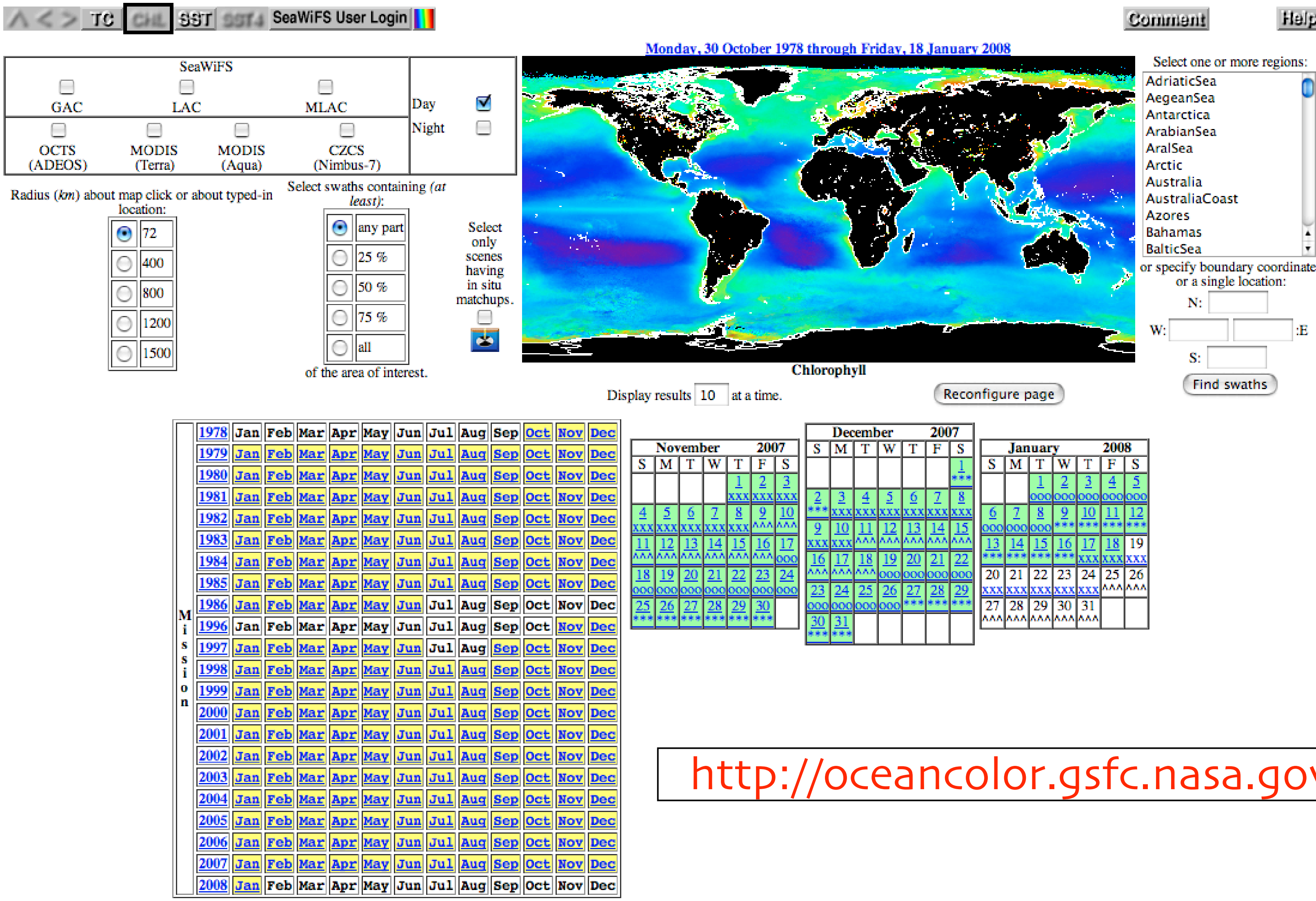
Web-based browsing & direct FTP access

automated ordering system

subscription services

geographic & parameter sub-setting

the NASA Ocean Biology Processing Group



http://oceancolor.gsfc.nasa.gov/

the NASA Ocean Biology Processing Group

standard ocean products

observed radiance (uncalibrated)

ocean color
- remote-sensing reflectances, Rrs(λ)
- chlorophyll, Chl
- diffuse attenuation, Kd(490)
- aerosol type & concentration
- FLH, FQY, iPAR, PAR, POC, PIC, Morel CDOM index

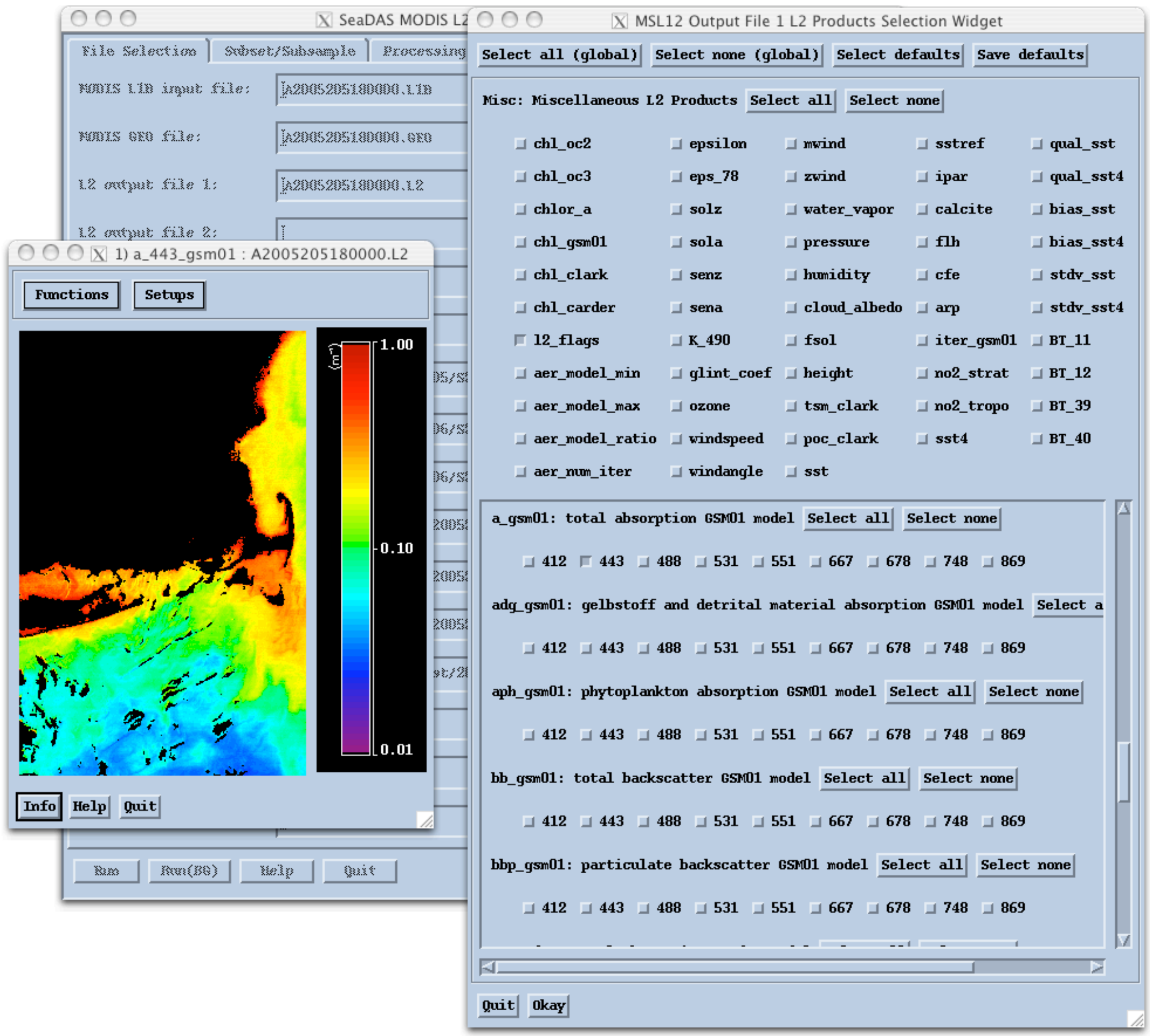
ocean temperature (MODIS only)

data types (online archive)
- Level-0 or Level-1A: uncalibrated radiances
- Level-2: retrieved geophysical parameters
- Level-3: global gridded composites - daily, 8-day, monthly, merged

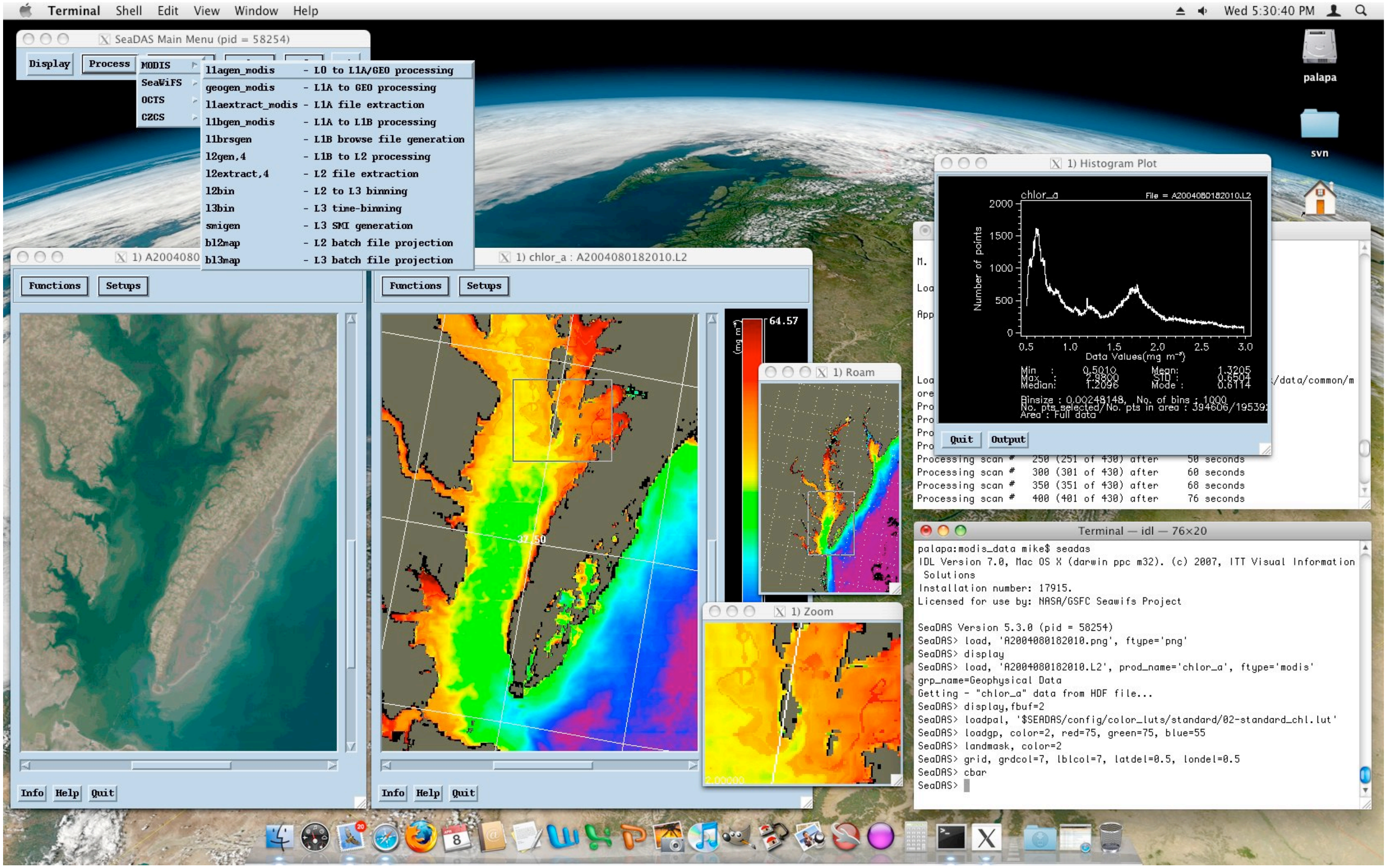
the NASA Ocean Biology Processing Group

SeaDAS

- free
- multi-mission
- display tools
- analysis tools
- processing
- open source



reprocessing algorithms in latest SeaDAS



15 years in distribution, free, open-source, linux/os-x/solaris/windows(vm), international training
~1400 downloads in 2009 alone

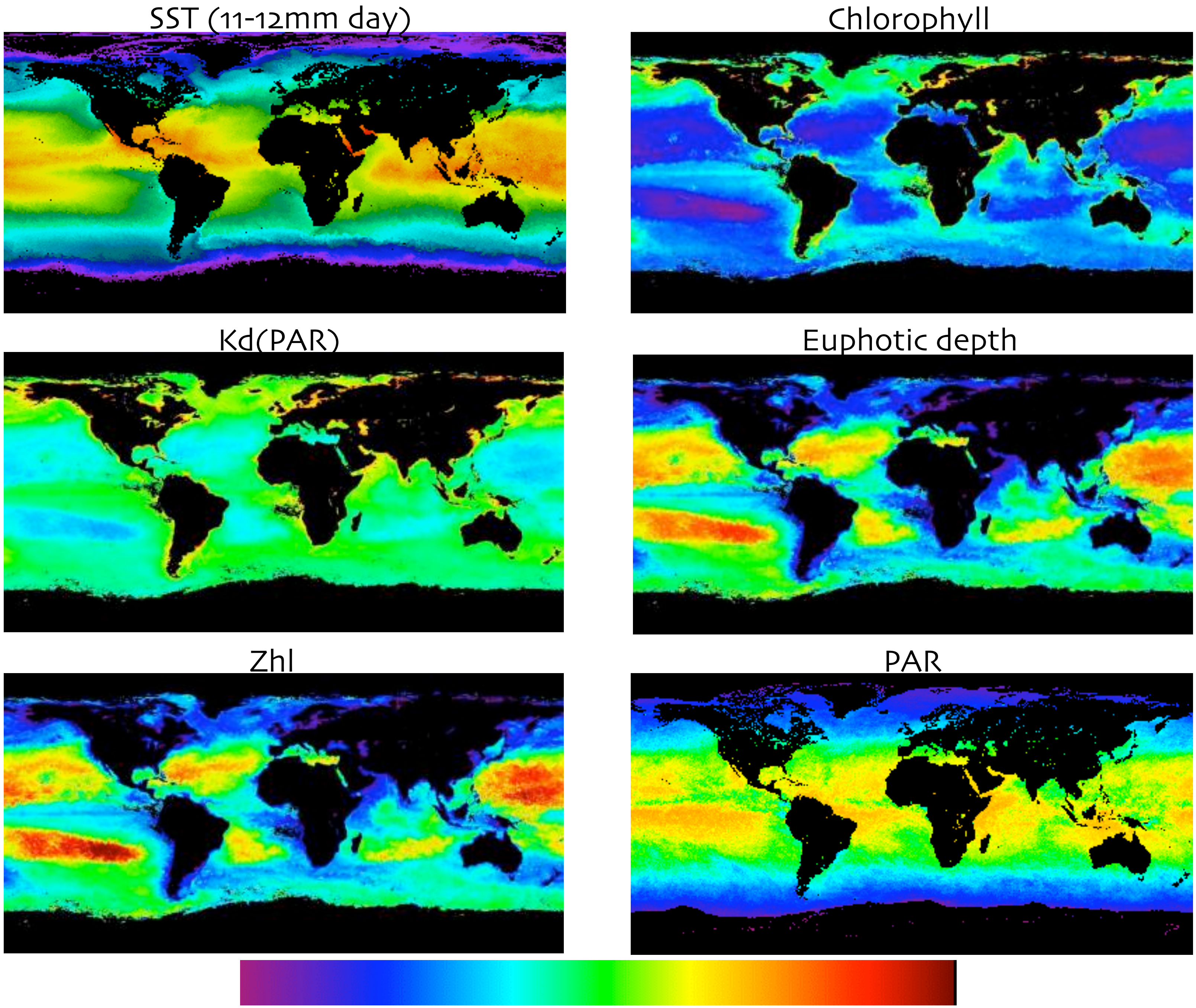
examples of non-standard ocean products

alternate C_a and K_d algorithms

inherent optical properties (various bio-optical models)
- absorption (total, phytoplankton, dissolved material)
- backscatter (total, particulate)

euphotic depth (Z_{eu}, Z_{sd})

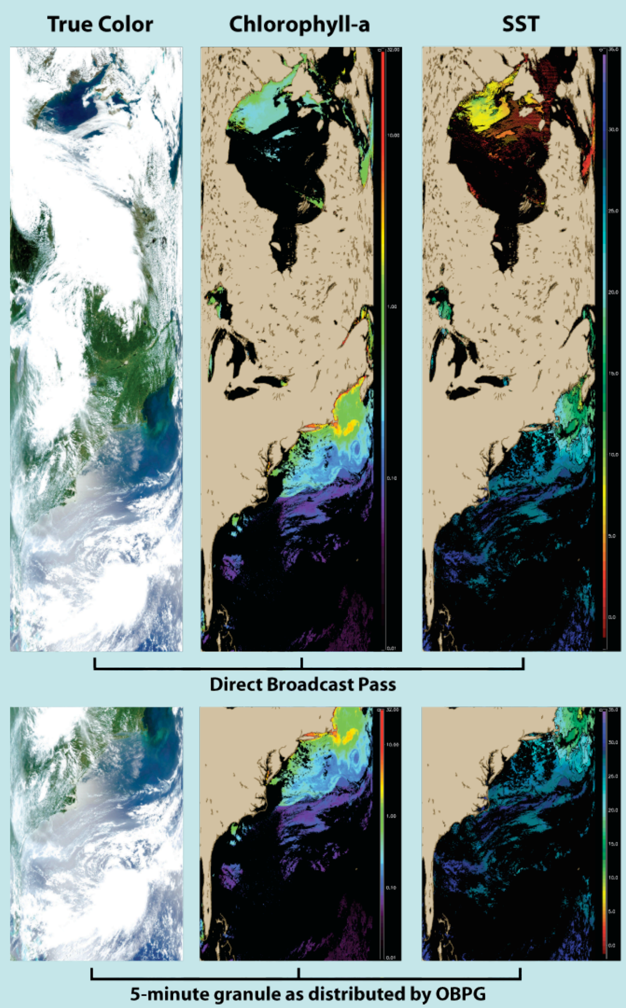
spectrally integrated diffuse attenuation, K_d(PAR)



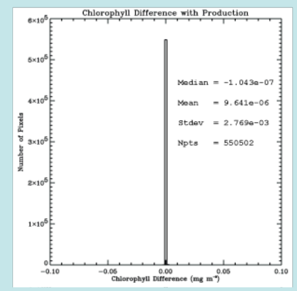
PJW, NASA/SSAI, 21 Jan 2010 @ SAC

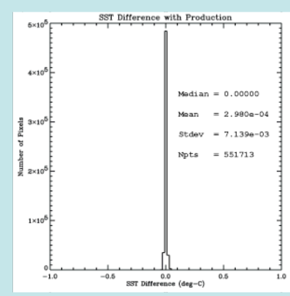
the NASA Ocean Biology Processing Group

MODIS direct broadcast support

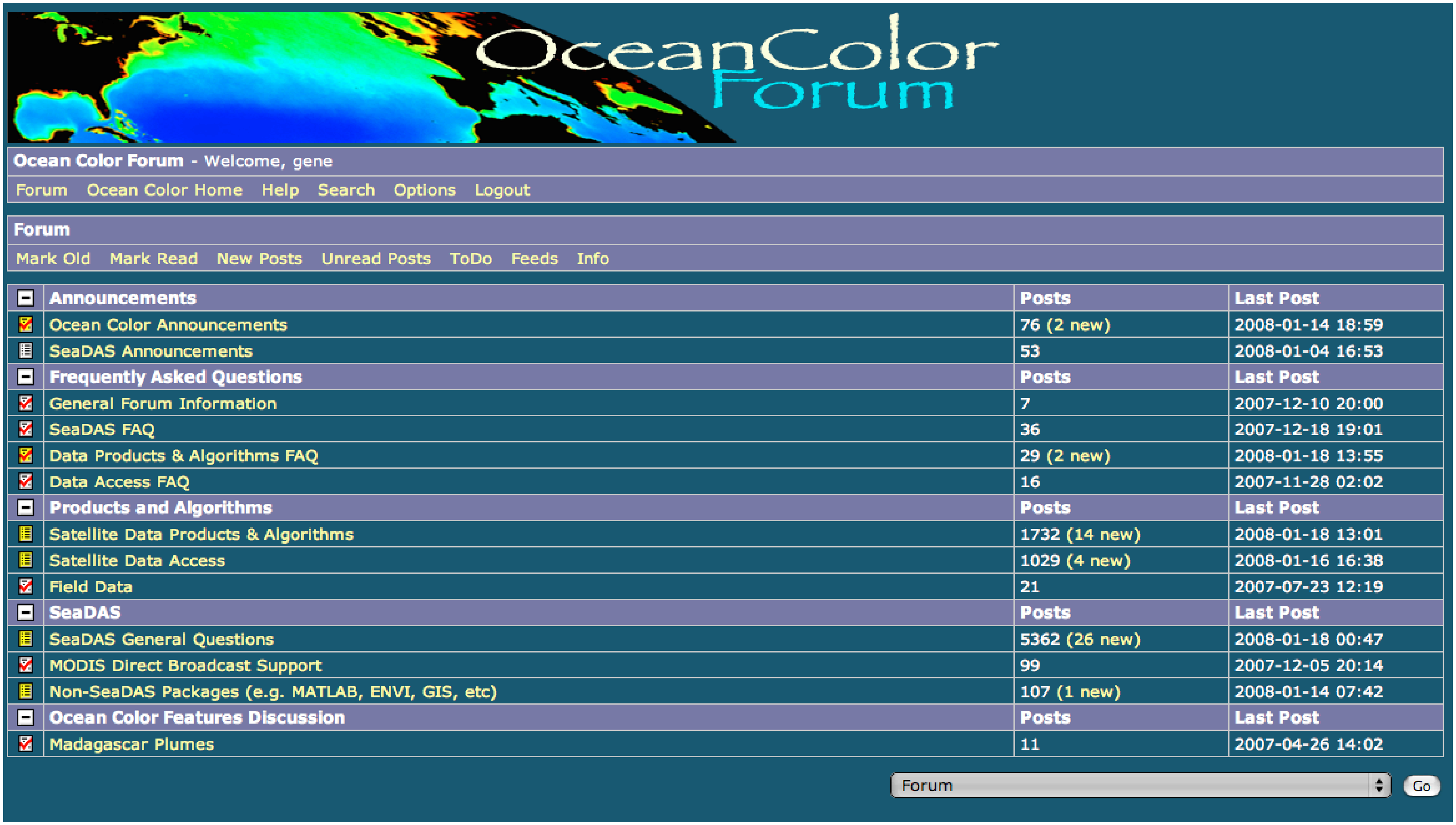


These images and histograms show pixel-for-pixel comparisons between MODIS/Aqua products generated from a Level-0 scene (UWisc DB station) using SeaDAS, and the overlapping 5-minute granule processed by the OBPG. Using SeaDAS, it is possible to exactly reproduce the standard products distributed by the OBPG, as well as a host of additional products.





the NASA Ocean Biology Processing Group


OceanColor Forum

Ocean Color Forum - Welcome, gene

Forum Ocean Color Home Help Search Options Logout

Forum

Mark Old Mark Read New Posts Unread Posts ToDo Feeds Info

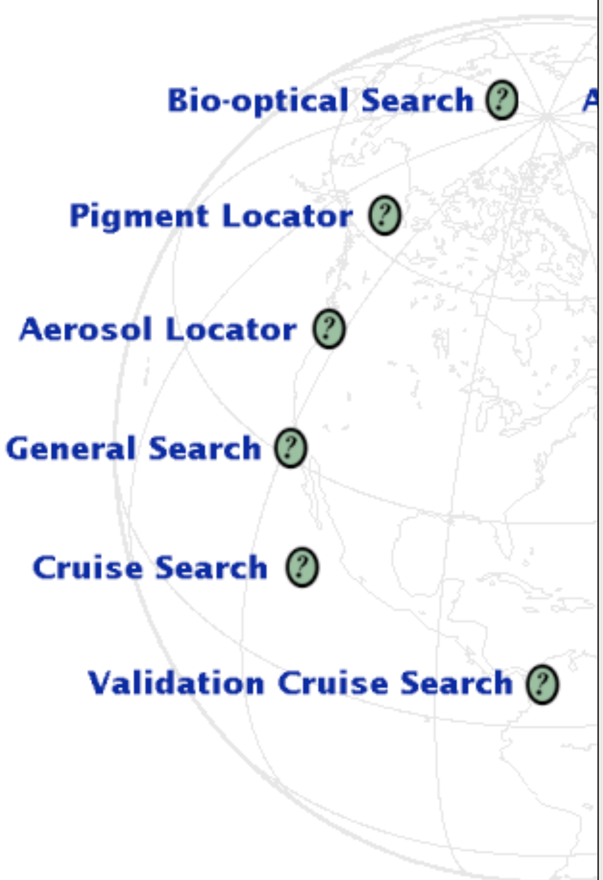
Announcements	Posts	Last Post
Ocean Color Announcements	76 (2 new)	2008-01-14 18:59
SeaDAS Announcements	53	2008-01-04 16:53
Frequently Asked Questions	**Posts**	**Last Post**
General Forum Information	7	2007-12-10 20:00
SeaDAS FAQ	36	2007-12-18 19:01
Data Products & Algorithms FAQ	29 (2 new)	2008-01-18 13:55
Data Access FAQ	16	2007-11-28 02:02
Products and Algorithms	**Posts**	**Last Post**
Satellite Data Products & Algorithms	1732 (14 new)	2008-01-18 13:01
Satellite Data Access	1029 (4 new)	2008-01-16 16:38
Field Data	21	2007-07-23 12:19
SeaDAS	**Posts**	**Last Post**
SeaDAS General Questions	5362 (26 new)	2008-01-18 00:47
MODIS Direct Broadcast Support	99	2007-12-05 20:14
Non-SeaDAS Packages (e.g. MATLAB, ENVI, GIS, etc)	107 (1 new)	2008-01-14 07:42
Ocean Color Features Discussion	**Posts**	**Last Post**
Madagascar Plumes	11	2007-04-26 14:02

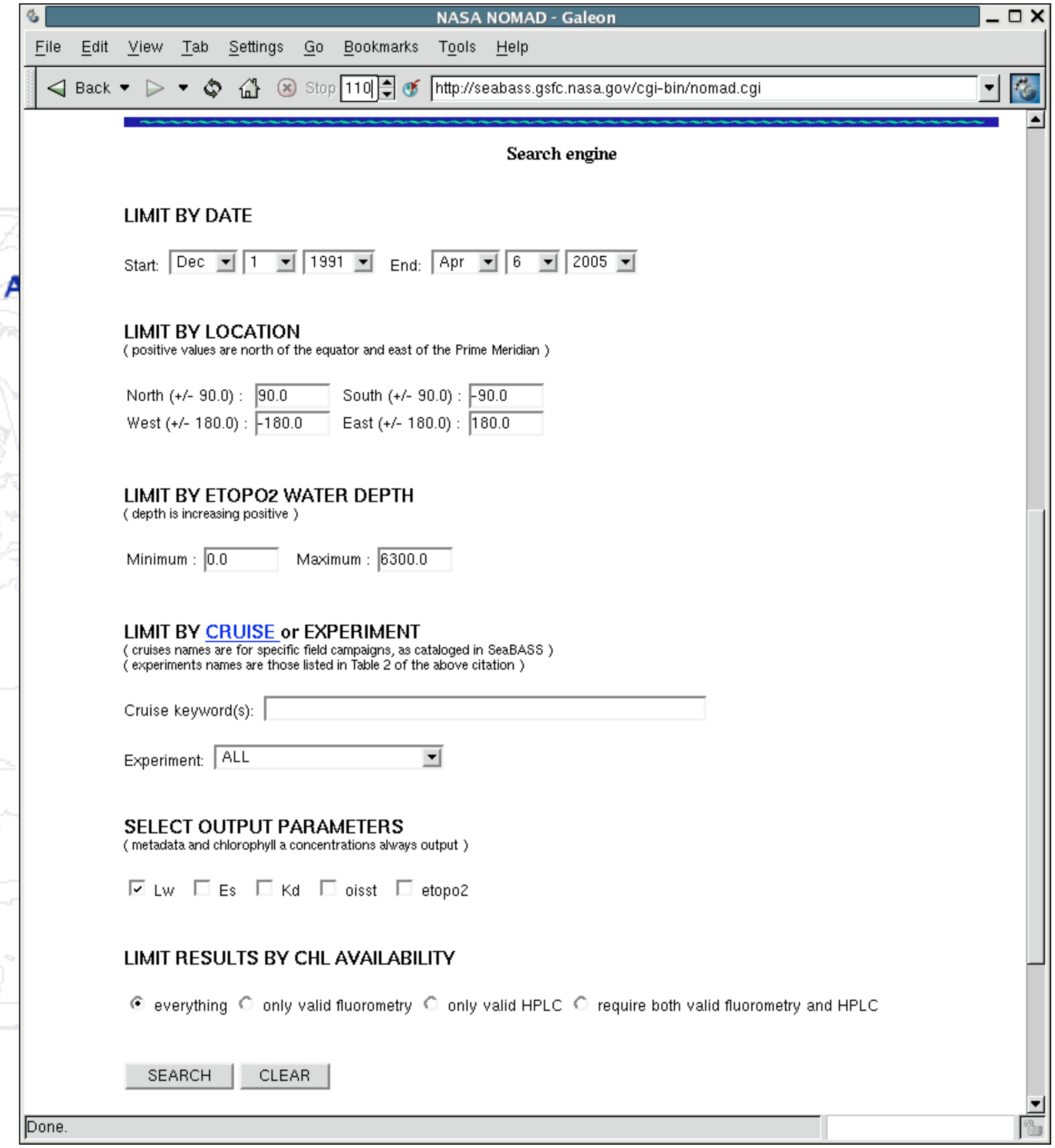
Forum Go

http://oceancolor.gsfc.nasa.gov/forum/oceancolor/forum_show.pl

the NASA Ocean Biology Processing Group

SeaBASS - *in situ* data archive





lessons learned

on-line direct access to data & “one-stop shopping” assures wide use & active participation of the research community.

distribution of low-level data (L0 or L1A) & calibration software reduces data distribution & storage costs.

open source software for localized data processing allows for community participation in new product development, enhances user understanding & confidence, & facilitates community feedback & support. (no black boxes!)

on-line forum allows knowledgeable staff to share the load of user support, which is vital to advancing research

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"A climate data record is a time series of measurements of sufficient length, consistency, & continuity to determine climate variability & change."

U.S. National Research Council, 2004

consistency:

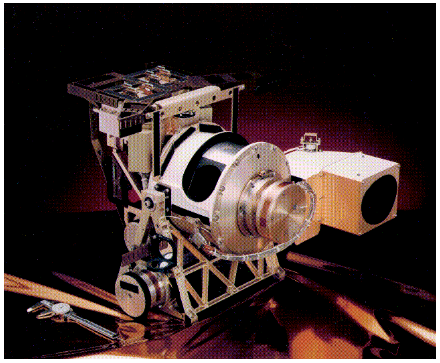
consistency between different sensors can be achieved through standardization of processing algorithms, calibration sources & methods, & validation techniques

calibrating & reprocessing an ocean color mission

MODIS

- 36 bands, 9 for OC (412-869nm)
- rotating scan mirror
- solar, lunar, bb, sdsm, srca
- polarization sensitivity ~3%
- no tilting capability
- 12 bit digitization
- 10 detectors per band along track
- higher SNR in most bands

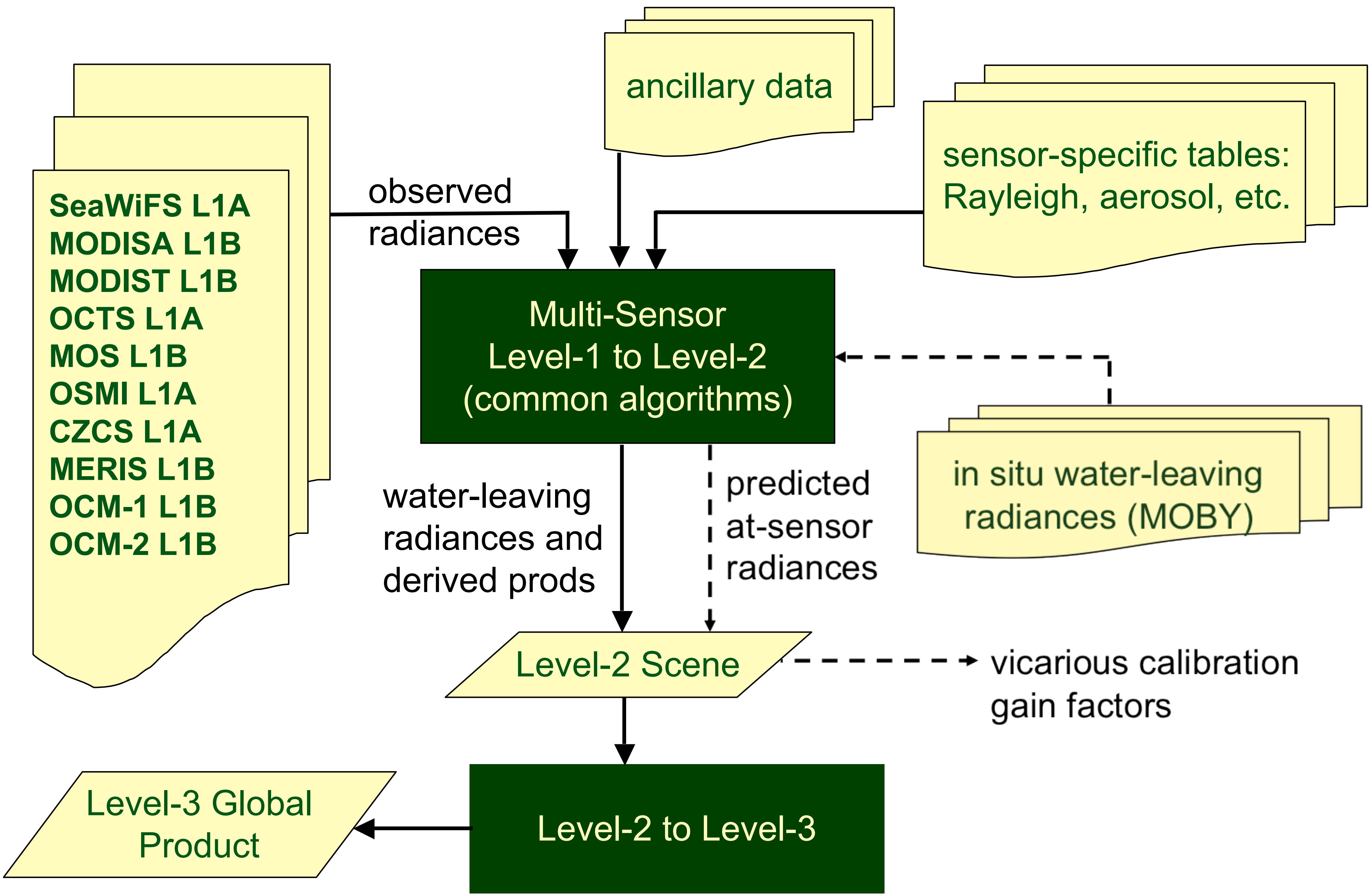
SeaWiFS



- 8 bands for OC (412-865nm)
- rotating telescope
- solar and lunar calibration
- polarization scrambler
- tilting to avoid sun glint
- 12-bit truncated to 10-bit
- 4 detectors averaged to 1 sample
- higher dynamic range (bilinear gain)

sensor design & performance varies

common processing framework



calibrating & reprocessing an ocean color mission

the Great Ocean Color Reprocessing of 2009/2010

scope:

- sensors: SeaWiFS, MODISA, MODIST, OCTS, CZCS

highlights:

- sensor calibration updates (instrument aging, new insights)
- new aerosol models based on AERONET
- improved turbid-water atmospheric correction
- accounting for atmospheric NO2 absorption
- updated chlorophyll and Kd algorithms based on NOMAD v2
- expanded product suite

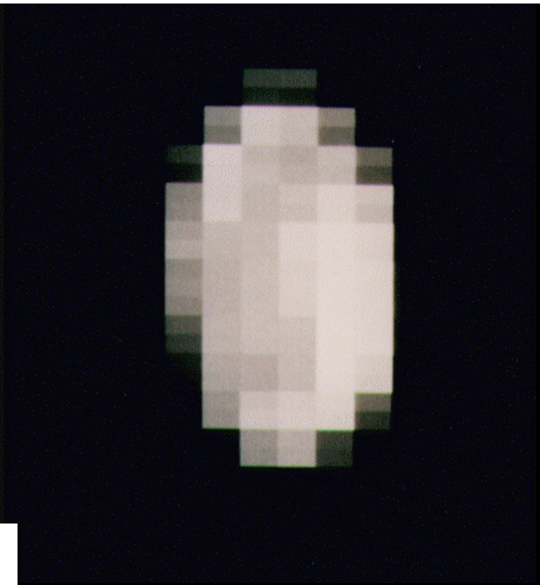
improved agreement between SeaWiFS and MODISA
improved agreement with in situ ocean color
improved agreement with AeroNET

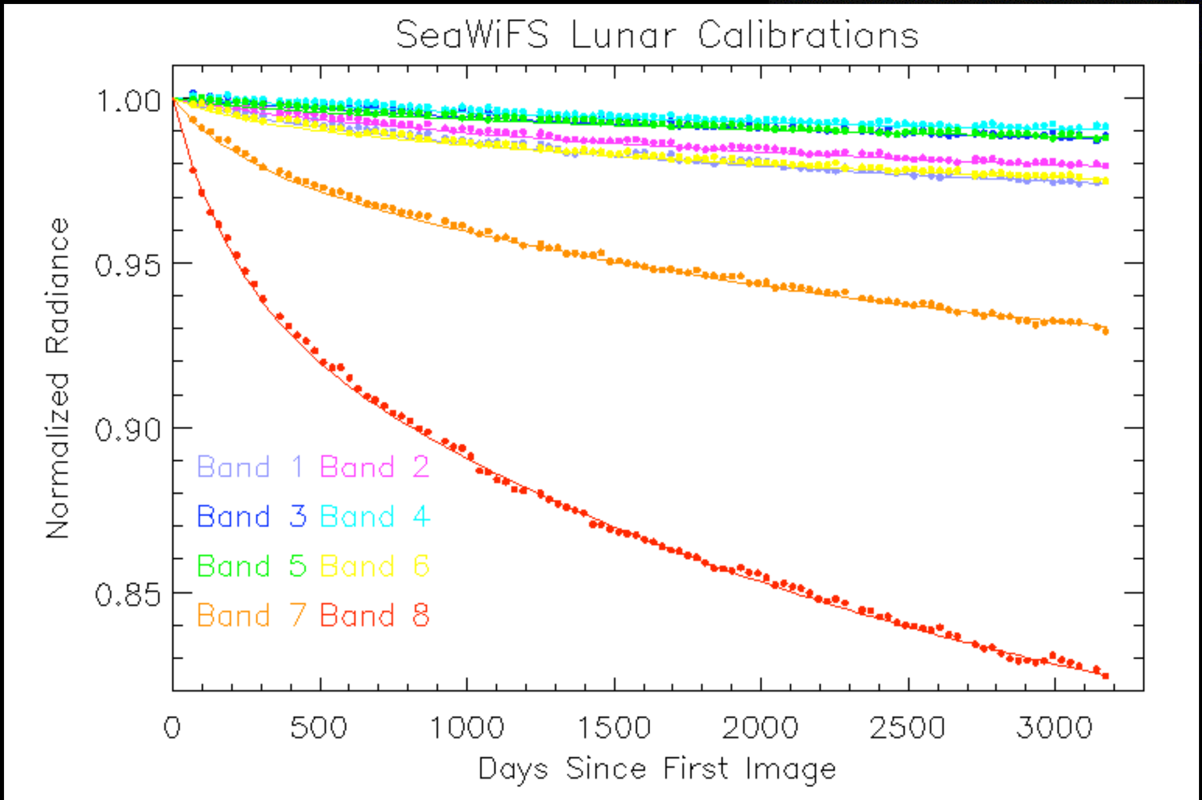
calibrating & reprocessing an ocean color mission

analysis topics related to reprocessing

- temporal calibration
- Level-2 satellite-to-*in situ* "match-ups"
- applied flags
- residual detector dependence
- residual scan dependence
- Level-3 time-series
- temporal anomalies

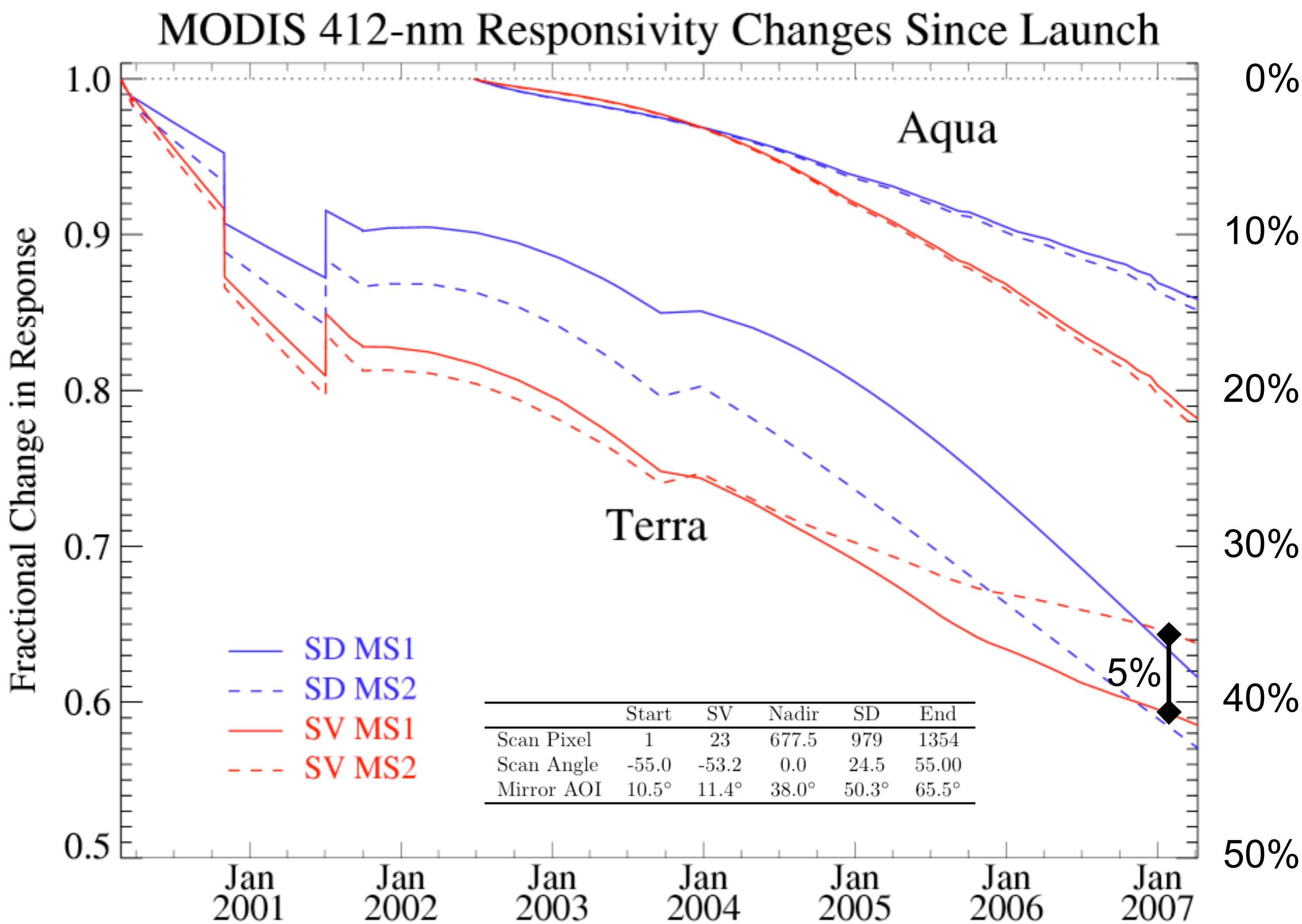
Temporal Calibration





SeaWiFS Band	SeaWiFS λ (nm)
1	412
2	443
3	490
4	510
5	555
6	670
7	765
8	865

MODIS temporal degradation @ 412 nm - lunar & solar calibration trends



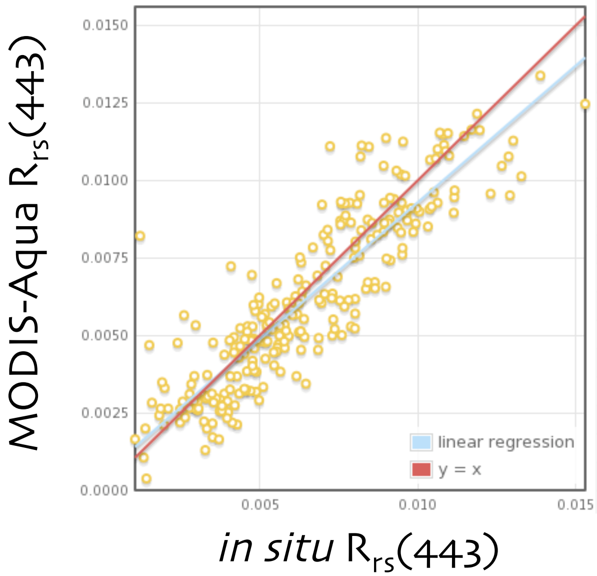
	Start	SV	Nadir	SD	End
Scan Pixel	1	23	677.5	979	1354
Scan Angle	-55.0	-53.2	0.0	24.5	55.00
Mirror AOI	10.5°	11.4°	38.0°	50.3°	65.5°

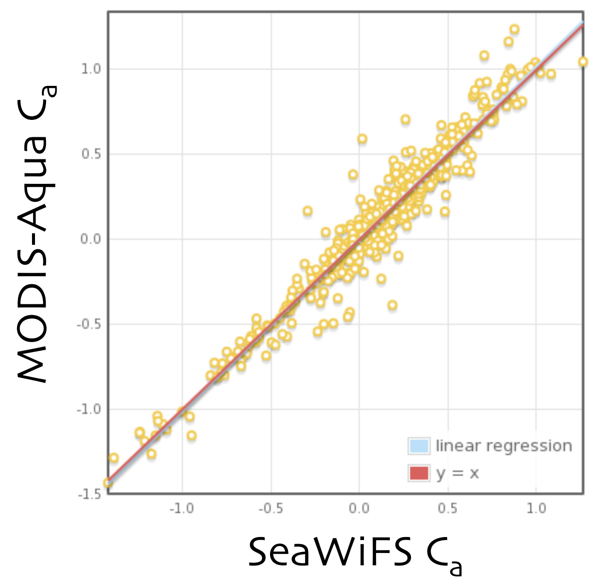
calibrating & reprocessing an ocean color mission

example of Level-2 satellite-to-*in situ* "match-ups"

highlights

- analyze match-ups for satellite-to-*in situ* & satellite-to-satellite
- search by date, location, water depth, or specific cruise
- customize exclusion criteria
- all operational data products





S.W. Bailey and P.J. Werdell, "A multi-sensor approach for the on-orbit validation of ocean color satellite data products," Remote Sensing of Environment 102, 12-23 (2006)

Level-2 satellite-to-*in situ* "match-ups"

- strengths:
  - the only truly independent validation of the science data products using ground truth measurements.

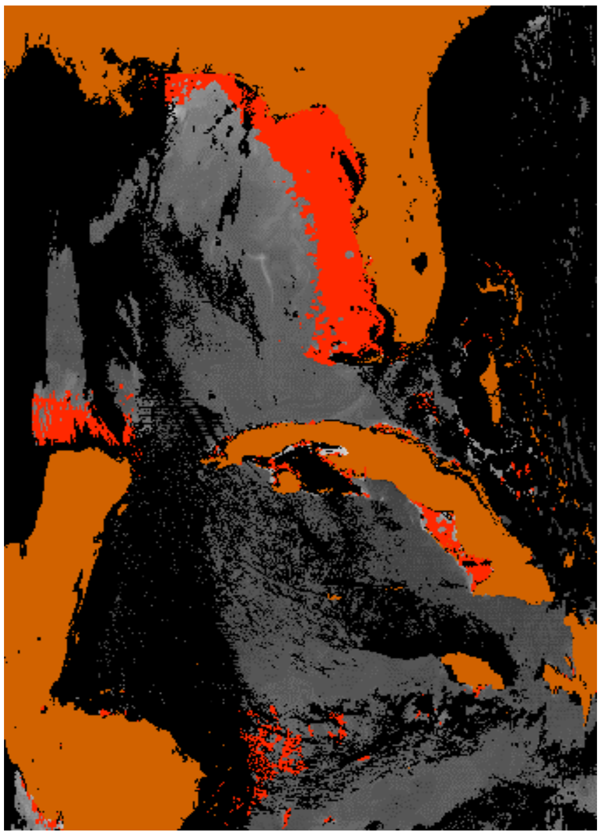
- limitations:
  - quality of *in situ* data is highly variable and difficult to assess.
  - coverage for OC *in situ* data is limited, both geographically & temporally.
  - assumes that highly localized (~meters) measurements are representative of pixel (km) area.
  - *in situ* measurements require discipline expertise to analyze & compare with satellite values
  - generally useful only for assessing static biases in final products.
  - availability of *in situ* data in future (e.g., VIIRS) is unknown

calibrating & reprocessing an ocean color mission

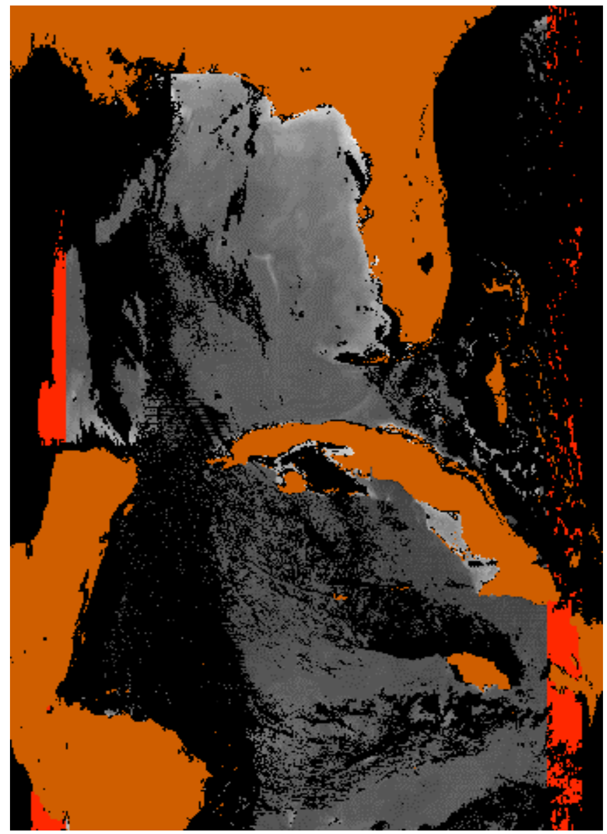
flag analyses

- determine loss of coverage resulting from each flag
- verify effectiveness of flags at removing invalid or questionable data

50-meter depth

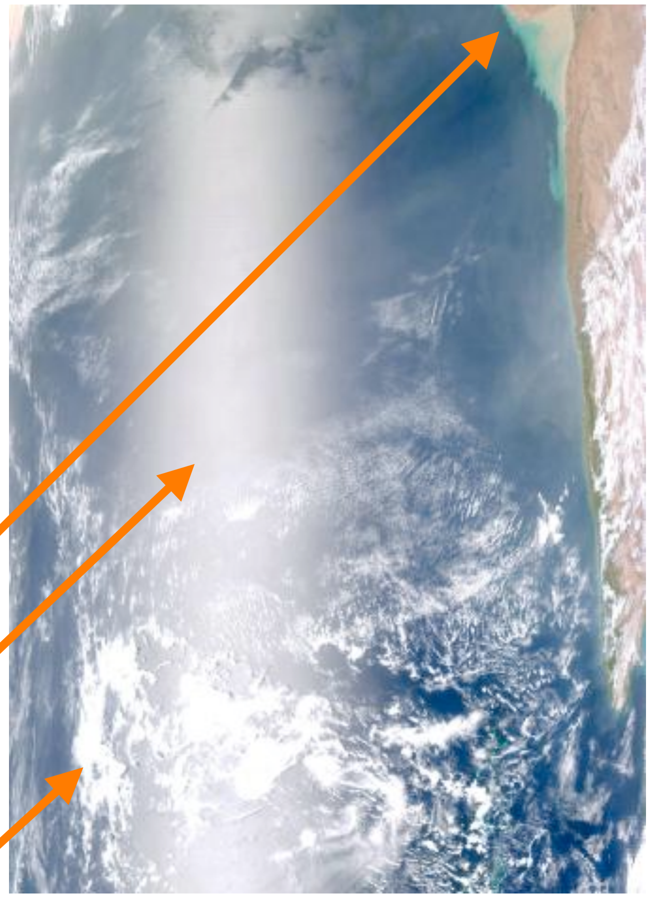


Sensor zenith



calibrating & reprocessing an ocean color mission

RGB image

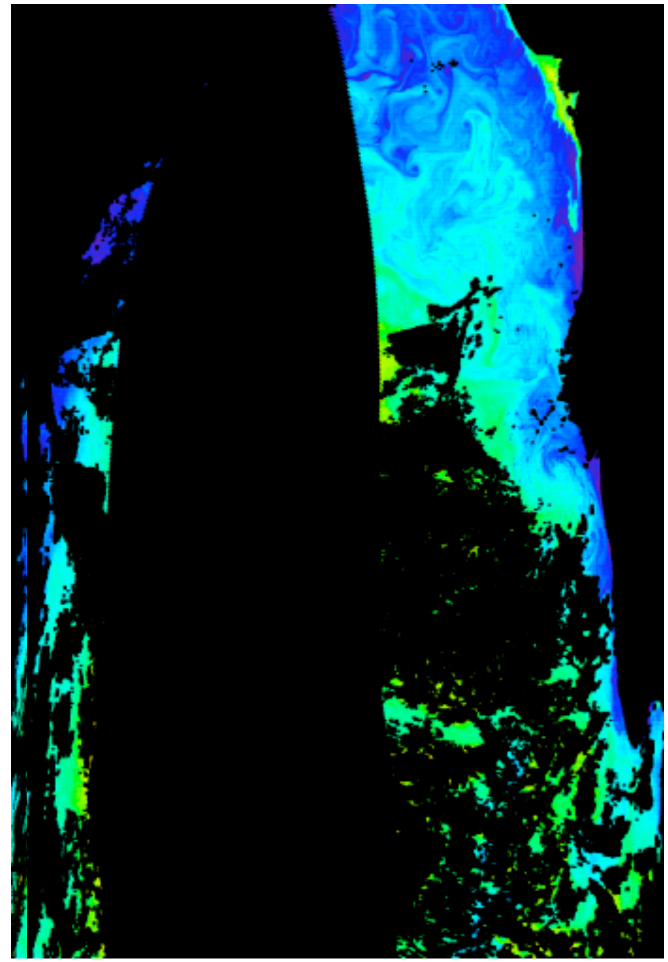


sediments

glint

cloud

nLw(443)

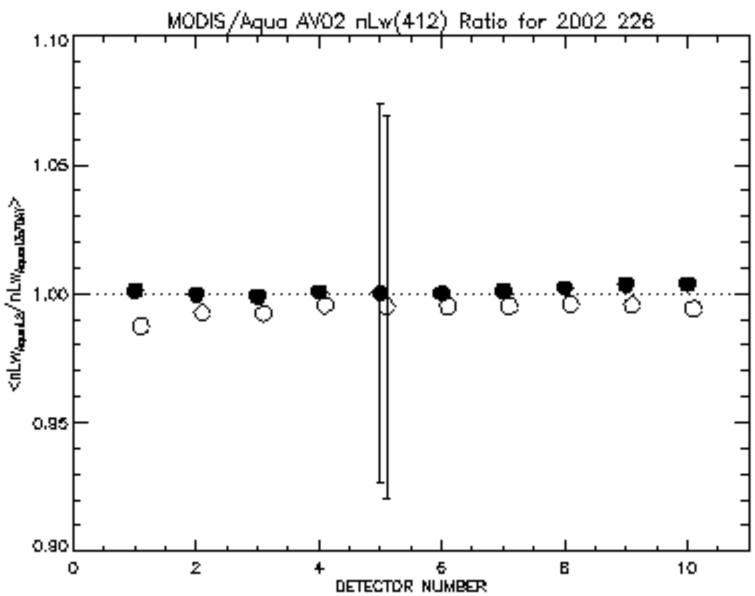


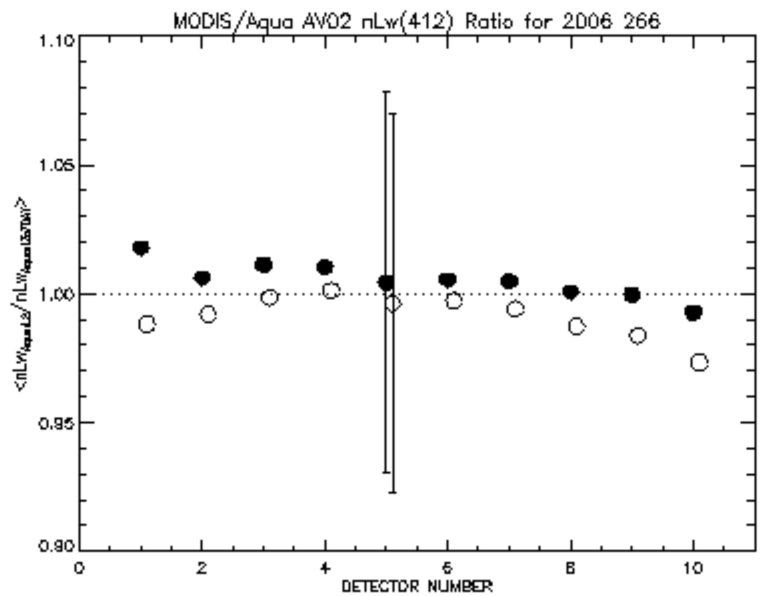
Add masking for straylight

calibrating & reprocessing an ocean color mission

residual detector dependence

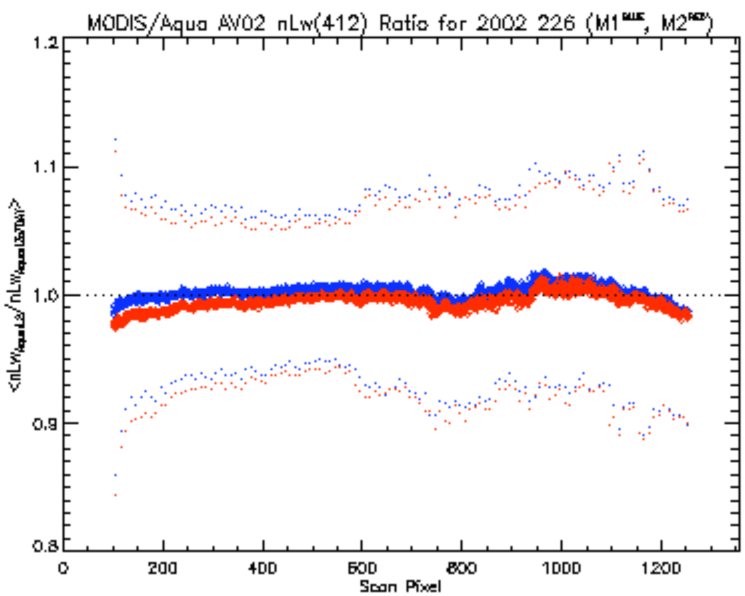
- Level-3 multi-day products (same or different sensor) are resampled to generate values at Level-2 resolution.
- comparisons are performed by detector & mirror side to evaluate residual detector response errors

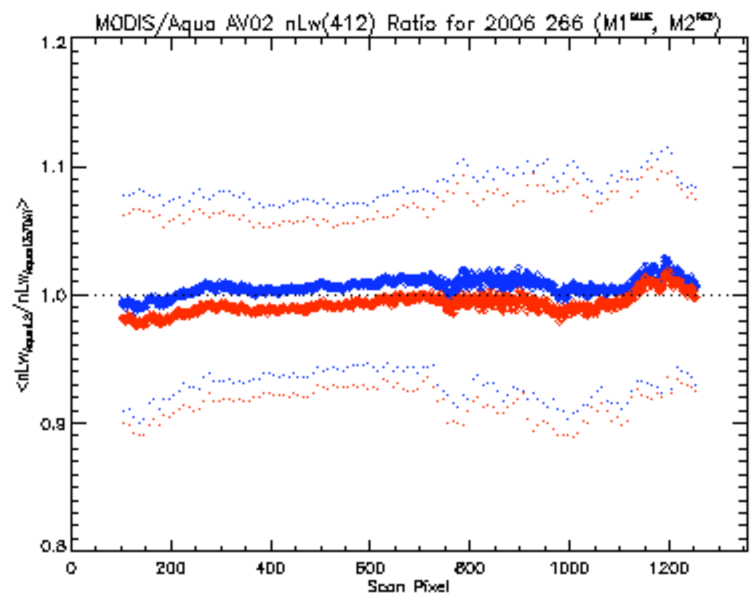




residual scan dependence

- Level-3 multi-day products (same or different sensor) are resampled to generate values at Level-2 resolution.
- comparisons are performed by pixel number and mirror side to evaluate residual response-vs-scan (RVS) errors





residual detector / scan dependence

- strengths:
  - provides evaluation of response vs. detector, scan angle & mirror side independent of onboard calibration
  - can also be used to evaluate errors in other sensor characteristics
- limitations:
  - works well mainly in temporally stable areas
  - noise levels may be large compared with residual errors

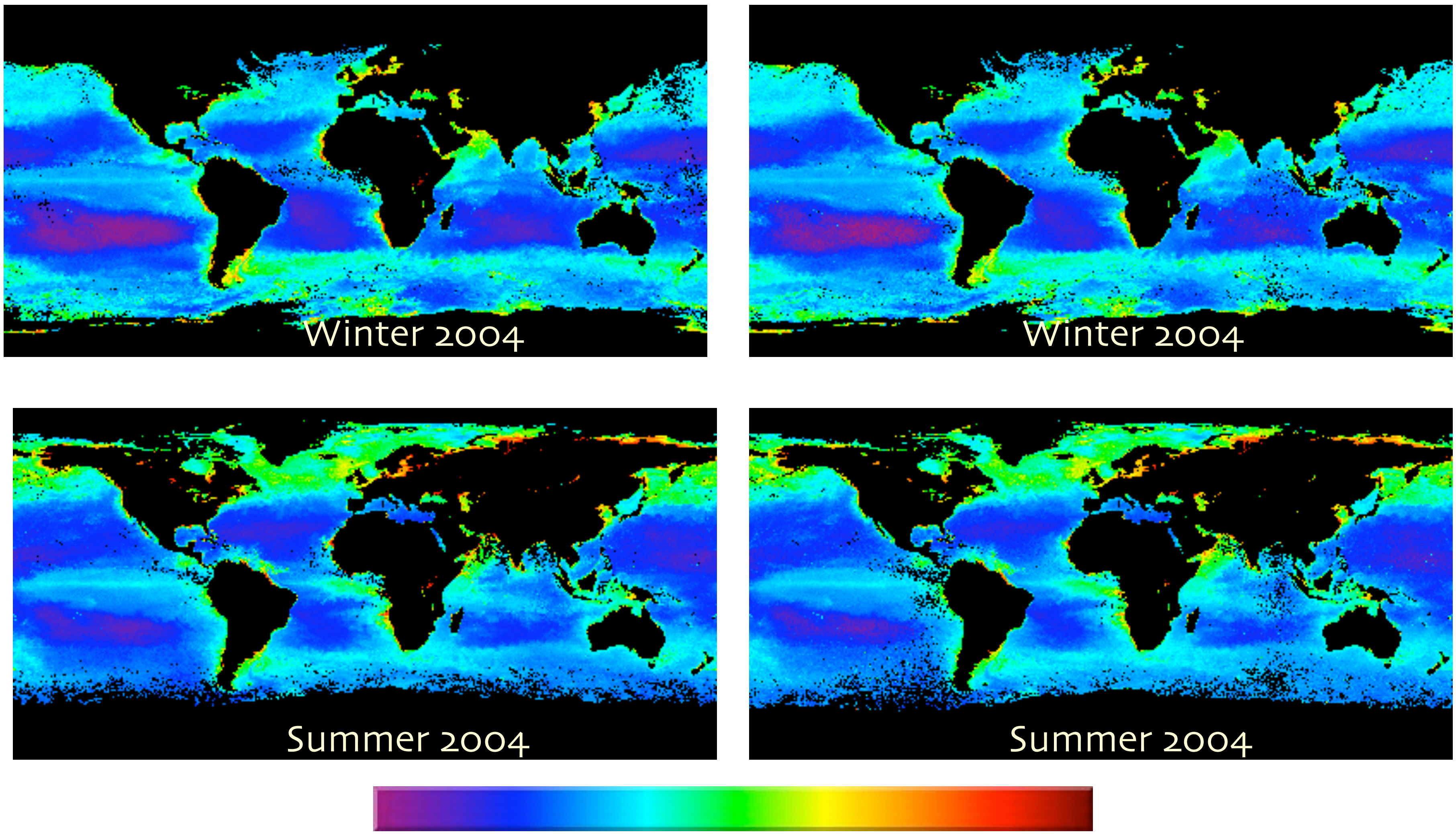
Franz, B.A., E.J. Kwiatkowska, G. Meister, and C. McClain, "Moderate Resolution Imaging Spectroradiometer on Terra: limitations for ocean color applications," J. Appl. Rem. Sens (2008)

Kwiatkowska, E.J., B.A. Franz, G. Meister, C. McClain, and X. Xiong, "Cross-calibration of ocean-color bands from Moderate Resolution Imaging Spectroradiometer on Terra platform," Appl. Opt. (2008)

calibrating & reprocessing an ocean color mission

Seasonal Chlorophyll Images

MODIS/Aqua SeaWiFS



$0.01\text{-}64\ \mathrm{mg\ m^{-3}}$

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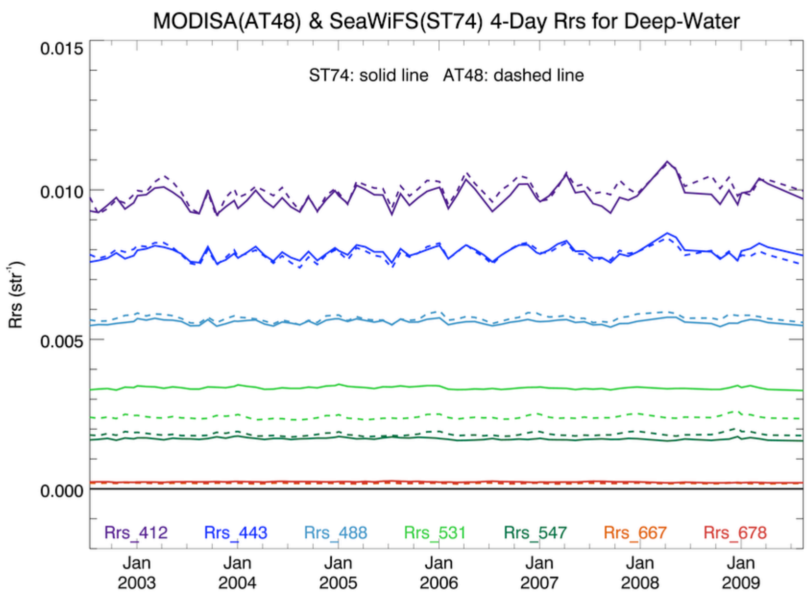
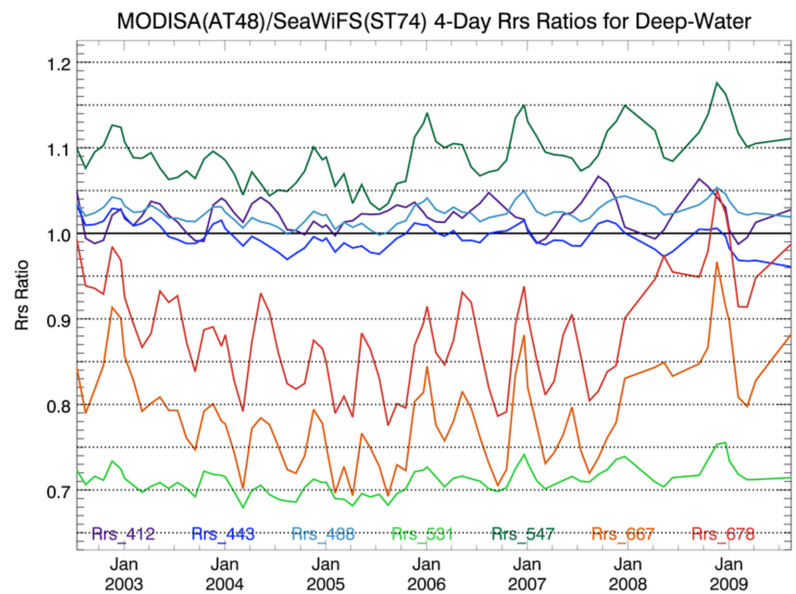
sensor & algorithm comparisons

Level-3 parameters (e.g., Rrs) compared for common spectral bands

common bins extracted & compared over the period of overlap between the sensors

comparisons performed globally, trophically, zonally & for specified regions





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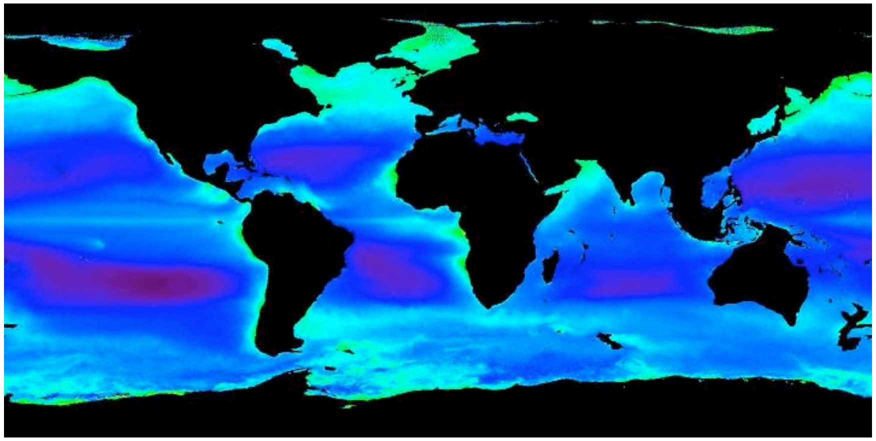
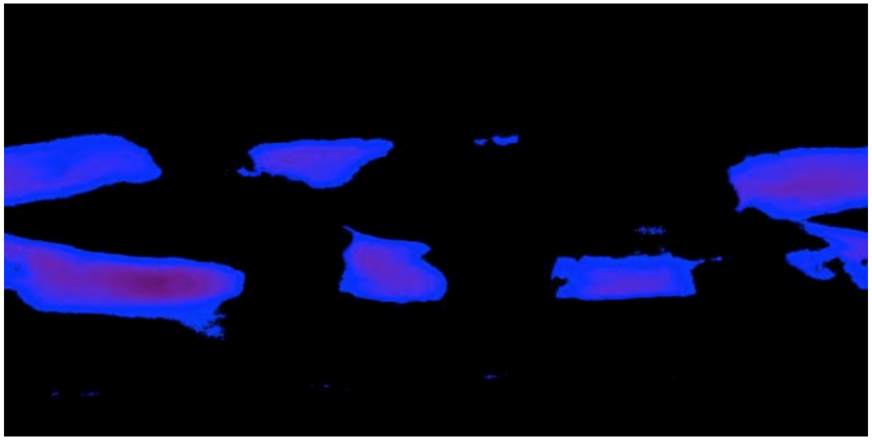
definitions of trophic subsets

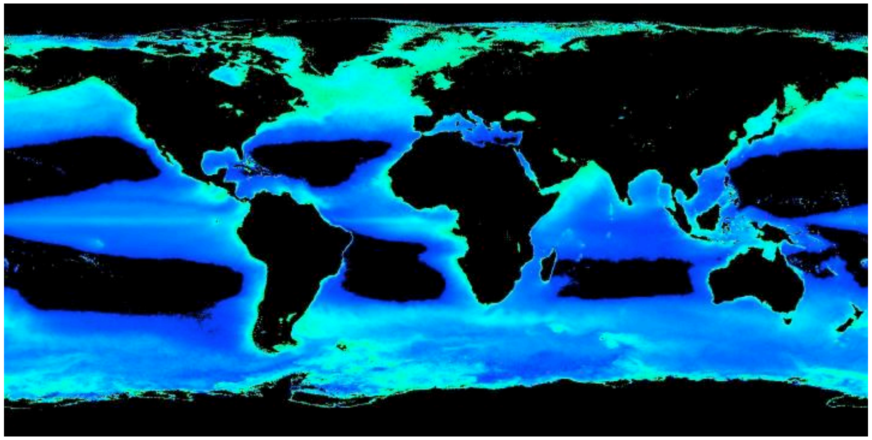
Deep-Water (Depth > 1000m)



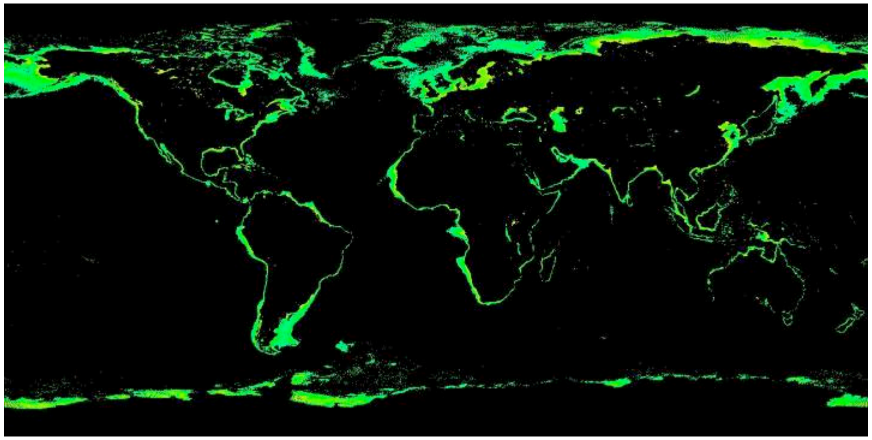
Oligotrophic (Chlorophyll < 0.1)



Mesotrophic (0.1 < Chlorophyll < 1)



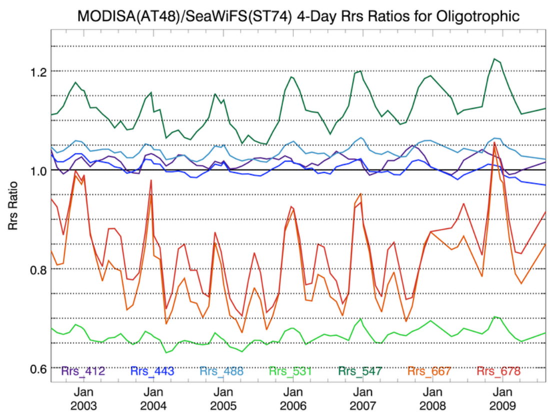
Eutrophic (1 < Chlorophyll < 10)

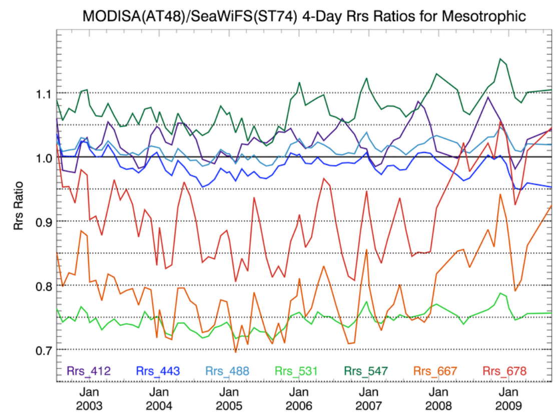


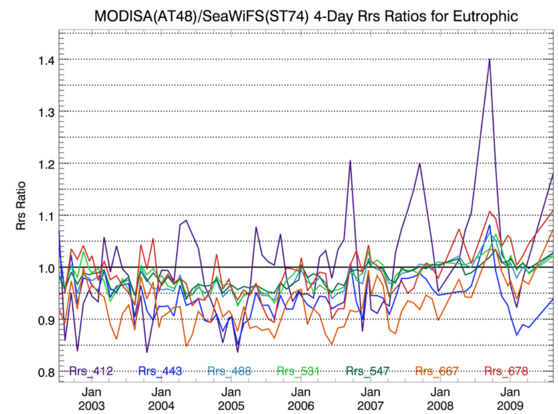
calibrating & reprocessing an ocean color mission

oligotrophic | mesotrophic | eutrophic

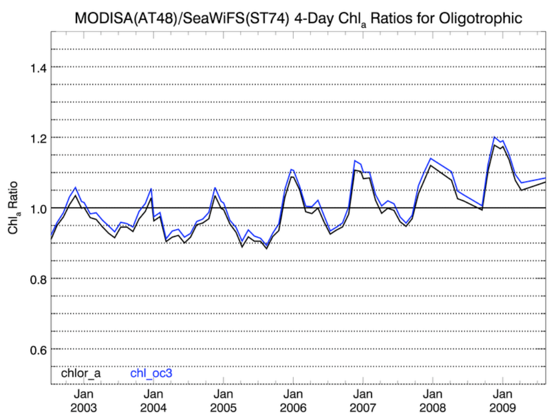
Rrs

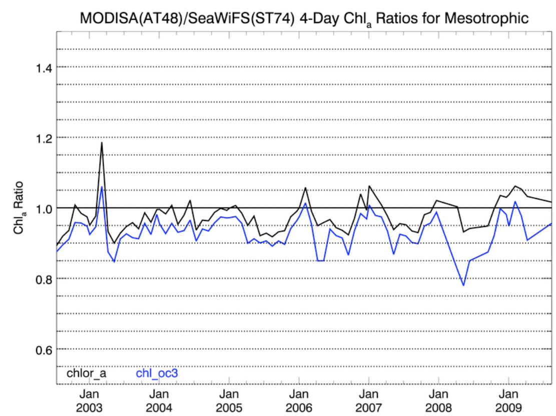


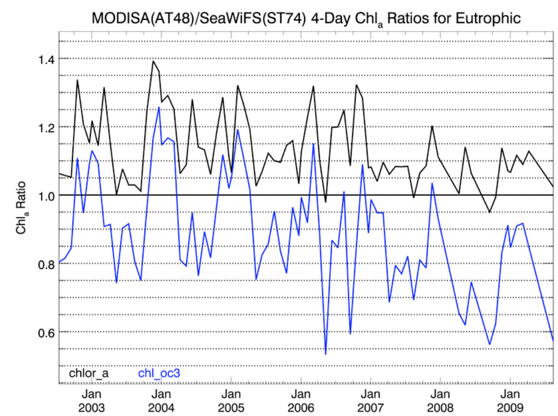




chlorophyll-a

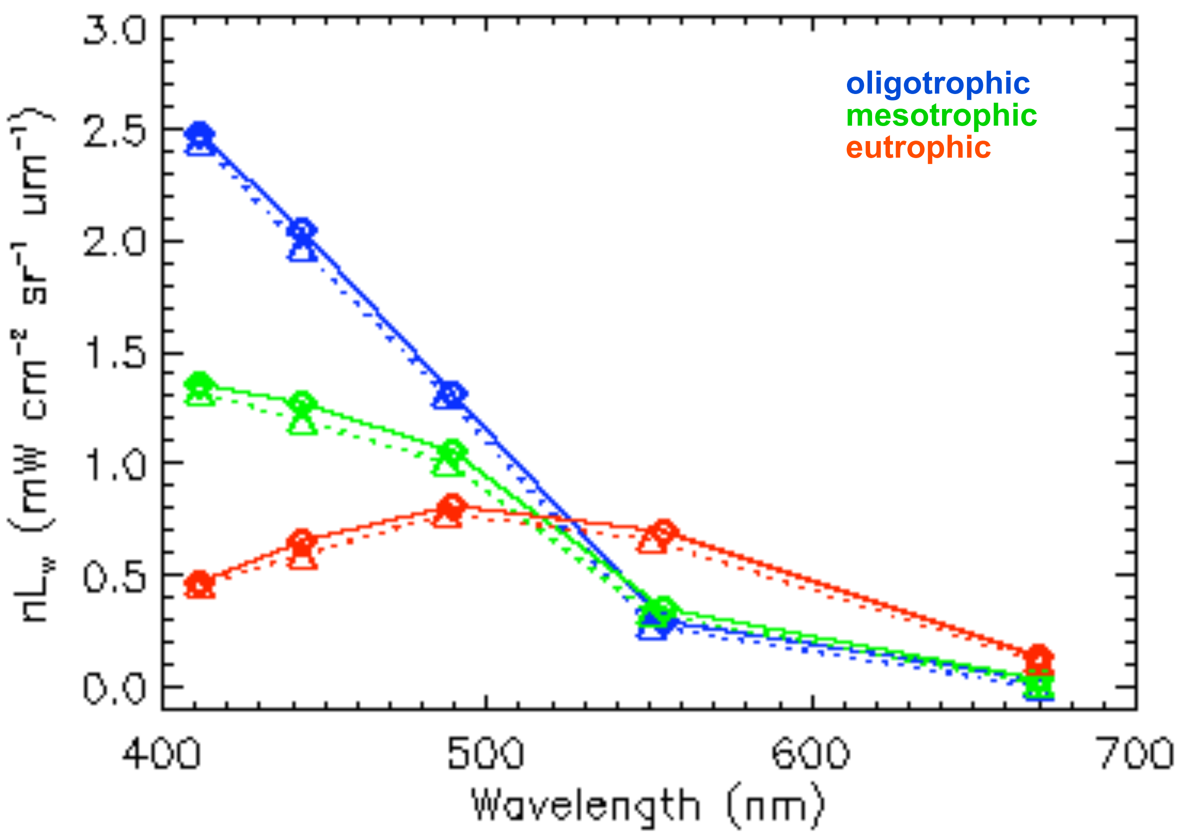






comparison of spectral distribution trends

MODIS & SeaWiFS mean nLw



Level-3 comparisons

- strengths:
  - sensitive to small differences in products from different sensors or algorithms
  - excellent coverage available, both temporal & geographic
  - can assess continuity among data sets (Climate Data Records)
- limitations:
  - no obvious truth in comparisons.
  - sensitive to band-pass differences.
  - may be affected by time-of-observation differences.
  - availability of other sensors for comparison (SeaWiFS or MODIS) is unknown; climatology is available as an alternative

temporal anomaly evaluations

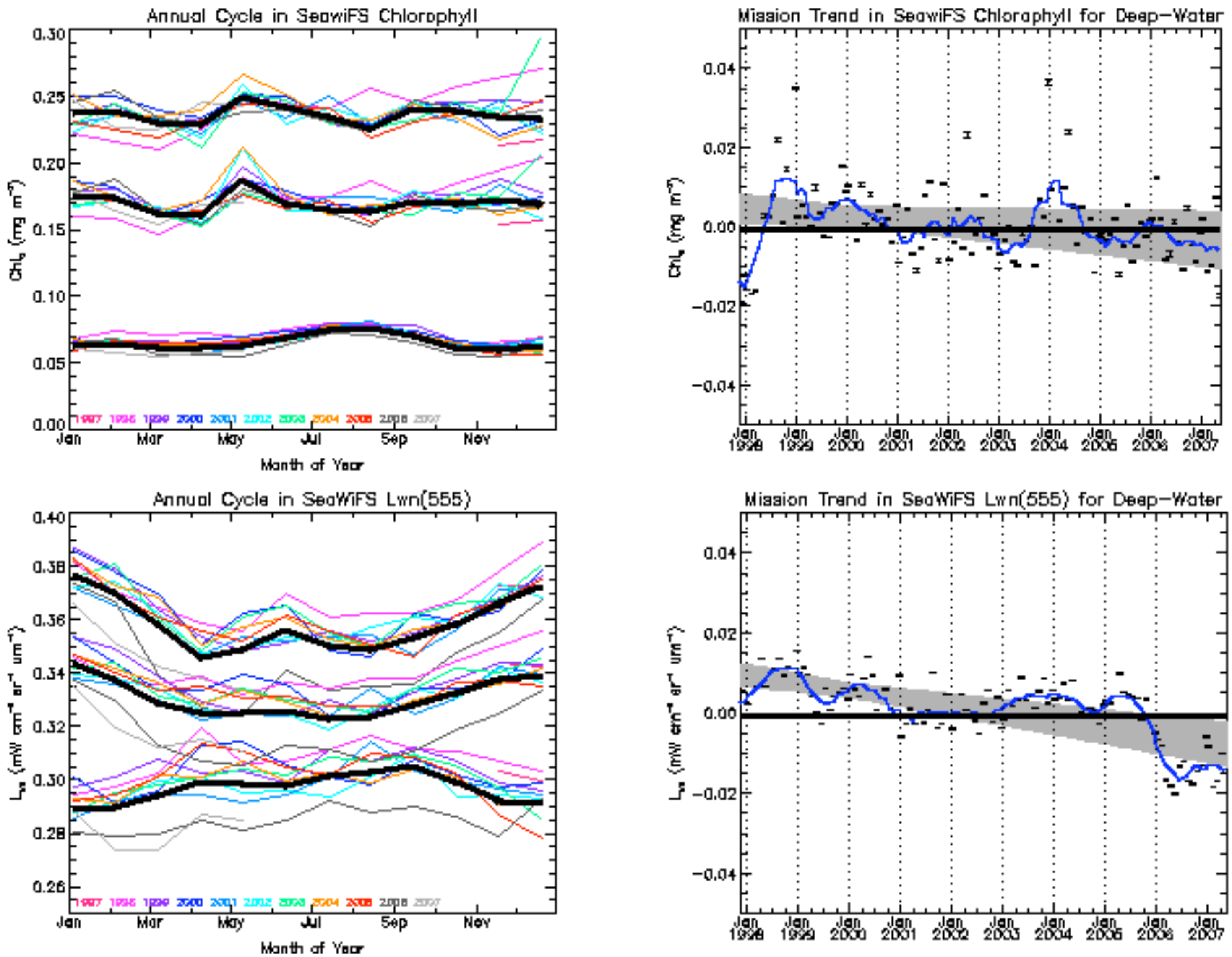
Level-3 global averages for the entire mission are fit to a periodic function to remove natural annual variability

the differences between the global averages & the annual cycle are then plotted over the mission

the results show both geophysical variations & any unexpected changes due to uncharacterized instrument effects or algorithm artifacts

calibrating & reprocessing an ocean color mission

temporal anomaly example



temporal anomaly evaluations

- strengths:
  - very sensitive to small changes in sensor performance
- limitations:
  - difficult to distinguish sensor from real geophysical changes
  - can be affected by sampling variations.

the problem with recovering MODIS-Terra ocean color

- Overheating event in pre-launch testing "smoked" the mirror
  - pre-launch characterization may not adequately represent at-launch configuration (mirror-side ratios, RVS, polarization sensitivities)
- Substantial temporal degradation of instrument response
  - degradation varies with mirror-side and scan-angle
  - temporal change in polarization sensitivity, RVS
- On-board calibration capabilities (lunar, solar) CANNOT assess
  - changes in polarization sensitivities, or
  - changes in RVS “shape”

reprocessing plans for MODIS-Terra

well documented issues with radiometric stability

Franz, B.A., E.J. Kwiatkowska, G. Meister, and C. McClain, "Moderate Resolution Imaging Spectroradiometer on Terra: limitations for ocean color applications," J. Appl. Rem. Sens (2008)

vicarious on-orbit recharacterization of RVS & polarization

Kwiatkowska, E.J., B.A. Franz, G. Meister, C. McClain, and X. Xiong, "Cross-calibration of ocean-color bands from Moderate Resolution Imaging Spectroradiometer on Terra platform," Appl. Opt. (2008)

analysis to be repeated and results fully implemented once SeaWiFS & MODIS-Aqua reprocessing is completed.

MODIS-Terra full mission will then be available through ocean color web browse & ordering system.

calibrating & reprocessing an ocean color mission

lessons learned

sensor pre-launch characterization is critical (e.g., *cross-scan response, polarization sensitivity, spectral out-of-band response, stray-light*). Post-launch characterization may not be possible.

evaluation of advances in on-orbit calibration & processing algorithms requires the capacity for rapid reprocessing, e.g.:

- 10-year SeaWiFS mission can be reprocessed in ~1 day
- SeaWiFS has been reprocessed & redistributed 8 times
- to facilitate new algorithm & calibration evaluations, global SeaWiFS mission has been reprocessed ~100 times

common (sensor-independent) software eliminates potential for algorithm & implementation differences between missions.

consolidated measurement-based team with strong international ties facilitates progress in product development and data quality

1. why ocean color?
2. ocean color @ NASA
3. the NASA Ocean Biology Processing Group (OBPG)
4. calibrating & reprocessing an ocean color mission
5. international collaborations

international collaborations

cost-free, open data policy for all NASA ocean color missions

open source software (SeaDAS - the SeaWiFS Data Analysis System)

SIMBIOS Program

sensor intercomparison studies, data merging algorithms, instrument pools & data processing round robins, & coordinated field data collection

visiting scientists and engineers

Antoine & Morel (f/Q algorithm evaluation), Tanaka (OCTS & GLI, cal/val & processing), Hagolle (POLDER implementation in SeaDAS), Kim (OSMI implementation in SeaDAS), Neumann (IRS-P3/MOS processing stream)

MOS/IRS-P3 Receiving Station at Wallops

OCTS/ADEOS reprocessing & distribution

MODIS SST data for GHRSST

international collaborations

ESA / NASA MERIS collaborations

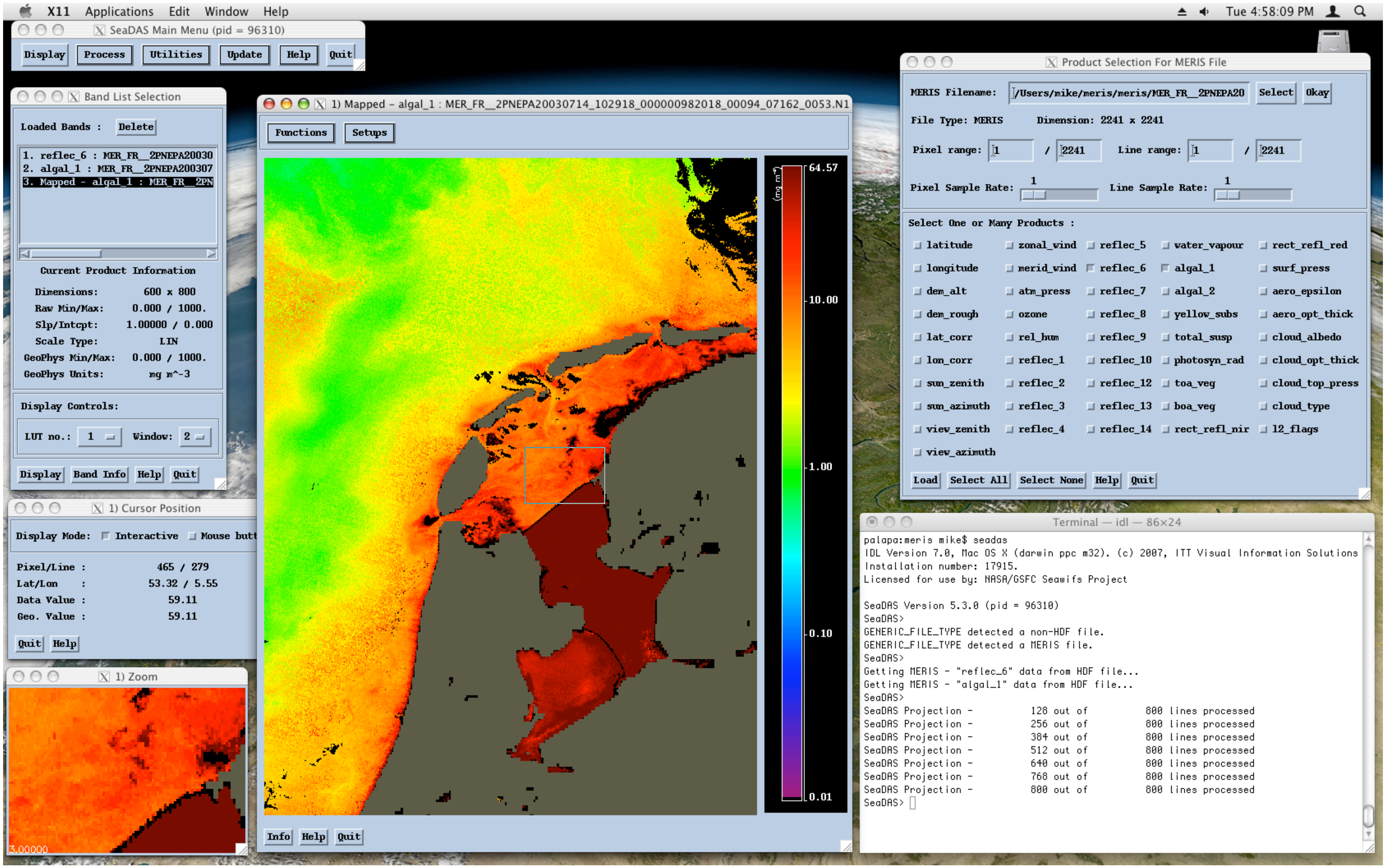
Bryan Franz & Gerhard Meister are participating members of the MERIS Quality Working Group

SeaDAS enhanced to support display & analysis of standard MERIS Level-2 products

MERIS processing capability incorporated into NASA software & released via SeaDAS

participation in the ESA CoastColour Program forthcoming

MERIS Level-2 data displayed in SeaDAS

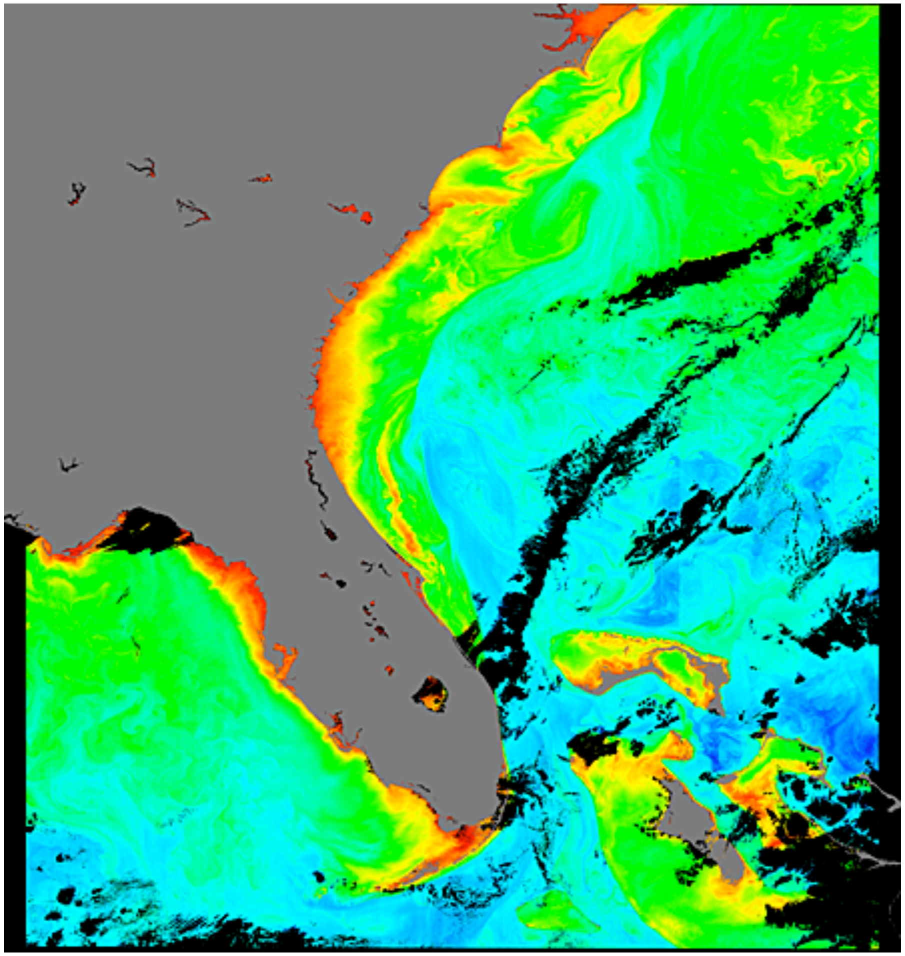


international collaborations

MERIS FRS processed with NASA OC algorithms

RGB

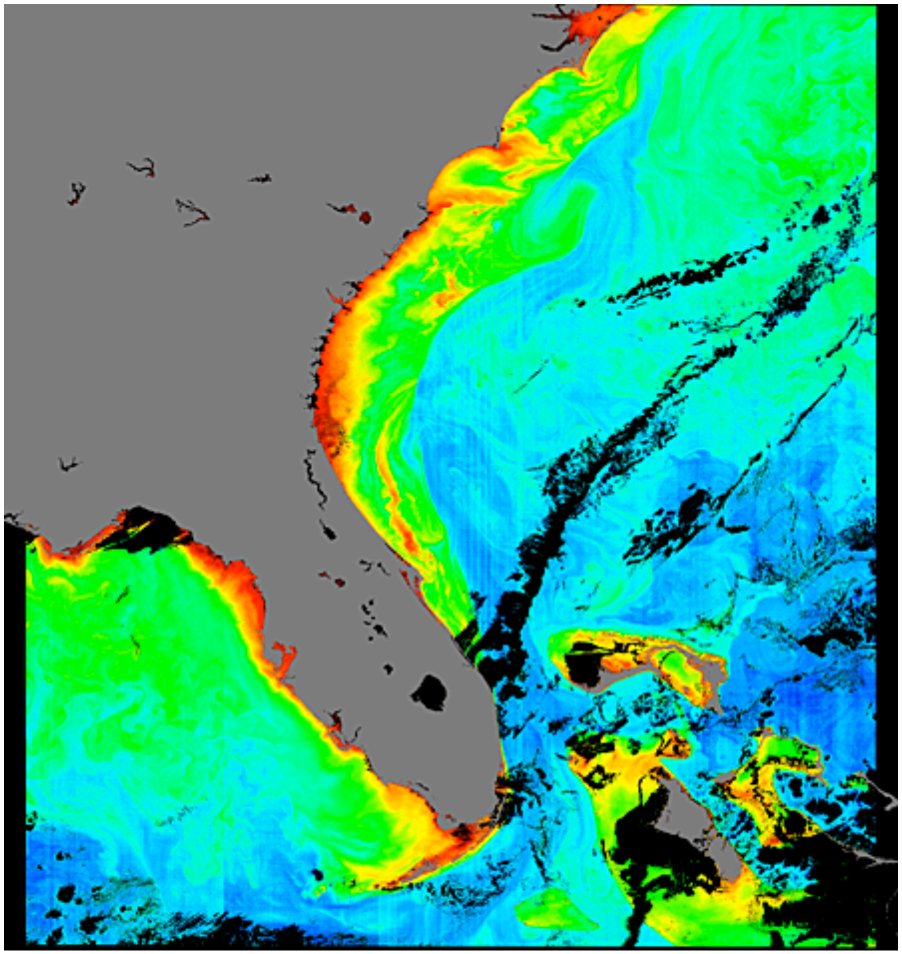
OC4 Chlorophyll



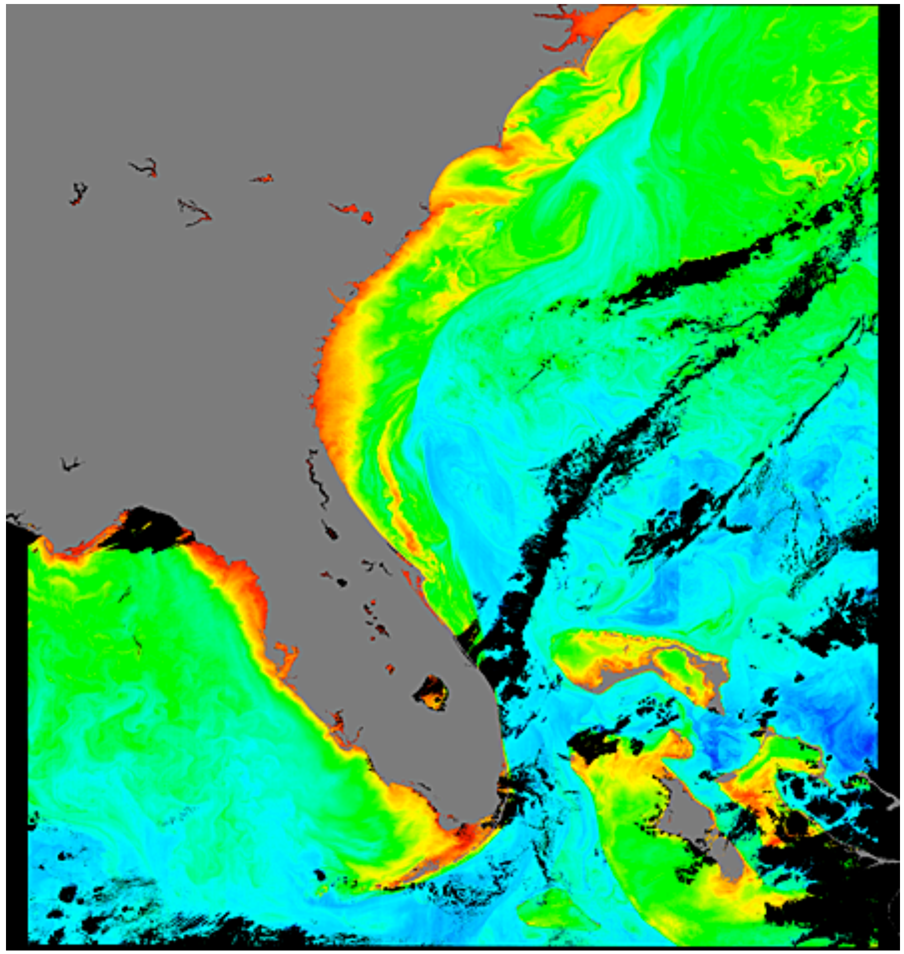
international collaborations

MERIS processing comparison

MERIS Algal1 (ESA/Kiruna)



MERIS OC4 (NASA/OBPG)



international collaborations

Letter of Intent & Proposed Responsibilities between NASA & ISRO (also NOAA & ISRO) signed 18 November 2009 regarding the OCM-2 & scatterometer instruments onboard the ISRO Oceansat-2 satellite

highlights:

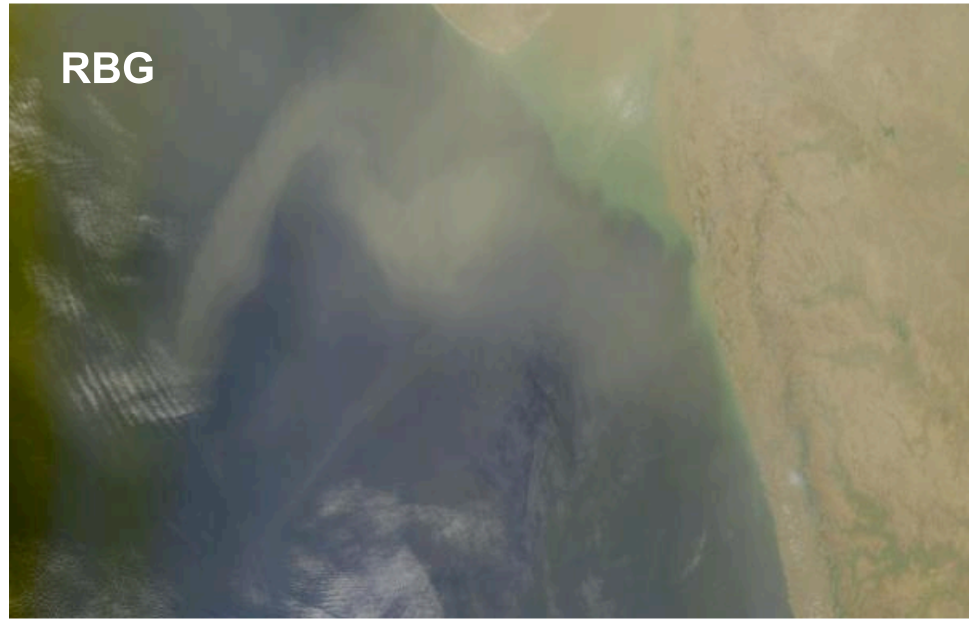
ISRO to provide online access to global OCM-2 data (4-km) at Level-1B for research use to all international users at no cost

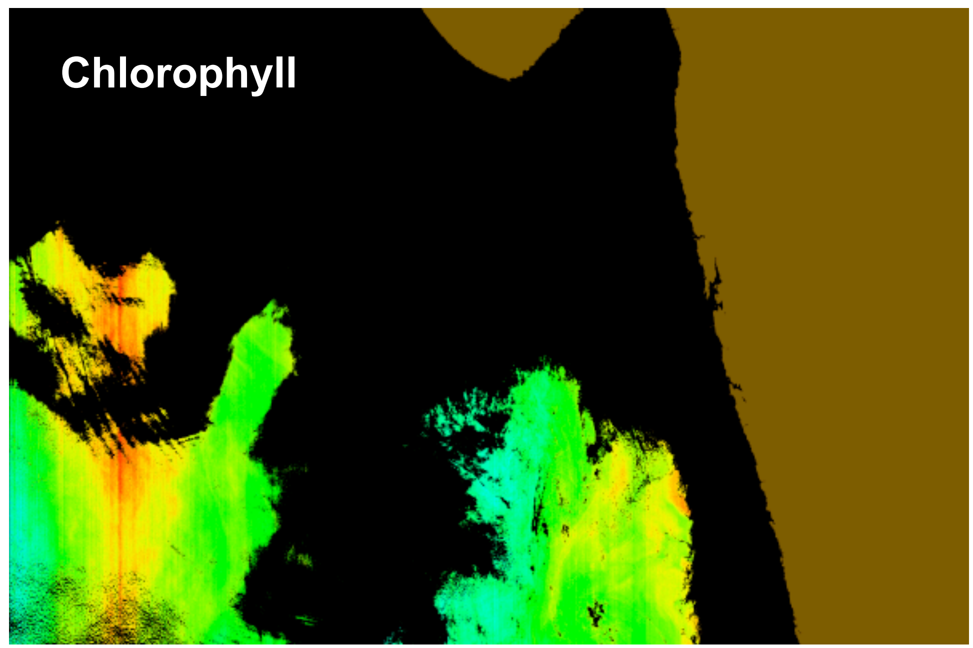
NASA to provide processing capability (Level-1B through Level-3) for use by ISRO & the international community

- distributed via SeaDAS
- preliminary cabability based on OCM already implemented
- need ISRO to finalize Level-1B format

NASA & NOAA to participate in Joint Cal/Val Team preliminary OCM-2 Level-1B format, simulated from OCM-1

sample OCM processing via NASA OBPG software & common SeaWiFS/MODIS algorithms.





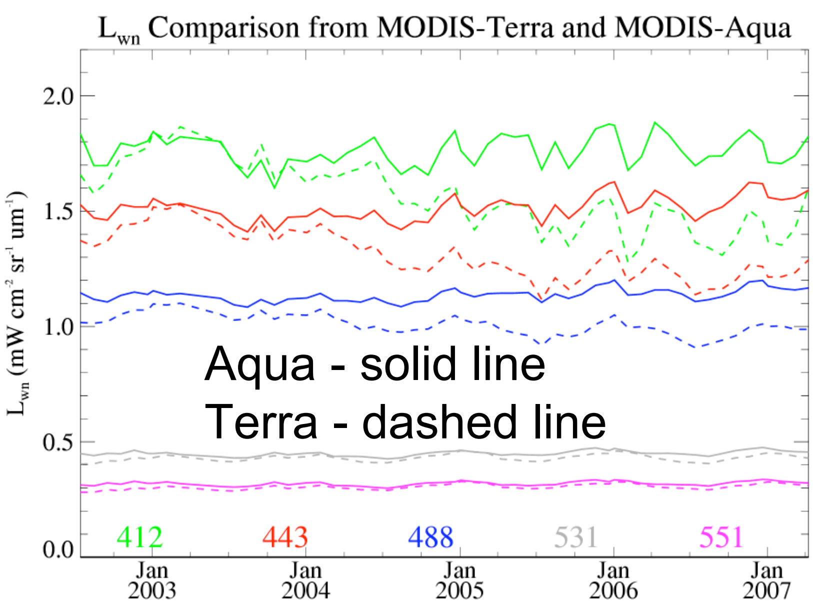

Thank
you
OceanColor
People

thank you!

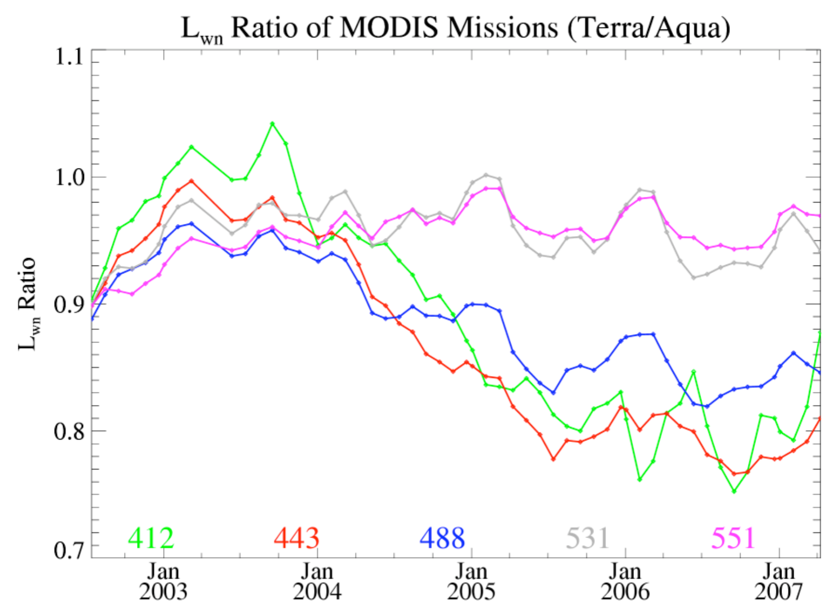
MODIS/Aqua vs MODIS/Terra "as-is"

Temporal Trends in Global Deep-Water nLw

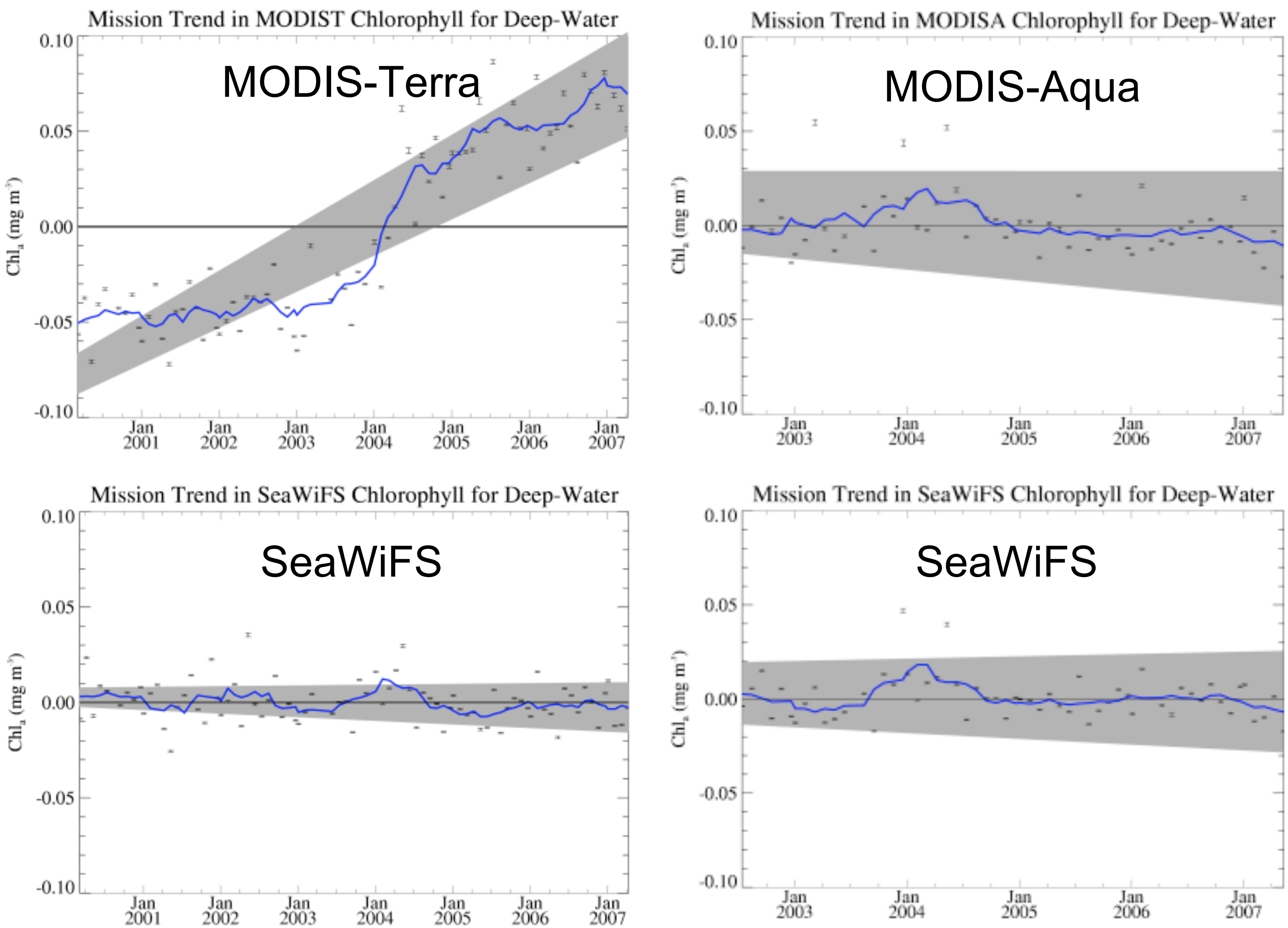
MODIST & MODISA



MODIST / MODISA



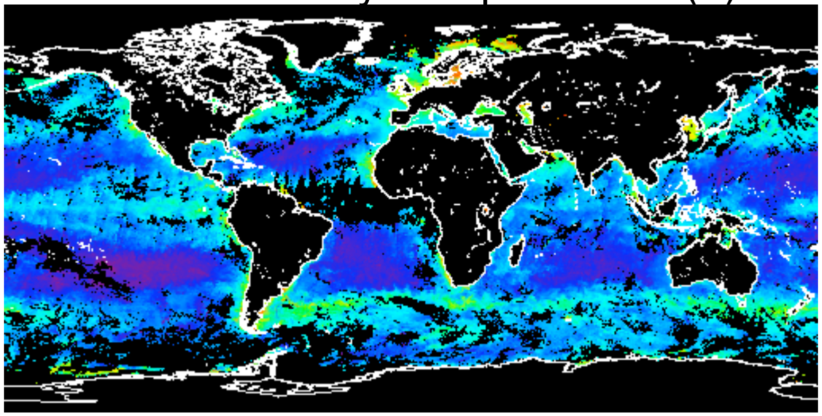
Deep-Water Seasonal Anomaly in Chlorophyll



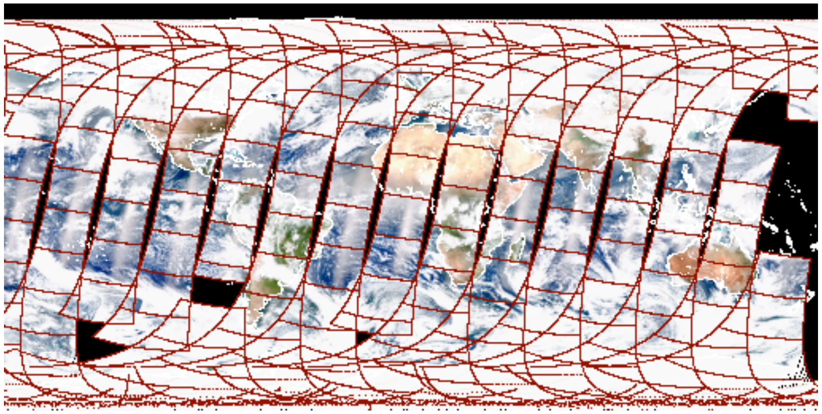
Recovering MODIS/Terra for Ocean Color Use on-orbit characterization of instrument RVS and polarization

$$L_m(\lambda) = \mathbf{M_{11}} L_t(\lambda) + \mathbf{M_{12}} Q_t(\lambda) + \mathbf{M_{13}} U_t(\lambda)$$

SeaWiFS 9-Day Composite nLw(λ)



MODIS Observed TOA Radiances



Vicarious calibration:

given $L_w(\lambda)$ and MODIS geometry, we can predict $L_t(\lambda)$

Global optimization:

find best fit M_{11}, M_{12}, M_{13} to relate $L_m(\lambda)$ to $L_t(\lambda)$

where M_{xx} = fn(mirror aoi)

per band, detector, and m-side

Vicarious Characterization of RVS and Polarization

MODIS – vicarious TOA radiance (unpolarized)

air aerosol whitecap glint water gas

$$L_l(\lambda) = [\ L_r(\lambda) + L_a(\lambda) + tL_f(\lambda) + TL_g(\lambda) + t_d(\lambda)L_w(\lambda)\ ] \cdot t_g(\lambda)$$

from MODIS NIR

assumes MCST NIR band characterization

$\lambda' \rightarrow \lambda,\quad (0,0,0) \rightarrow (\theta_0, \theta, \Delta\phi)$

Morel model, f/Q, etc.

SeaWiFS
9-day mean

$nL_w(\lambda')$

Vicarious Characterization of RVS and Polarization

MODIS – vicarious TOA radiance (unpolarized)

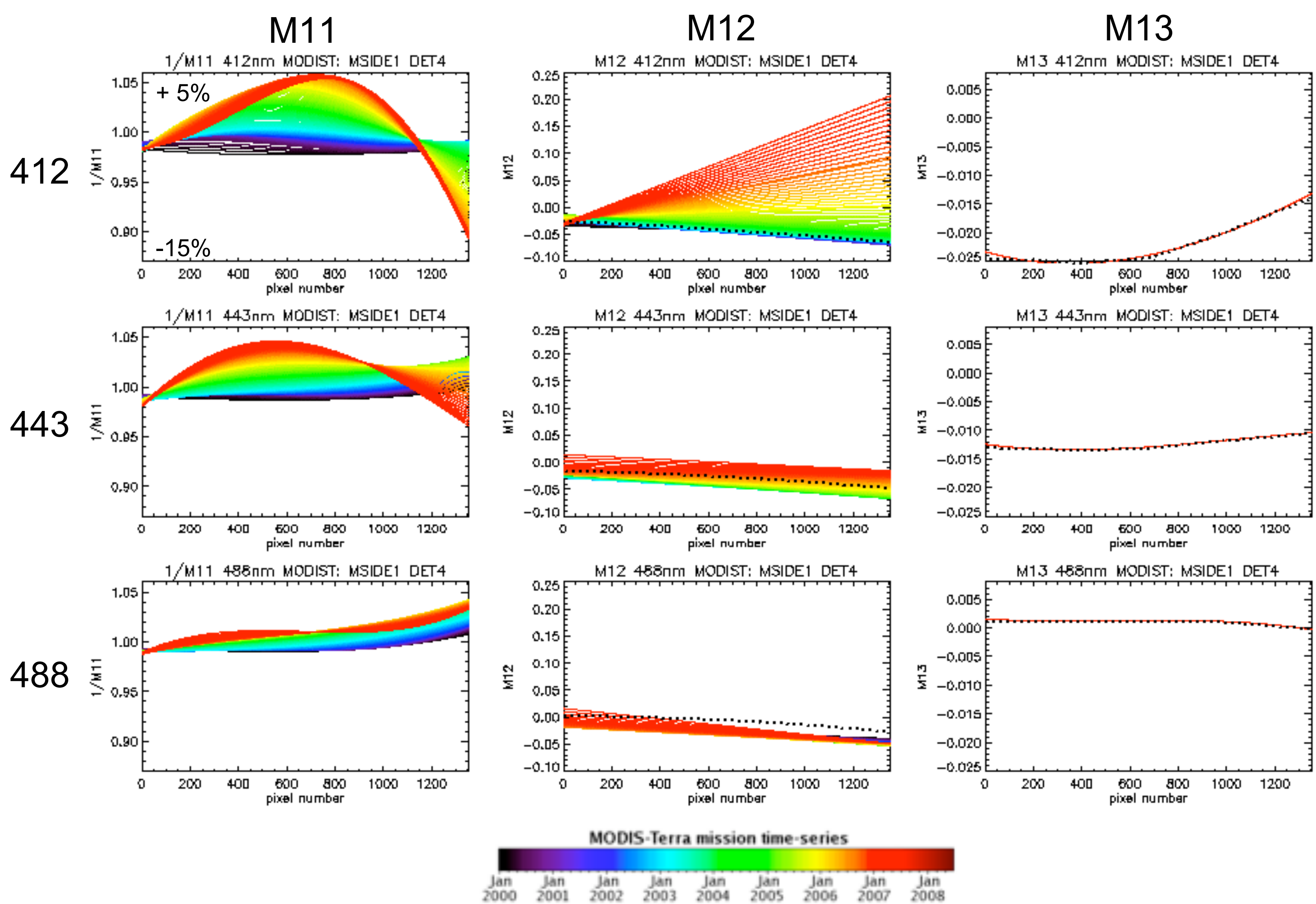
$$L_I(\lambda) = [\ \overset{\text{air}}{L_r(\lambda)} + \overset{\text{aerosol}}{\mathbf{L_a(\lambda)}} + \overset{\text{whitecap}}{tL_f(\lambda)} + \overset{\text{glint}}{TL_g(\lambda)} + t_d(\lambda)\overset{\text{water}}{\mathbf{L_w(\lambda)}}\ ] \cdot \overset{\text{gas}}{t_g(\lambda)}$$

$$\Sigma\ L_t(\lambda) - [M_{11}L_I(\lambda) + M_{12}L_Q(\lambda) + M_{13}L_U(\lambda)]$$

minimize over global distribution of path geometries to find best M_{11}, M_{12}, M_{13} per band, detector, and mirror-side

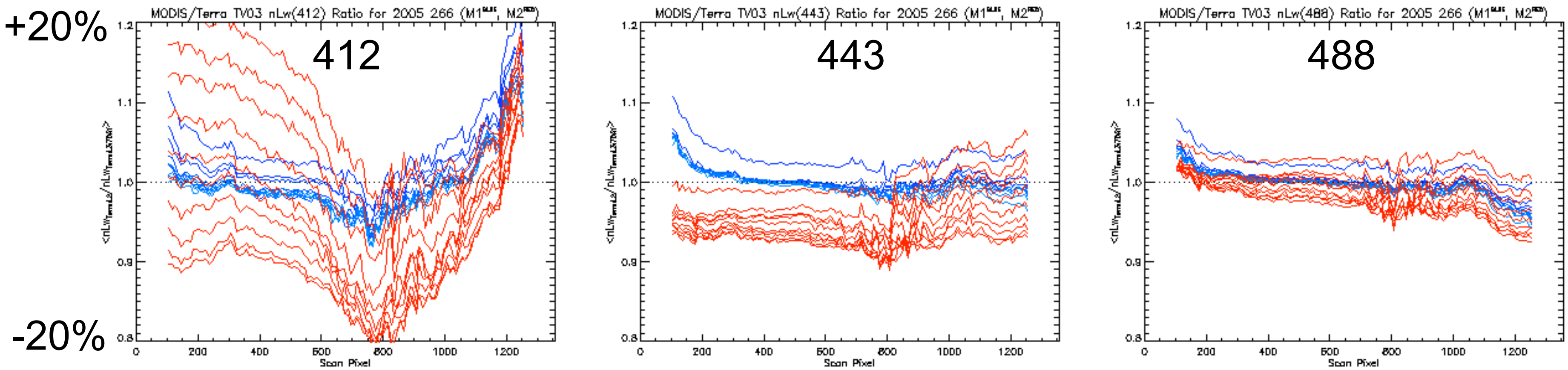
do this for one day per month over the mission lifespan

MODIS-Terra Vicarious Characterization

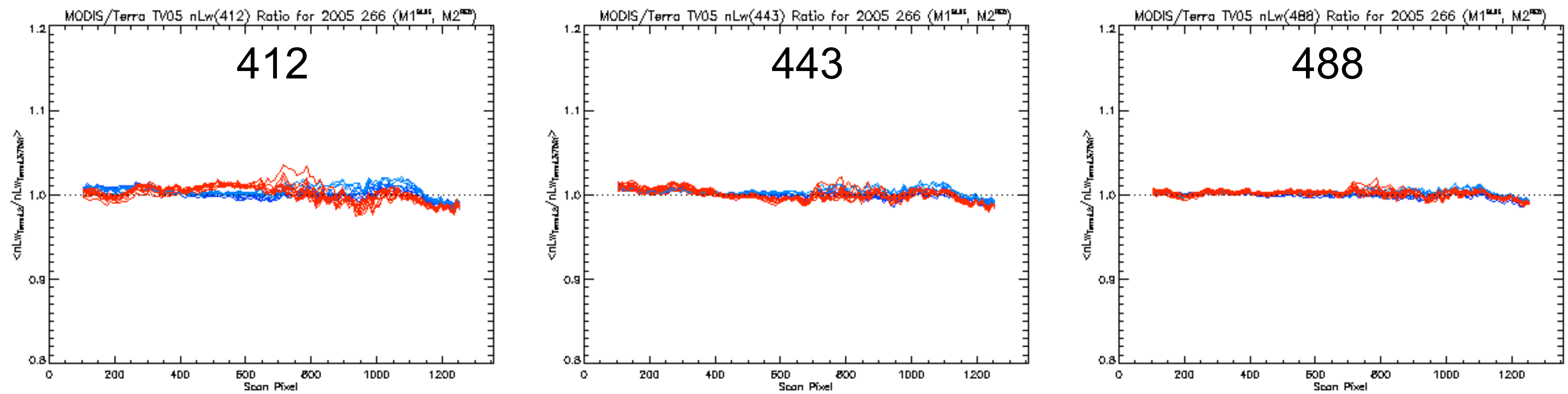


MODIS-Terra Scan-Dependent Variability in nLw

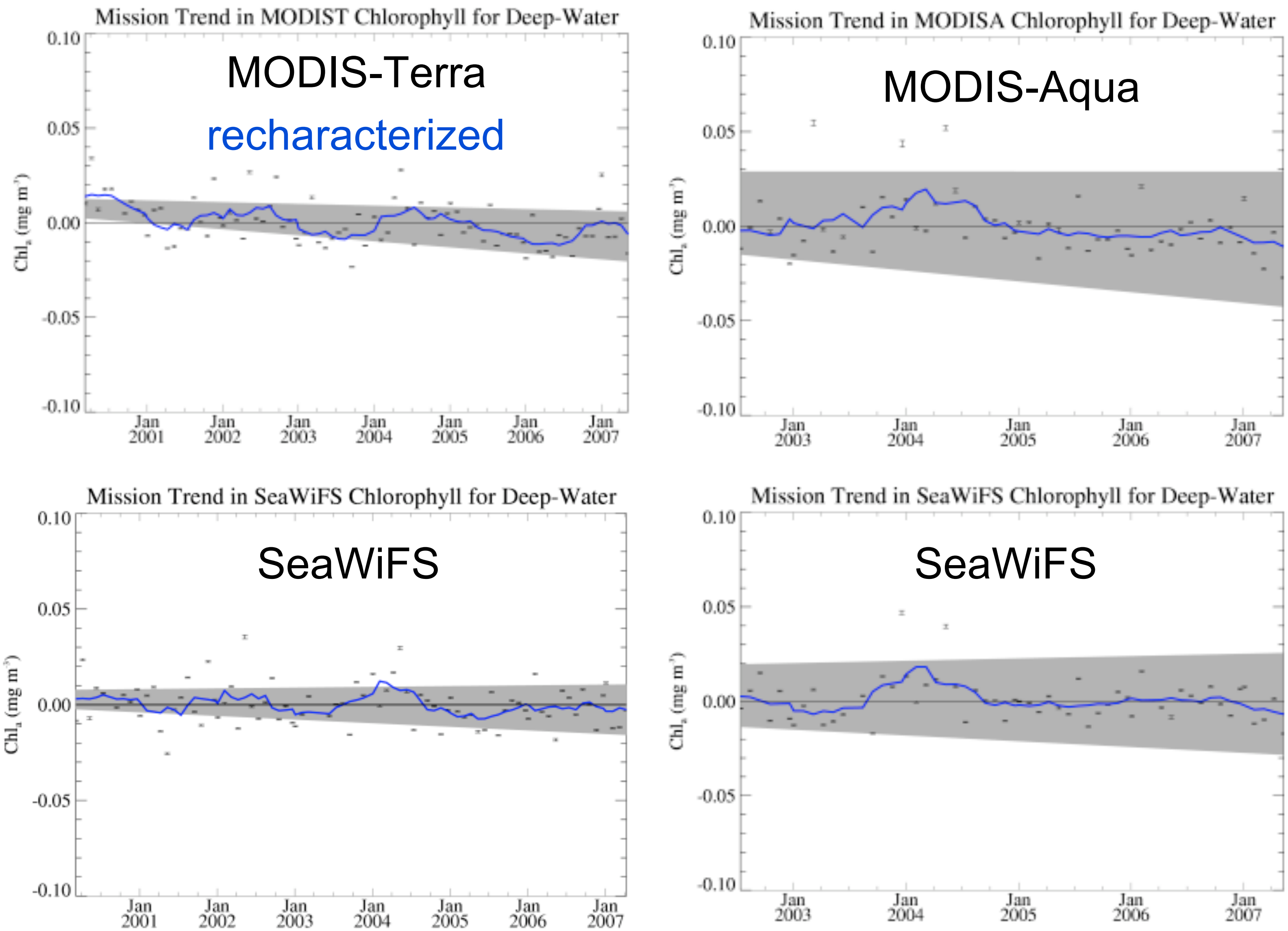
Before Vicarious Characterization



After Vicarious Characterization

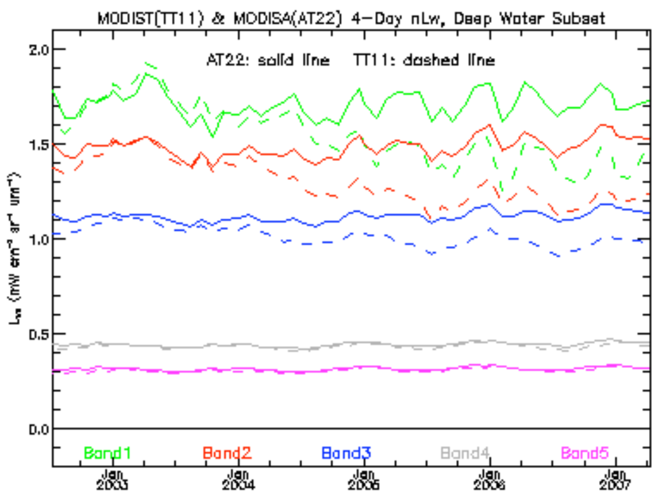


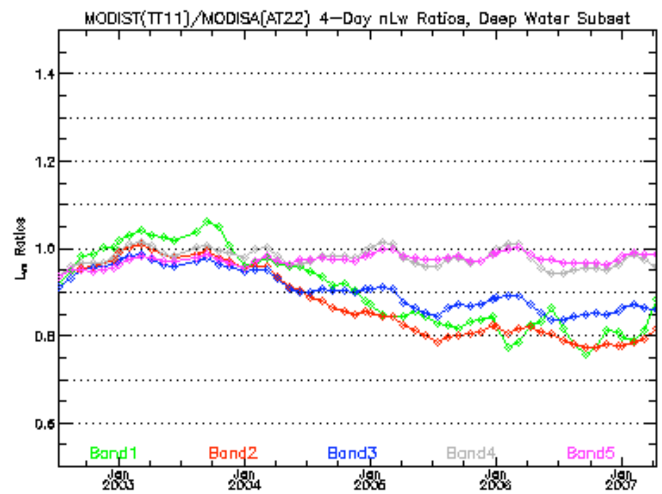
Deep-Water Seasonal Anomaly in Chlorophyll



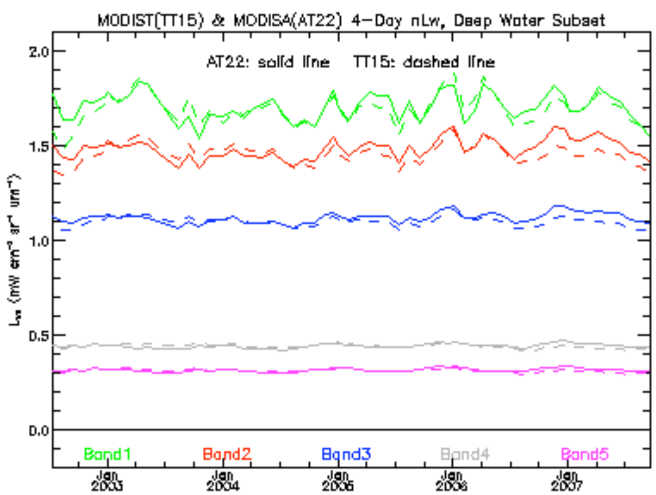
MODIS-Terra and MODIS-Aqua nLw

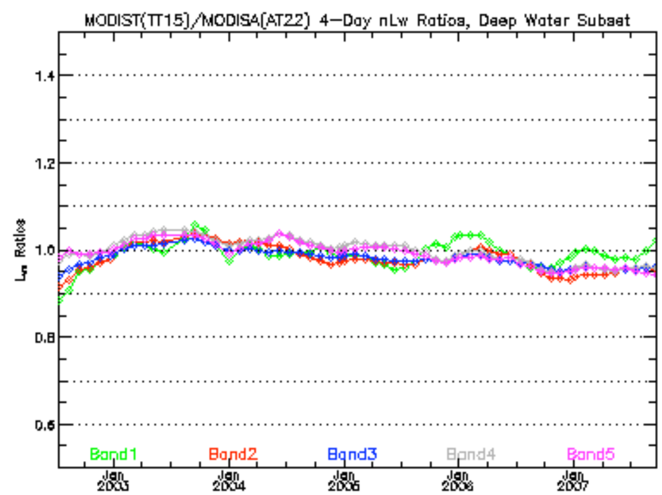
Before Vicarious Characterization



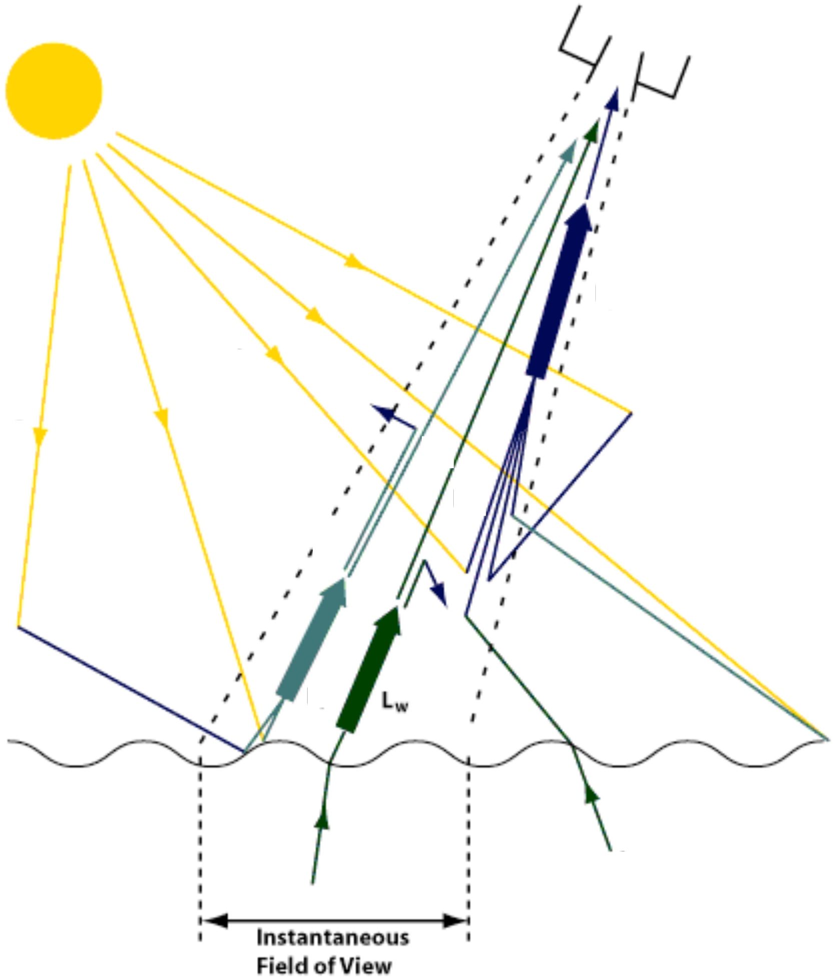


After Vicarious Characterization





Light paths to the sensor



the satellite observes both the **ocean** and the **atmosphere**

Effects of the atmosphere

gaseous absorption (ozone, water vapor, oxygen)

Rayleigh scattering by air molecules

Mie scattering and absorption by aerosols (haze, dust, pollution)

polarization (MODIS response varies with polarization of signal)

Rayleigh (80-85% of total signal)

- small molecules compared to nm wavelength, scattering efficiency decreases with wavelength as λ^{-4}
- reason for blue skies and red sunsets
- can be accurately approximated for a given atmospheric pressure and geometry (using a radiative transfer code)

Aerosols (0-10% of total signal)

- particles comparable in size to the wavelength of light, scattering is a complex function of particle size
- whitens or yellows the sky
- significantly varies and cannot be easily approximated

Atmospheric correction

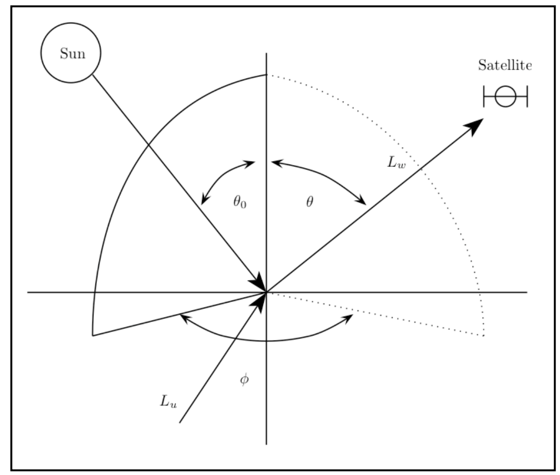
TOA gas pol glint whitecap air aerosol

$$t_d(\lambda)\ L_w(\lambda) = L_t(\lambda)\ /\ t_g(\lambda)\ /\ f_p(\lambda) - TL_g(\lambda) - tL_f(\lambda) - L_r(\lambda) - L_a(\lambda)$$

brdf Sun

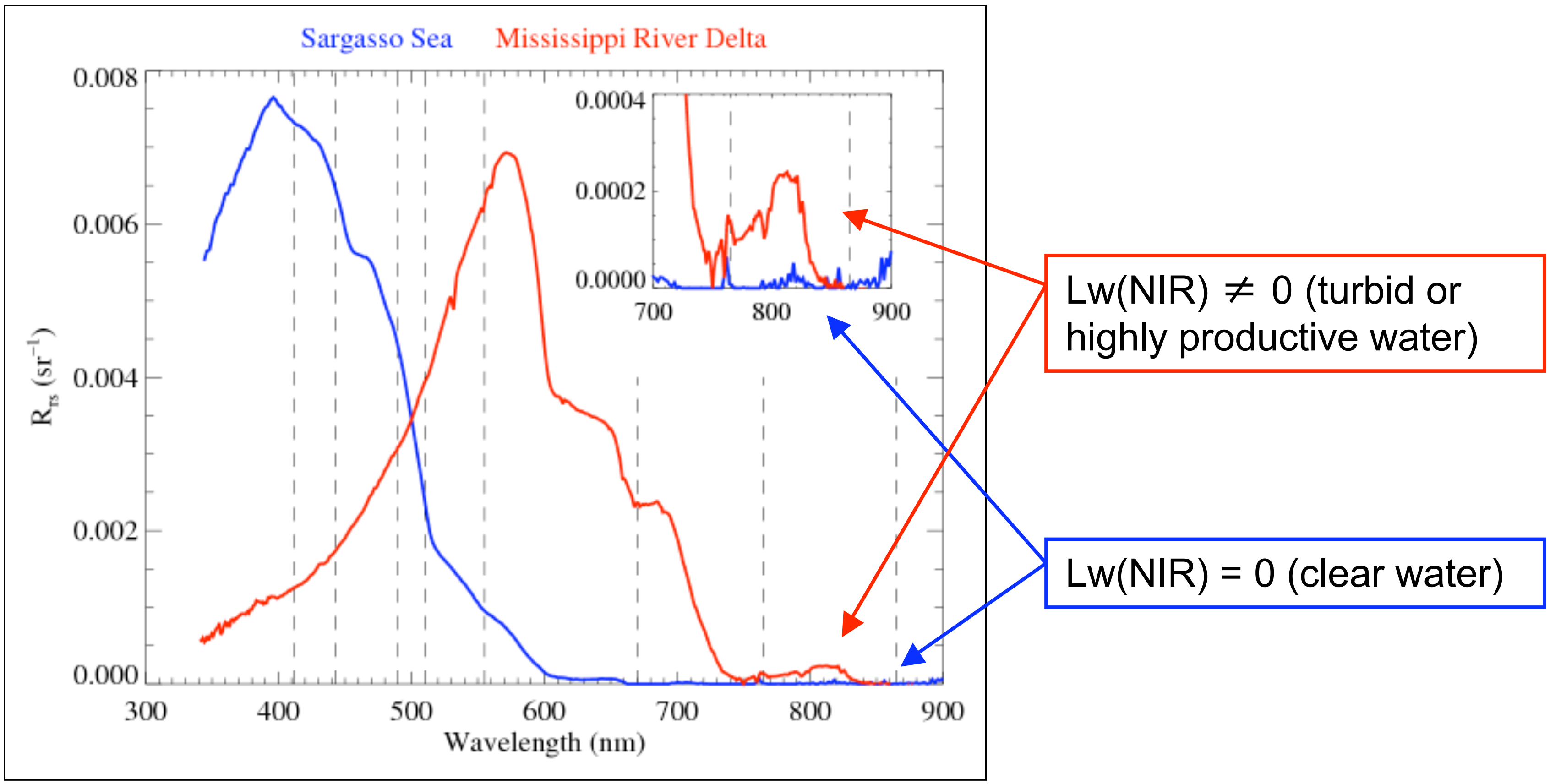
$$nL_w(\lambda) = L_w(\lambda)\ f_b(\lambda)\ /\ t_{d0}(\lambda)\ \mu_0\ f_0$$

But, <u>we need aerosol</u> to get $L_w(\lambda)$



$L_w(\lambda=\mathrm{NIR}) \approx 0$ and can be estimated (model extrapolation from VIS) in waters where *Chl* is the primary driver of $L_w(\lambda)$

Magnitudes of *Lw*(NIR)



Aerosol determiniation in visible wavelengths

Given retrieved aerosol reflectance at two λ, and a set of aerosol models fn(θ,θ_0,ϕ).

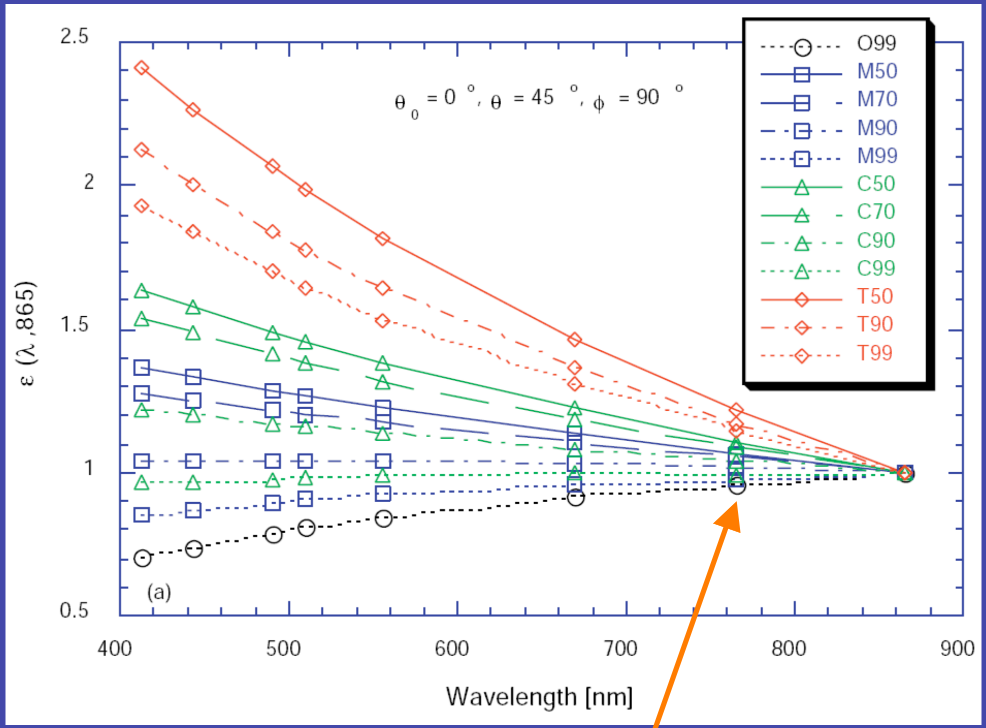
$$\rho = \frac{\pi L}{F_0 \cdot \mu_0}$$

$\rho_a(748)$ & $\rho_a(869)$

$$\rho_a(NIR) \overset{\text{model}}{\Rightarrow} \rho_{as}(NIR)$$

$$\varepsilon\,(748,869) = \frac{\rho_{as}(748)}{\rho_{as}(869)}$$

$$\varepsilon\,(\lambda,869) = \frac{\rho_{as}(\lambda)}{\rho_{as}(869)}$$



$\varepsilon\,(748,869)$

Iterative correction for non-zero *Lw*(NIR)

(1) assume Lw(NIR) = 0

(2) compute La(NIR)

(3) compute La(VIS) from La(NIR)

(4) compute Lw(VIS)

(5) estimate Lw(NIR) from Lw(VIS) + model

(6) repeat until Lw(NIR) stops changing

iterating up to 10 times

Level-2 ocean color processing

(1) determine atmospheric and surface contributions to total radiance at TOA and subtract, iterating as needed.

(2) normalize to the condition of Sun directly overhead at 1 AU and a non-attenuating atmosphere (nLw or Rrs = nLw/F_0).

(3) apply empirical or semi-analytical algorithms to relate the spectral distribution of nLw or Rrs to geophysical quantities.

(4) assess quality (set flags) at each step