

Satellite Ocean Color/Biogeochemistry Climate Data Records

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Ocean Biology Processing Group**

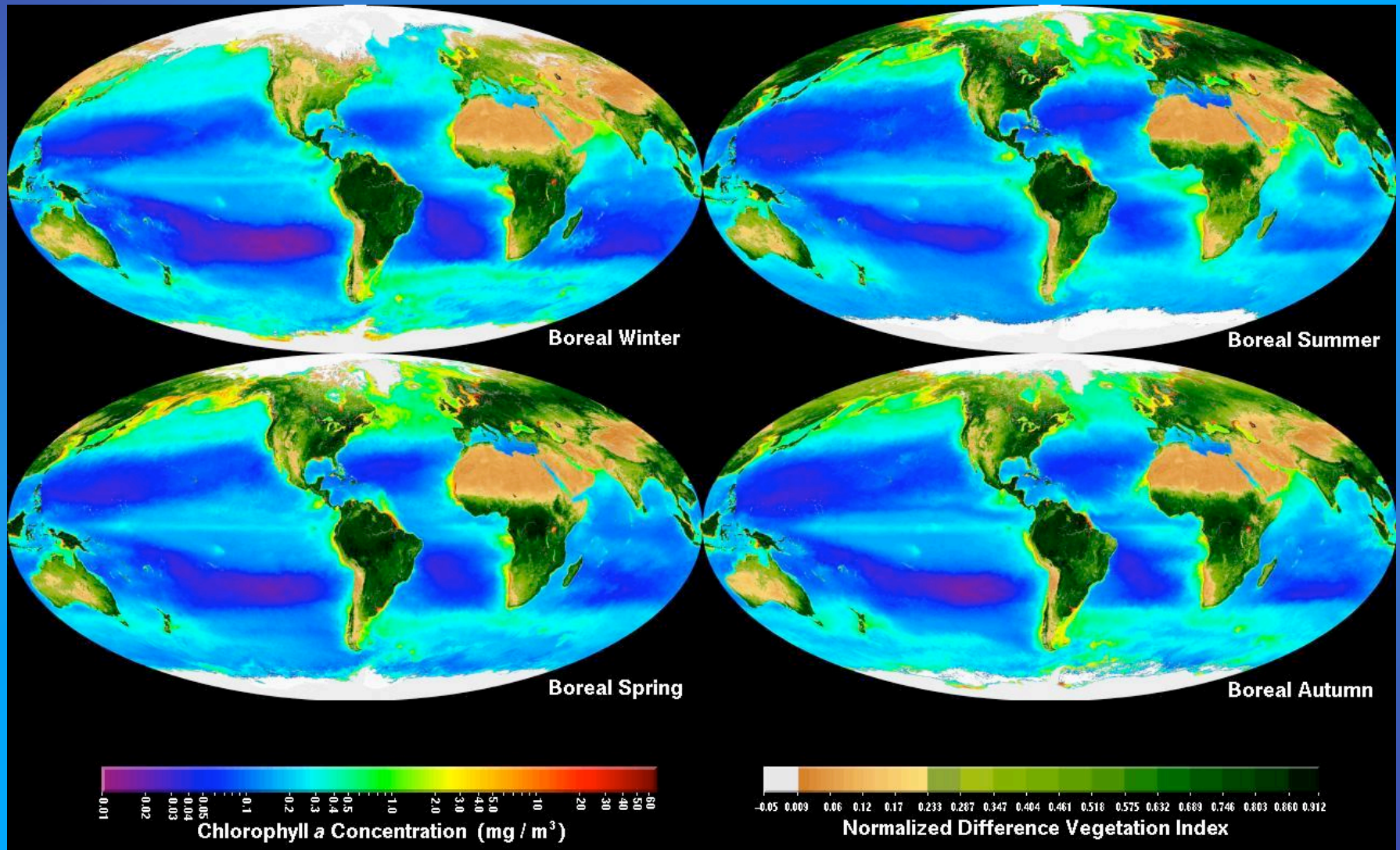
NASA MODIS Science Team Meeting

March 22-24, 2005



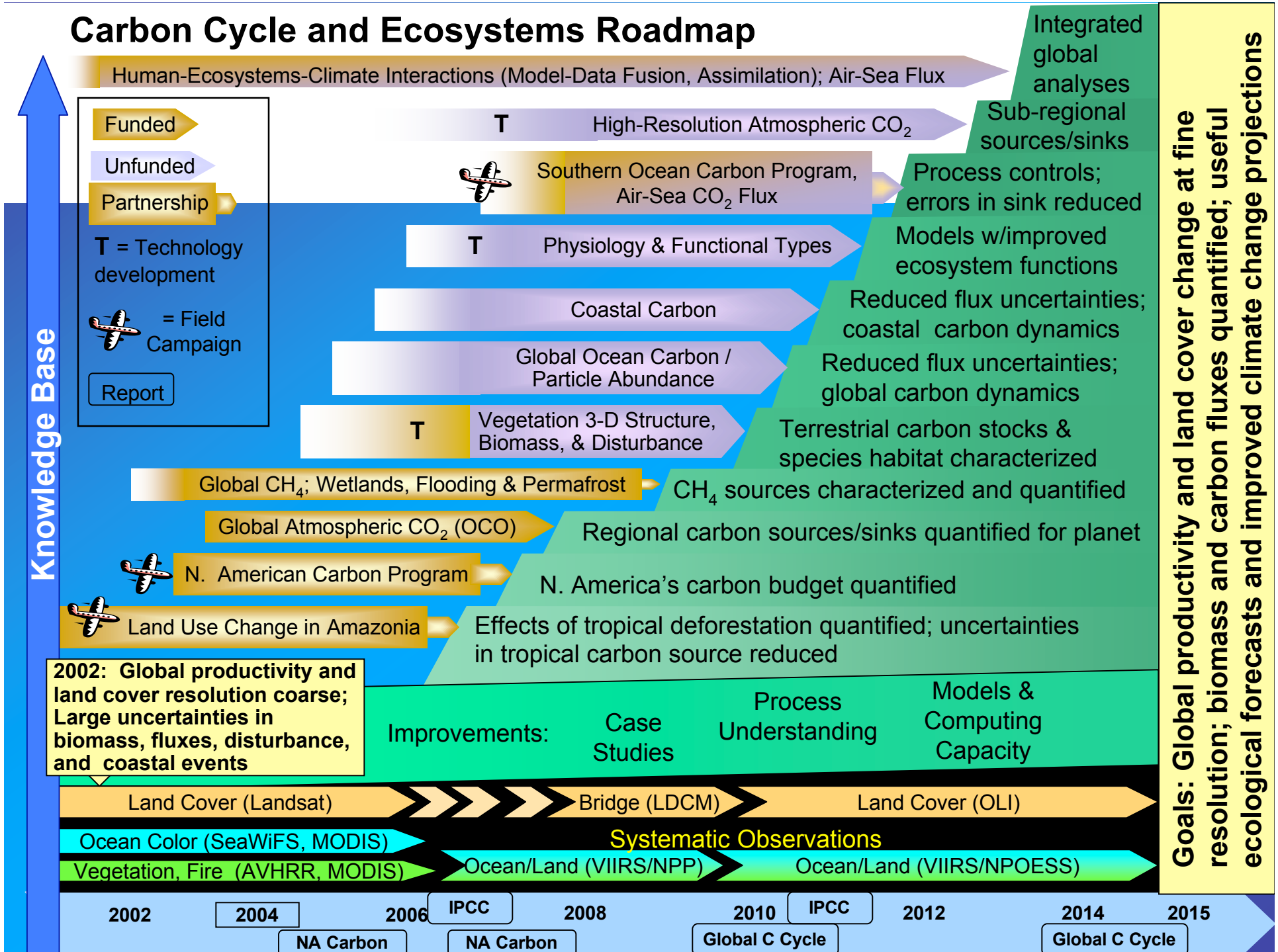
Seasonal Biosphere

Ocean Chlorophyll-a & Terrestrial NDVI



Data from SeaWiFS

Carbon Cycle and Ecosystems Roadmap



Data Requirements for Climate Research: Climate Data Records

- **Long-term continuous time series**
 - Must span interannual and short-term natural variability (e.g., ENSO)
 - Necessarily requires data from **multiple missions** (e.g., CZCS to NPOESS)
 - Must include most recent data, e.g., NPP/VIIRS
 - Continuous ocean color time series starts in 1996 with ADEOS-I/OCTS
 - Must minimize data gaps to avoid aliasing of natural climate oscillations (e.g., ENSO)
- **Highest possible quality (satellite & in situ)**
 - Must not include significant sensor artifacts and trends
 - Decadal scale variability and climate trends are small and can be easily confused with sensor drift
 - Ocean color products are particularly sensitive to sensor characterization/calibration errors (e.g., 1% error in calibration produces about a 10% error in water-leaving radiance)
 - Must be validated with **ample highly accurate field data**
 - Requires **reprocessings** (e.g., SeaWiFS has been reprocessed 5 times in 7.5 years)
- **Consistency between satellite data sets**
 - Must be **cross-calibrated** and processed using **similar algorithms**, i.e, no abrupt transitions between data sets
 - Requires periodic reprocessings to improve products & maintain consistency

GLOBAL OCEAN BIOGEOCHEMISTRY MISSIONS

Instrument (Mission; Country)	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	12	
GLOBAL MISSIONS																		
OCTS (ADEOS-I; Japan)																		
POLDER (ADEOS-I/II; France)**																		
SeaWiFS (Orbview-2; U.S.)																		
MODIS (Terra; U.S.)*																		
MERIS (ENVISAT; ESA)																		
GLI (ADEOS-II; Japan)																		
MODIS (Aqua; U.S.)																		
VIIRS (NPP; U.S.)**																		
VIIRS (NPOESS series; U.S.)																		
Note: CZCS (1978-1986) did not routinely collect global data.	*MODIS/Terra ocean color data not presently in production						** NPP launch will probably slip											

Primary CDR Data Set
 Future CDR Data Set
 Data Sets Not Being Used in CDR Analysis

Historical Ocean Color Accuracy Goals

- **Sensor radiometric calibration**
 - * $\pm 5\%$ absolute
 - * $\pm 1\%$ band-to-band relative

- **Water-leaving radiances**

- * $\pm 5\%$ absolute

- **Chlorophyll-a**

- * $\pm 35\%$ over range of 0.05-50.0 mg/m³

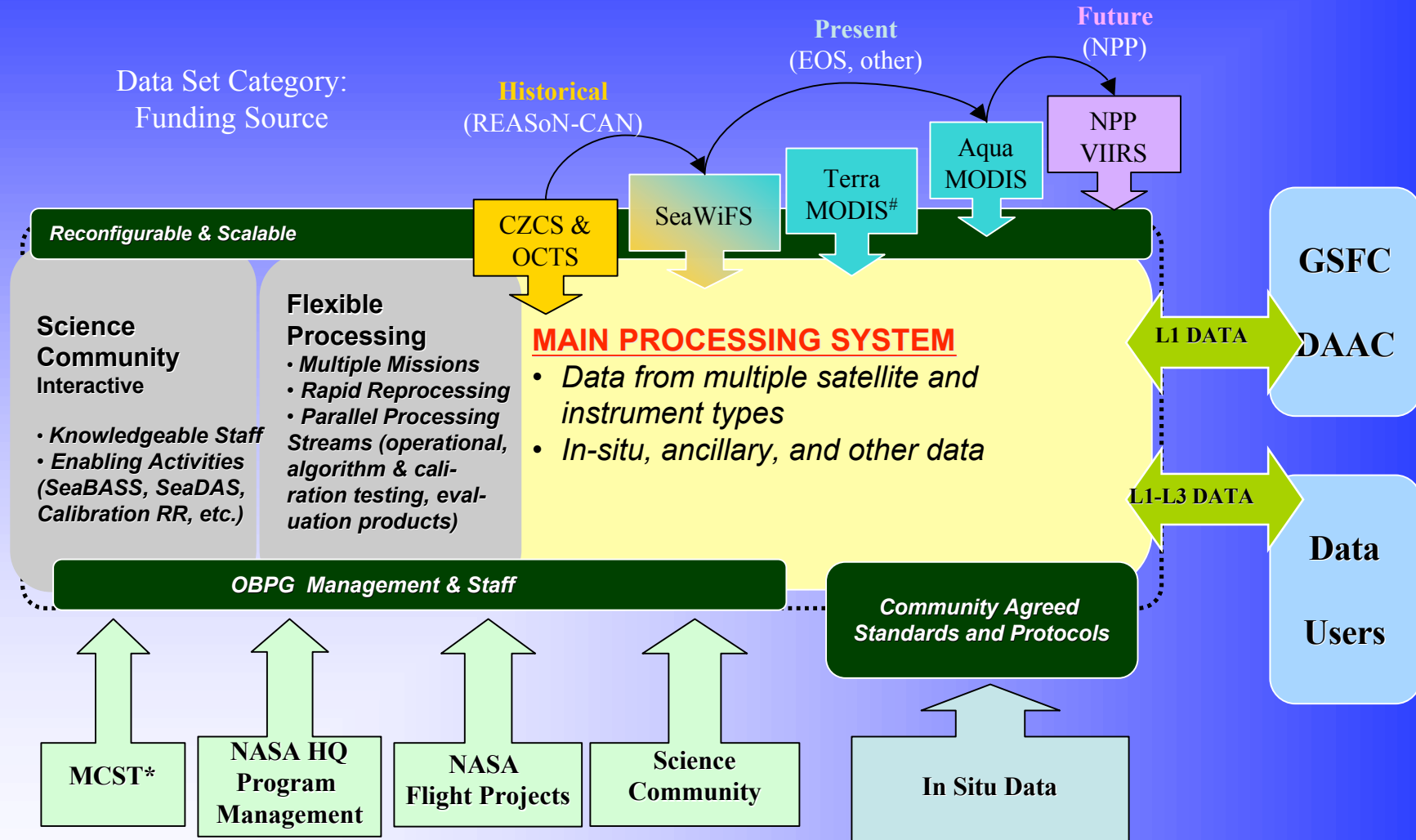
Current Ocean Biogeochemistry CDRs. Community presently revising product suite & CDR requirements.

These accuracy specifications are being reconsidered based on experience with SeaWiFS & MODIS.

Infrastructure Requirements for CDR Development

- Protocols for laboratory & in situ observations
- Advanced instrumentation development & ongoing instrument performance evaluations
- Calibration and data analyses round robins
- In situ data archive and standardized QC procedures
- Algorithm development (atmospheric & bio-optical)
- On-orbit calibration capabilities
 - On-board methods (e.g., lunar data)
 - Vicarious methods (e.g., MOBY)
- Multi-mission reprocessing capability

Ocean Biology Processing System

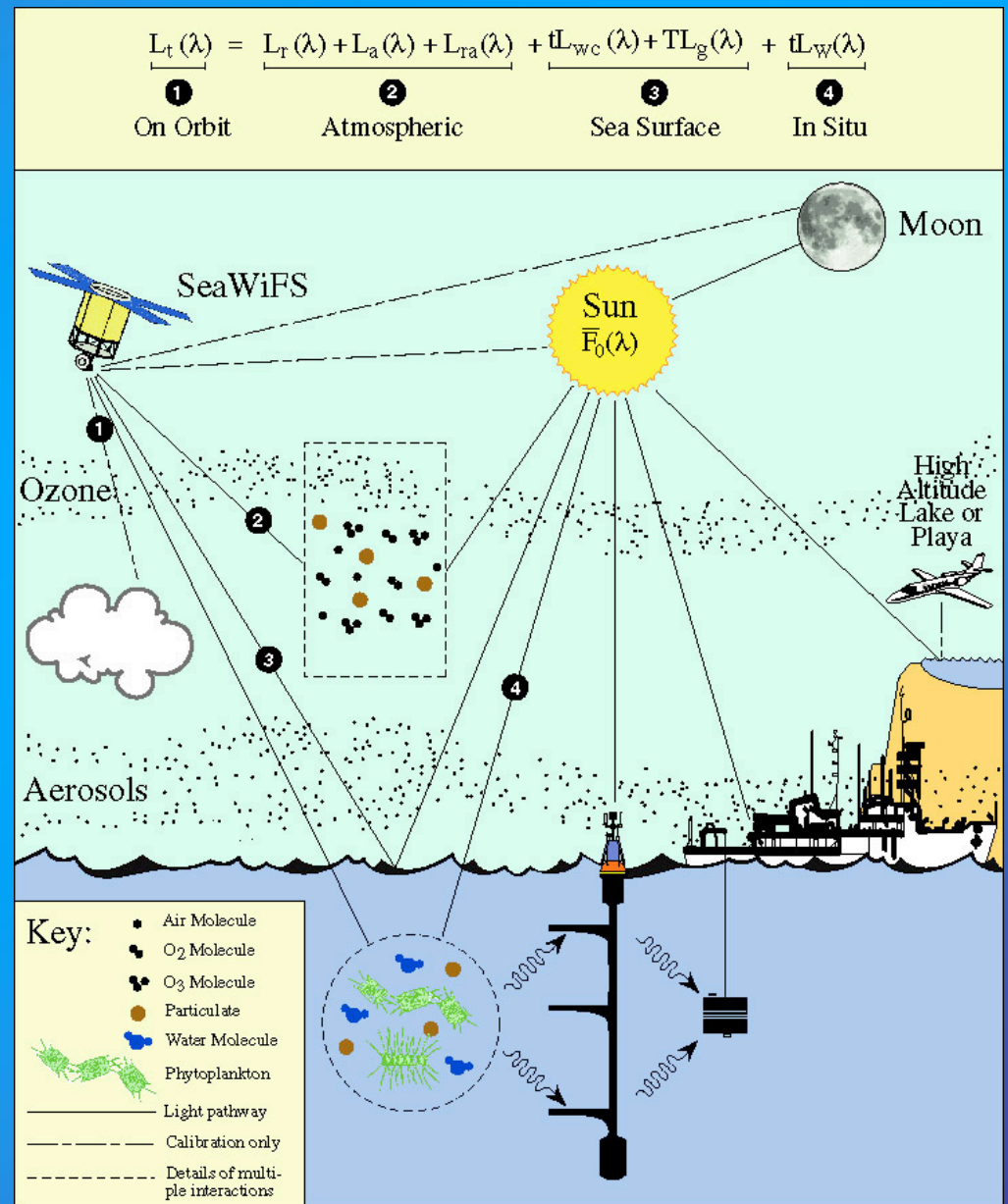


* MODIS Characterization Support Team (NASA/GSFC)
Terra MODIS OC processing suspended in Jan. 2004

Calibration Validation Paradigm

Satellite Calibration Elements:

- **Laboratory** - before launch, sensor is calibrated in lab
- **On-orbit** - daily solar and monthly lunar observations are used to track changes in sensor response
- **Vicarious** - comparison of data retrievals to in-water, ship, and airborne sensors is used to adjust instrument gains



Ocean Optics Protocols for Satellite Ocean Color Sensor Validation

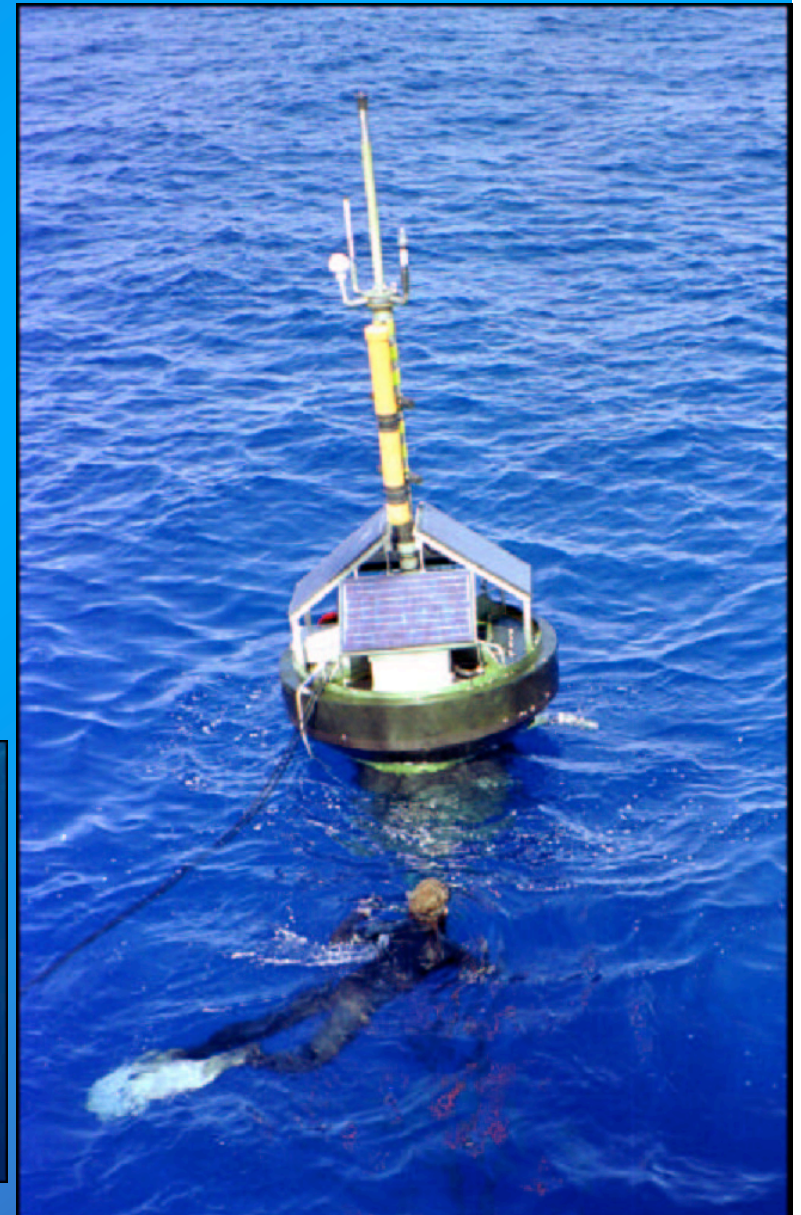
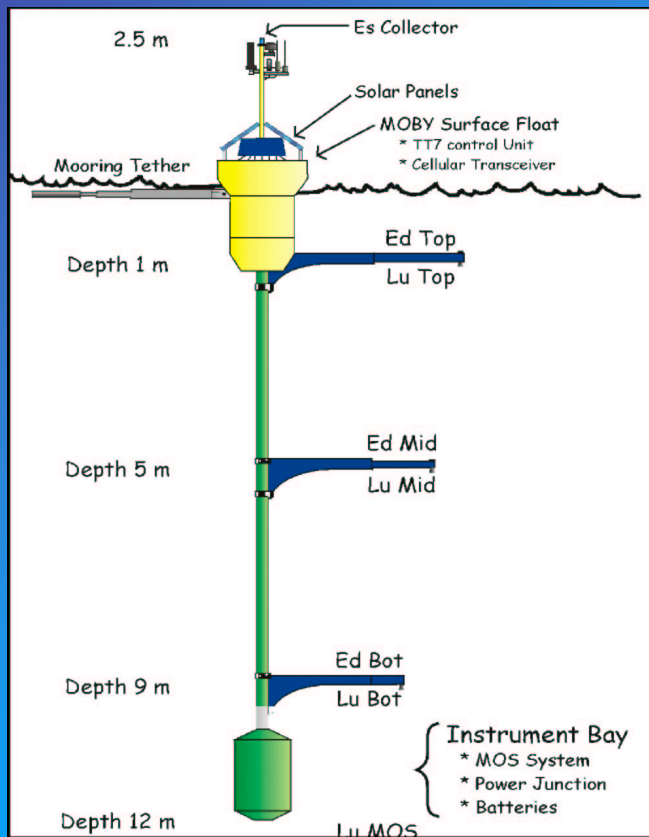
Original Protocols:

- Mueller & Austin 1992, Ocean Optics Protocols for SeaWiFS Validation, NASA TM 104566, Vol. 5, 43 pp.

Revisions and Other Protocols:

- Mueller & Austin 1995, Revision 1, Volume 25 in the SeaWiFS Technical Report Series.
- Fargion & Mueller 2000, Revision 2, NASA TM 2000-209966.
- Fargion et al., 2001, AOT Protocols, NASA TM 2001-209982.
- Mueller et al., 2002, Revision 3, NASA TM 2002-21004 (Vol.1-2).
- Mueller et al., 2003, Revision 4, NASA TM 2003-211621 (Vol. 1-6).

MOBY: Vicarious Calibration

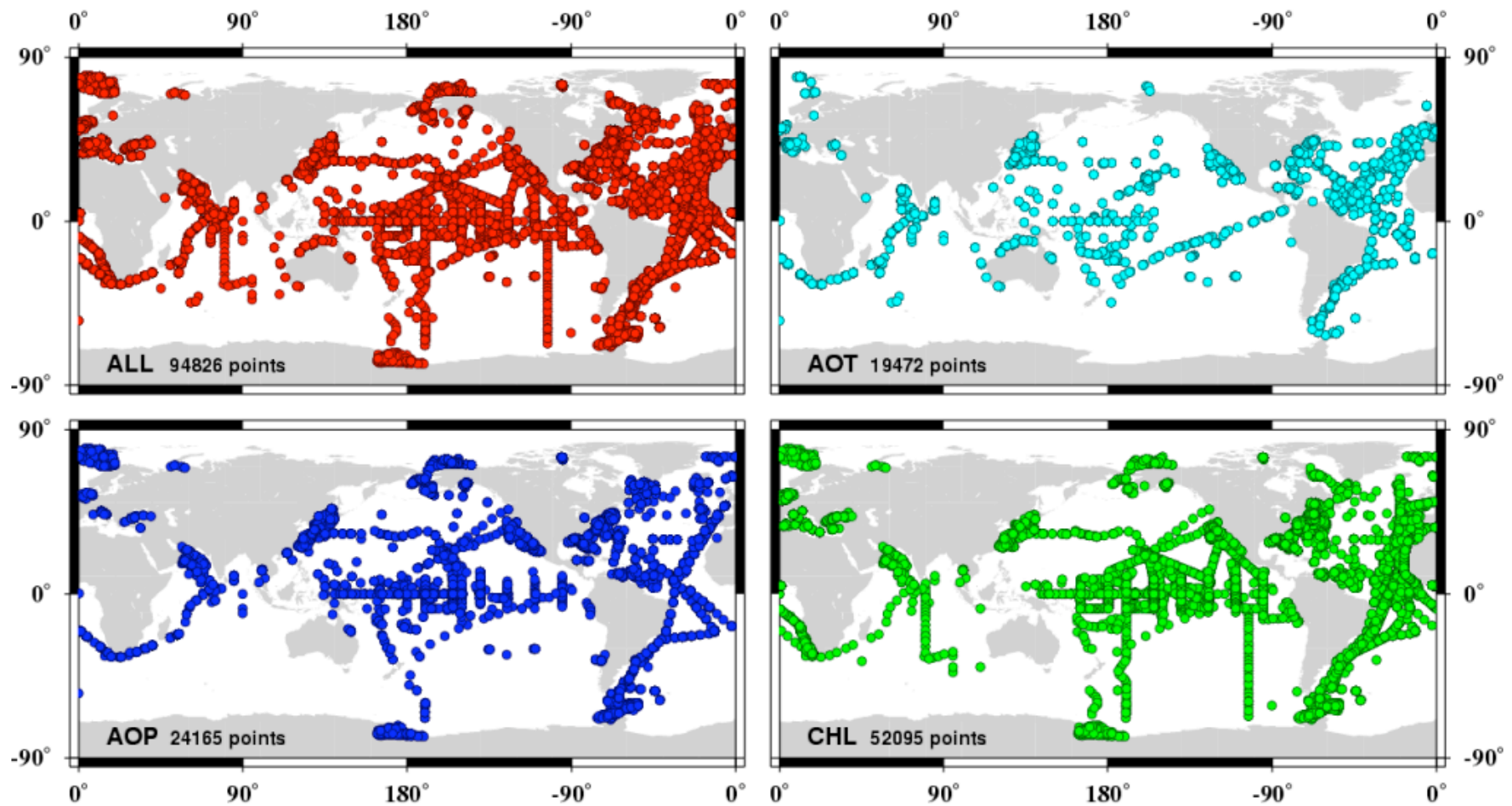


MOBY used to adjust prelaunch calibration gains for visible bands using satellite-buoy comparisons.



SeaWiFS Bio-optical data Archive & Storage System (SeaBASS)

SeaBASS data points as of March 2005



Data from over 1360 cruises

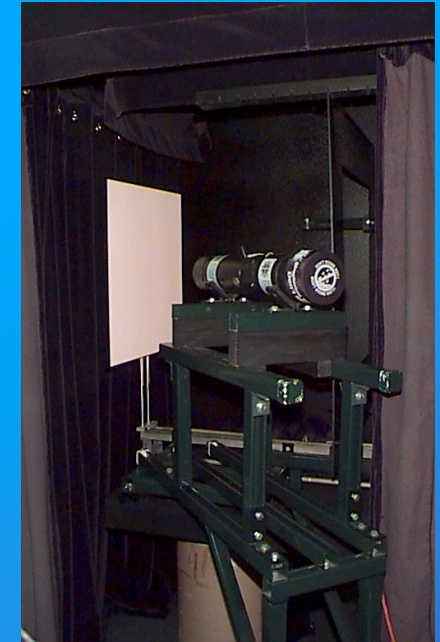
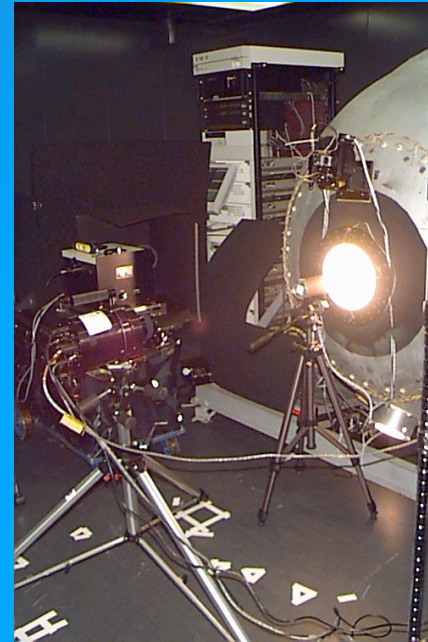
Apparent Optical Property (AOP); Chlorophyll-a (CHL); Aerosol Optical Thickness (AOT)

SeaWiFS & SIMBIOS Calibration Round Robins

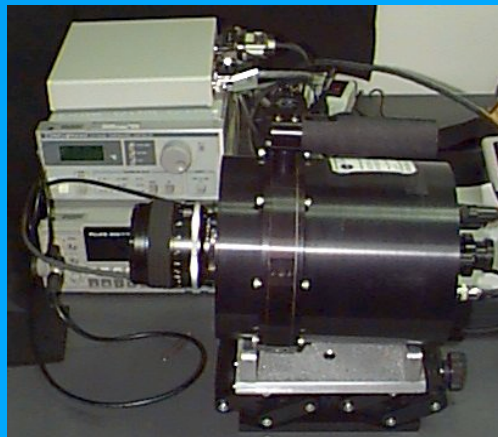
(RR experiments in 1992, 1993, 1996, 1998, 1999, 2001, & 2002)

Goals

- Verify that all labs are on the same radiometric scale
- Document calibration protocols
- Encourage the use of standardized calibration protocols
- Identify where the protocols need to be improved



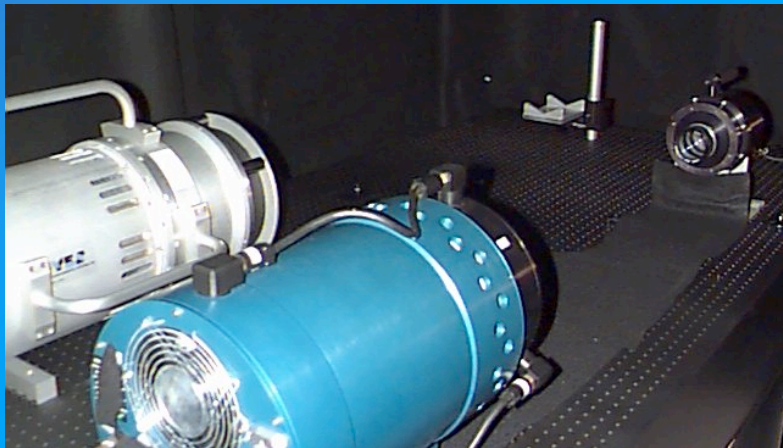
**Radiance Calibrations
(spheres & plaques)**



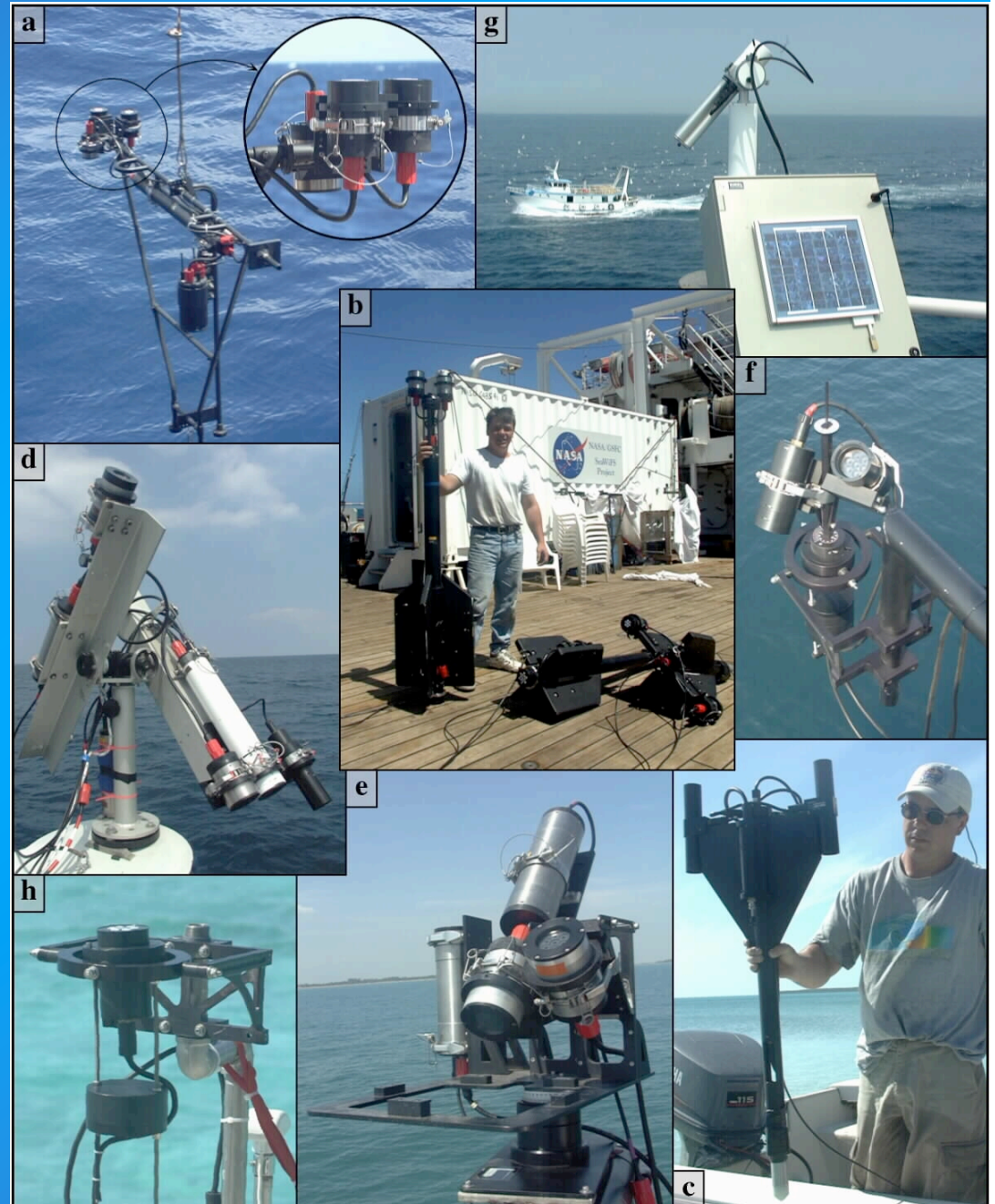
**SeaWiFS Transfer Radiometer
(SXR-1 & -2)**

Field Measurement Technology Development

Various in-water & above
water radiometers



SeaWiFS Quality Monitor (SQM)
(NIST/NASA-developed portable
field source for stability monitoring)



SeaWiFS, MODIS, & VIIRS

- **SeaWiFS**

- Rotating telescope
- 412, 443, 490, 510, 555, 670, 765, 865 nm bands
- 12 bit digitization truncated to 10 bits on spacecraft
- 4 focal planes, 4 detectors/band, 4 gain settings, bilinear gain configuration
- Polarization scrambler: sensitivity at 0.25% level
- Solar diffuser (daily observations)
- Monthly lunar views at 7° phase angle via pitch maneuvers

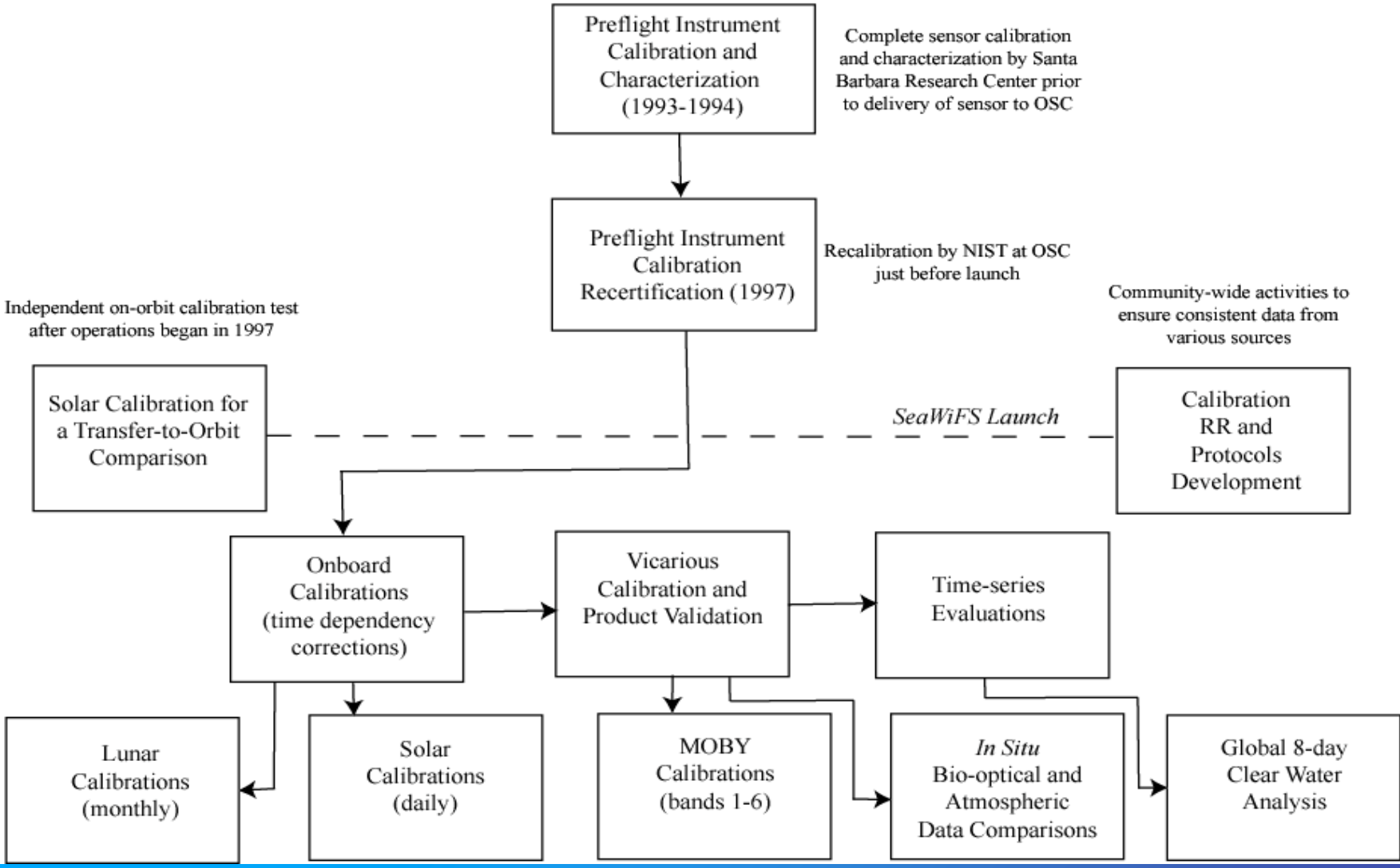
- **NPP/VIIRS**

- SeaWiFS-like rotating telescope
- MODIS-like focal plane arrays
- No polarization scrambler
- Solar diffuser with stability monitor
- 7 OC bands (412, 445, 488, 555, 672, 746, 865 nm)

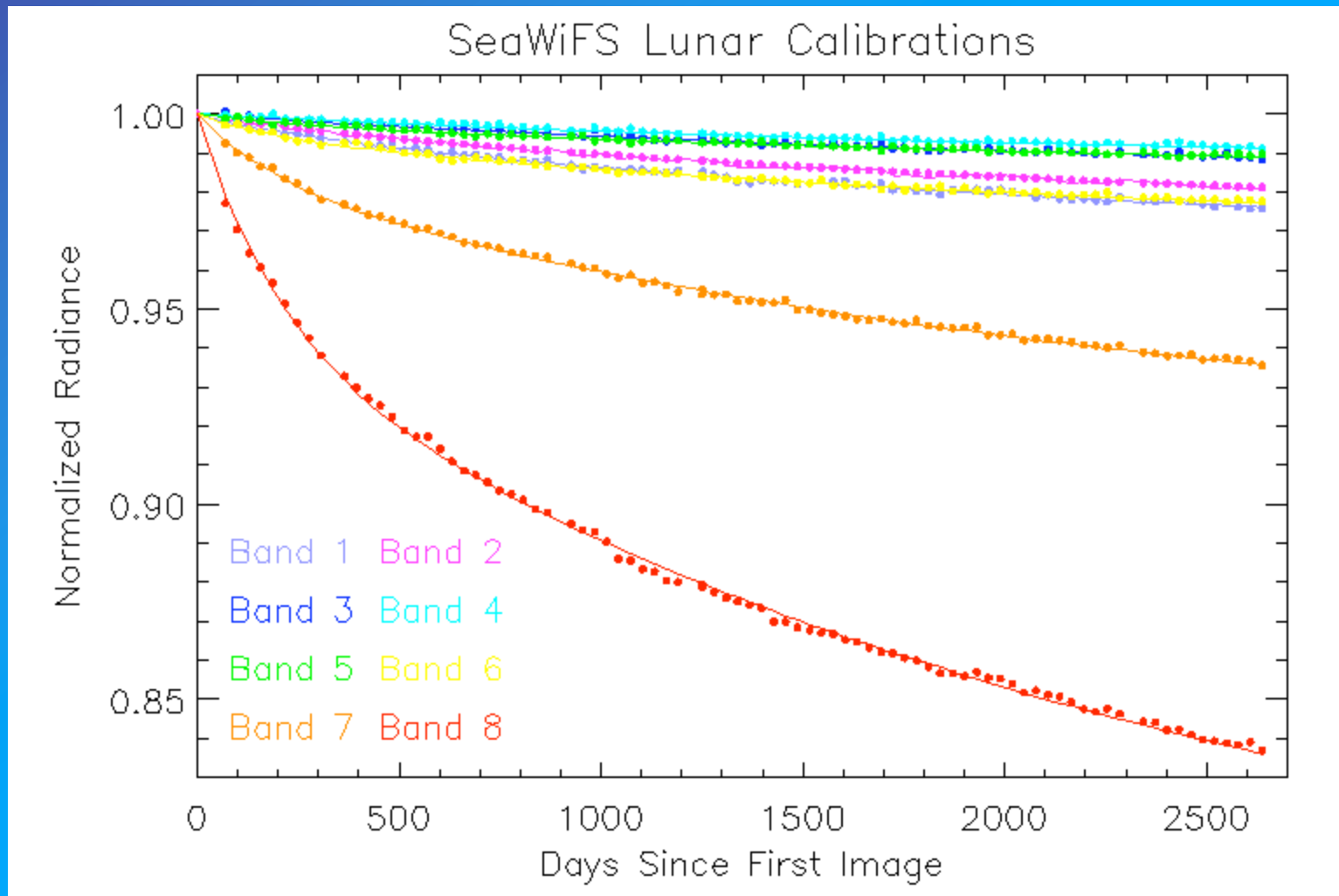
- **MODIS (Ocean Color)**

- Rotating mirror
- 413, 443, 488, 531, 551, 667, 678, 748, 870 nm bands
- 12 bit digitization
- 2 Vis-NIR focal planes, 10x40 detector arrays
- No polarization scrambler: sensitivity at ~3% level
- Spectral Radiometric Calibration Assembly (SRCA)
- Solar diffuser (observations every orbit), Solar Diffuser Stability Monitor (SDSM)
- Monthly lunar views at 55° phase angle via space view port

SeaWiFS Calibration Strategy



SeaWiFS Lunar Calibration Stability Tracking

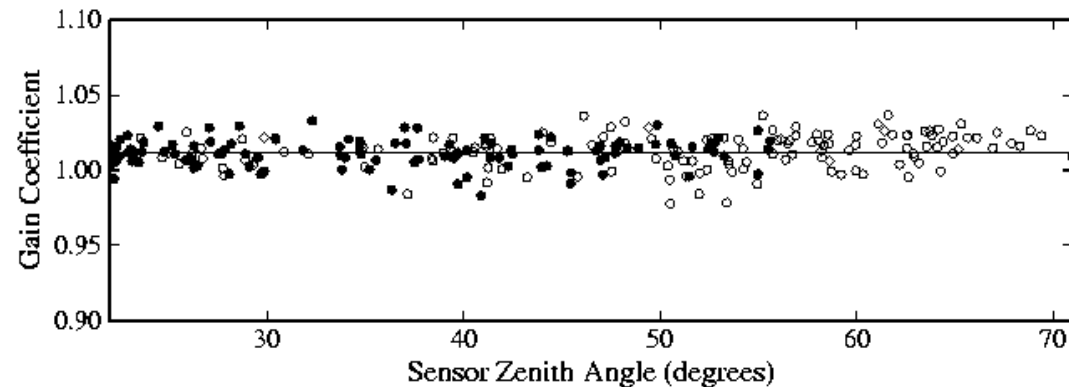
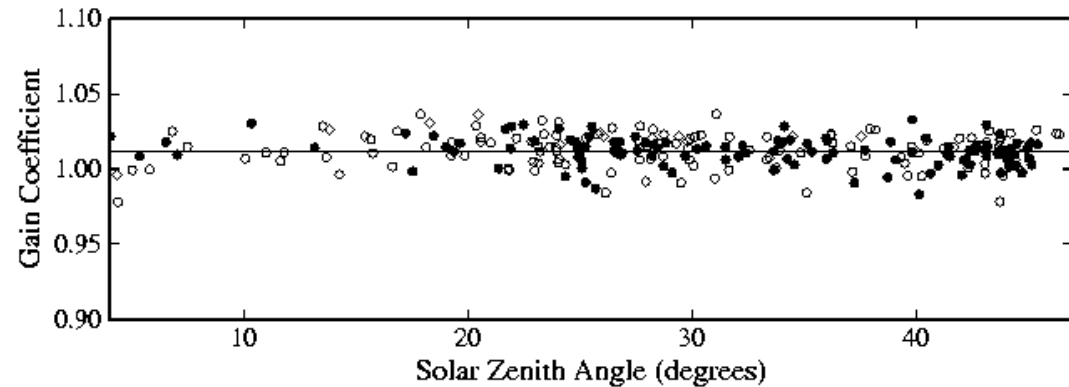
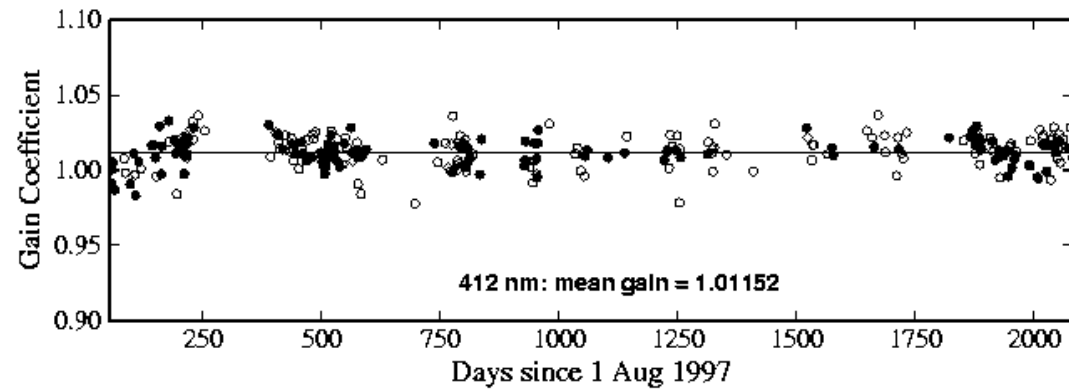


Lunar calibration: Monthly views of the moon at $\sim 7^\circ$ phase angle.
Gradual monotonic degradation primarily in NIR bands.

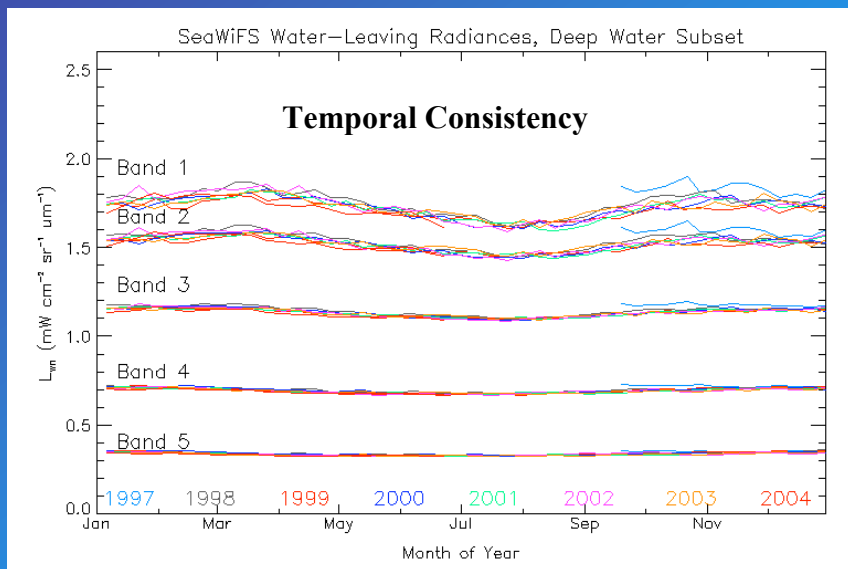
MOBY-based Vicarious Band 1 Gain Factors

- Overpasses used in operational gain determination

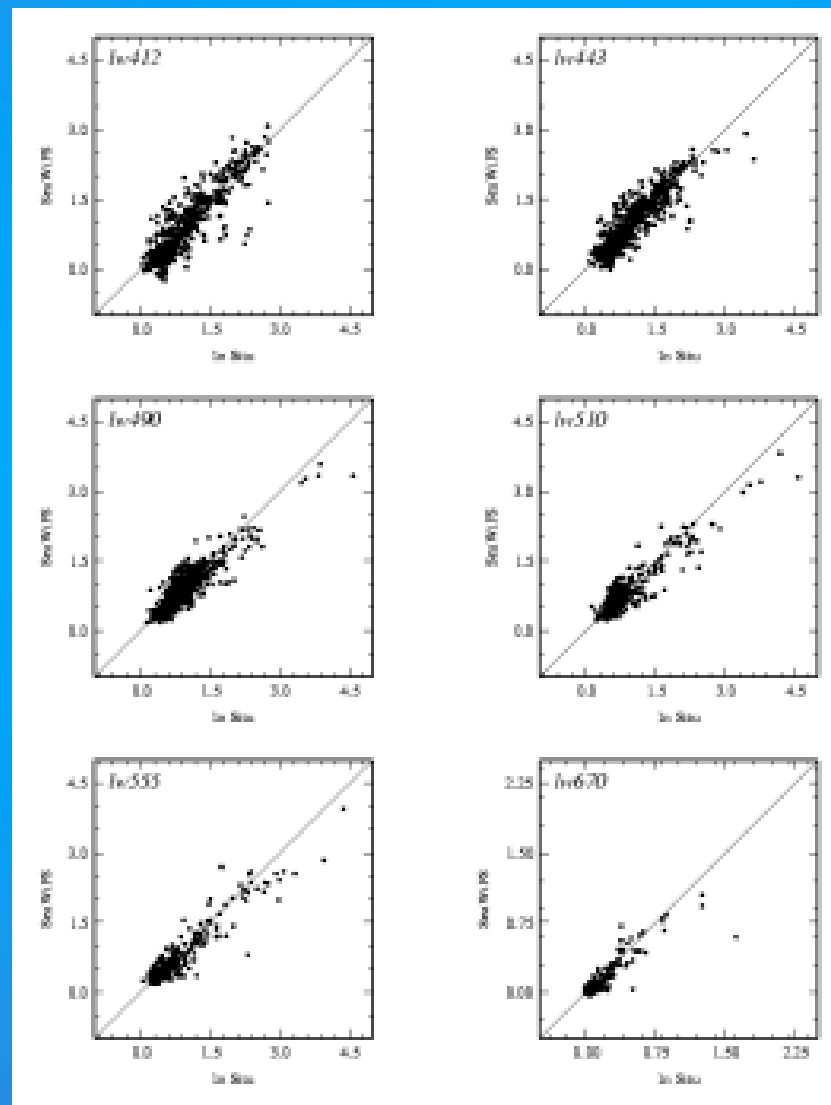
γ Overpasses that failed gain analysis Q/C criteria



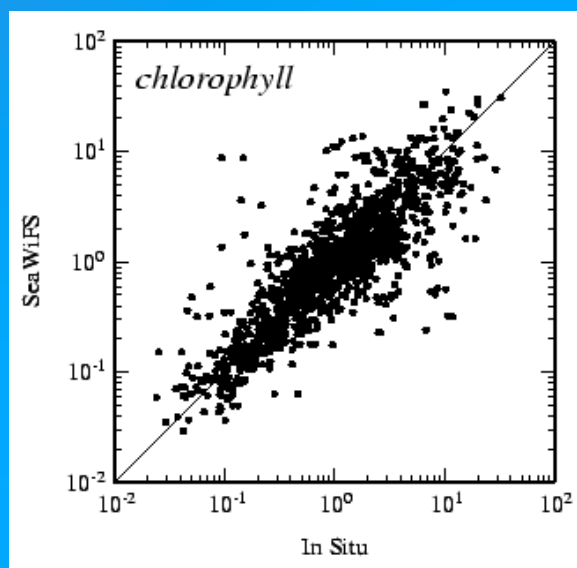
SeaWiFS Data Quality: Global Consistency & In Situ Verification



Field Validation: Lwn's

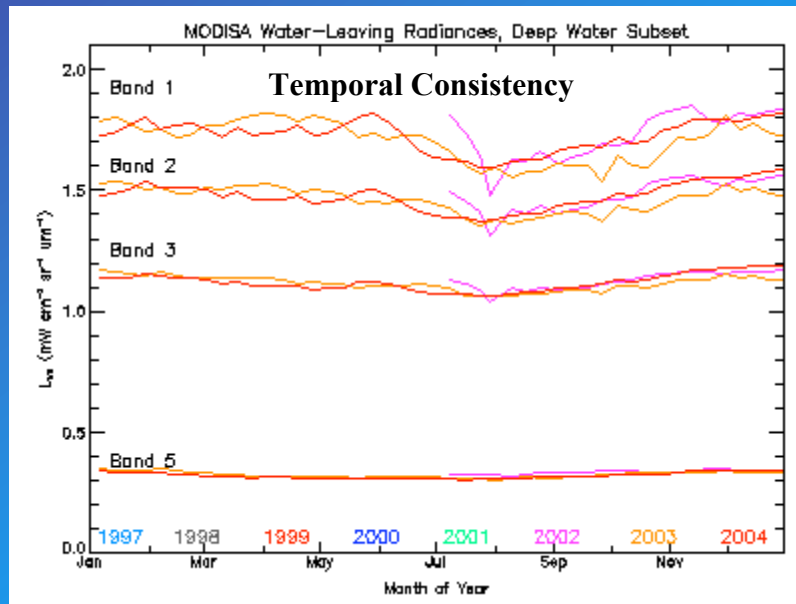


Field Validation: Chl-a

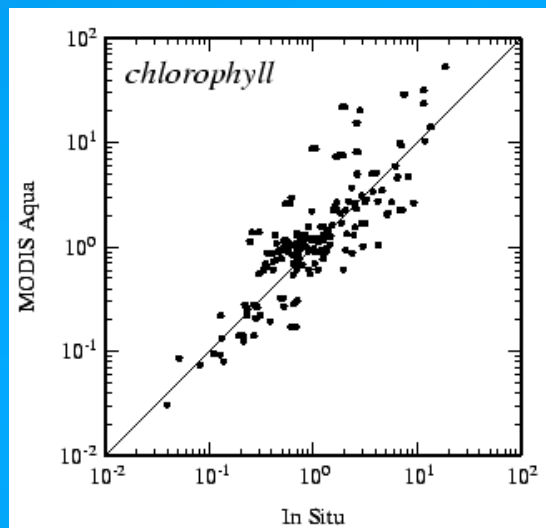


* Lwn: Normalized Water-leaving Radiance

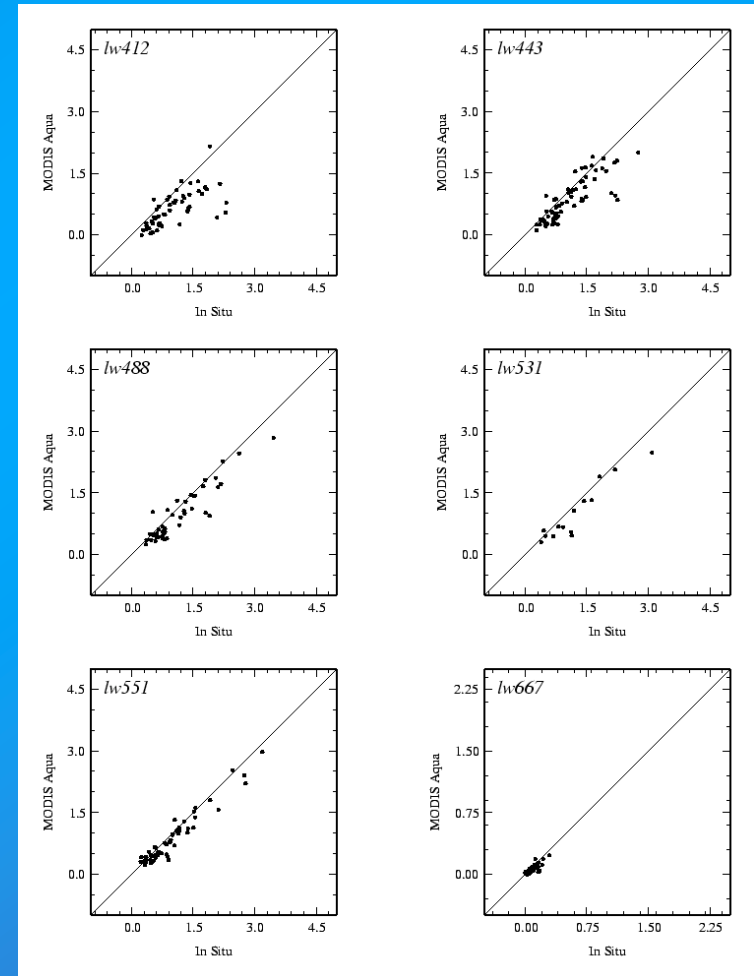
MODIS/Aqua Data Quality: Global Consistency & In Situ Verification



Field Validation: Chl-a

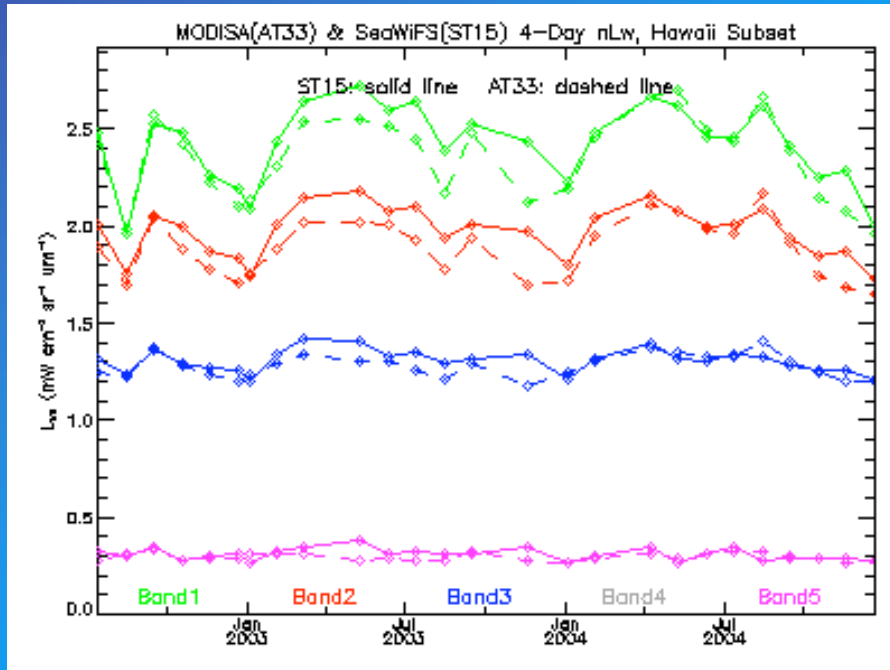


Field Validation: Lwn's

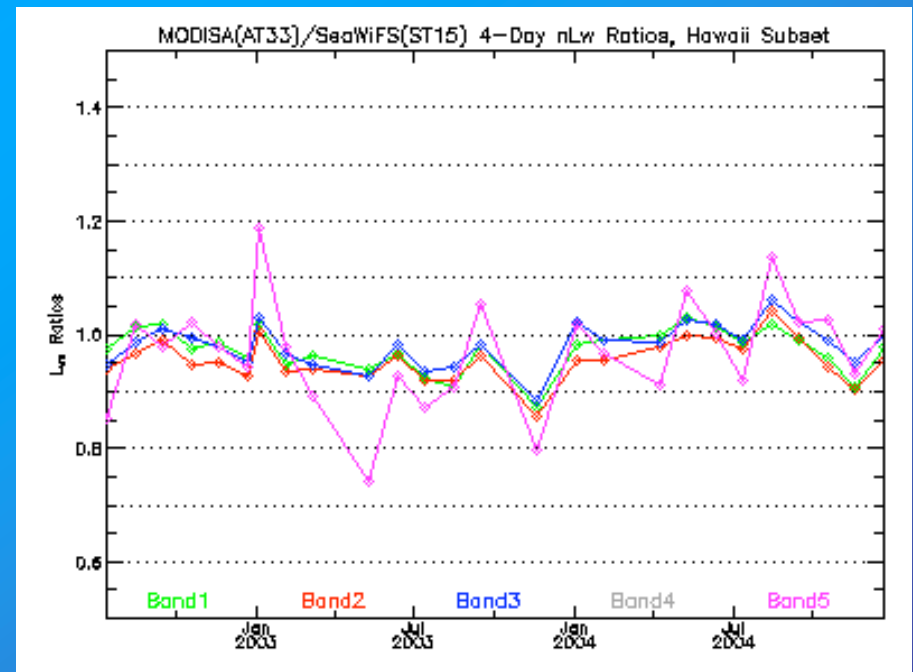


* Lwn: Normalized Water-leaving Radiance

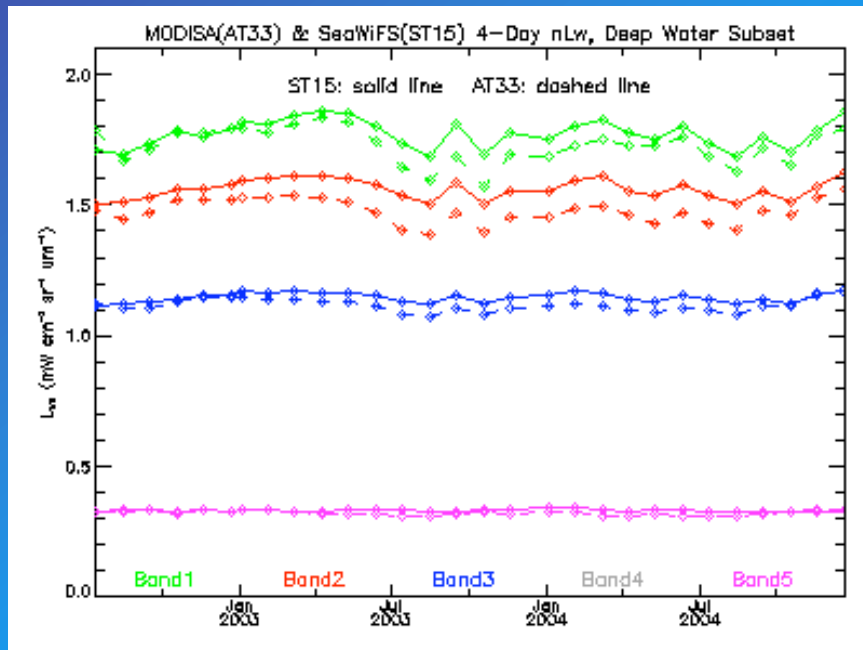
MODIS(Aqua)/SeaWiFS Lwn Ratios (Hawaii): Vicarious Calibration Region



- Most MOBY data used for vicarious calibration is near beginning & end of time series due to sun glint
- Differences during 2003 are presently unexplained



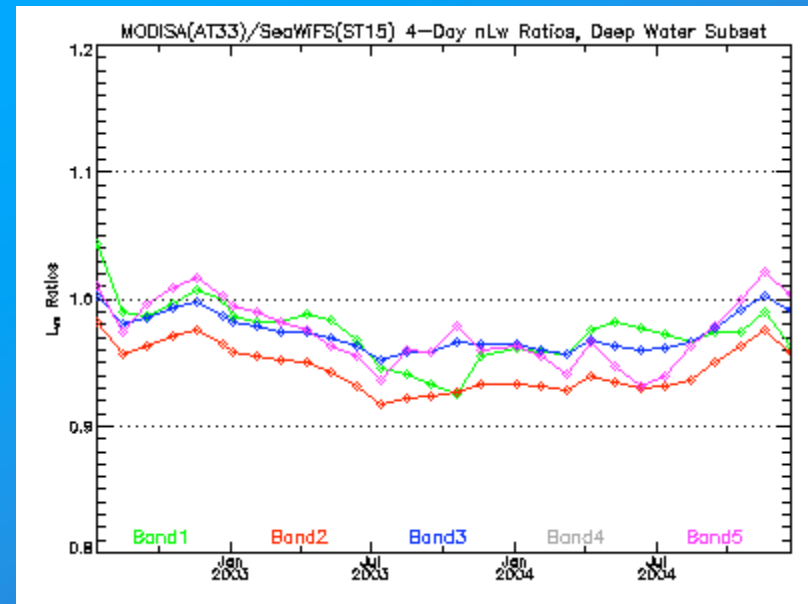
MODIS/Aqua-SeaWiFS Global Lwn's



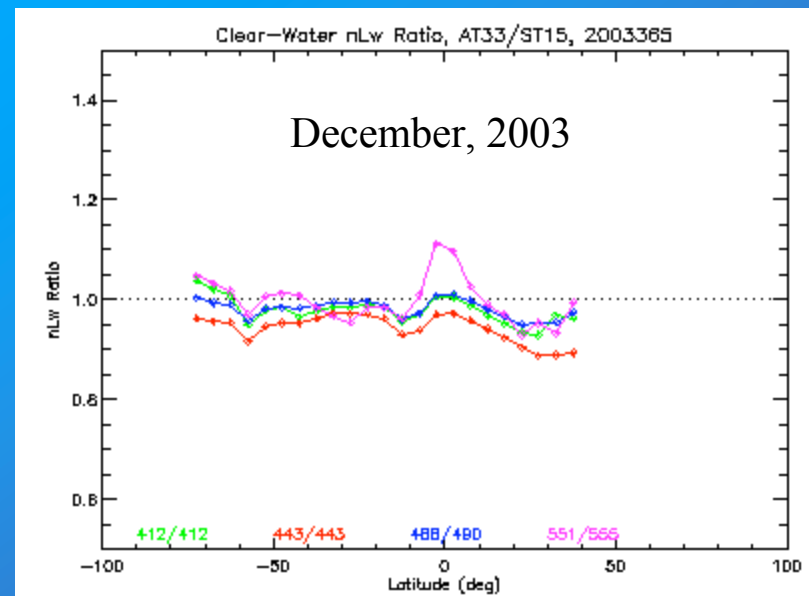
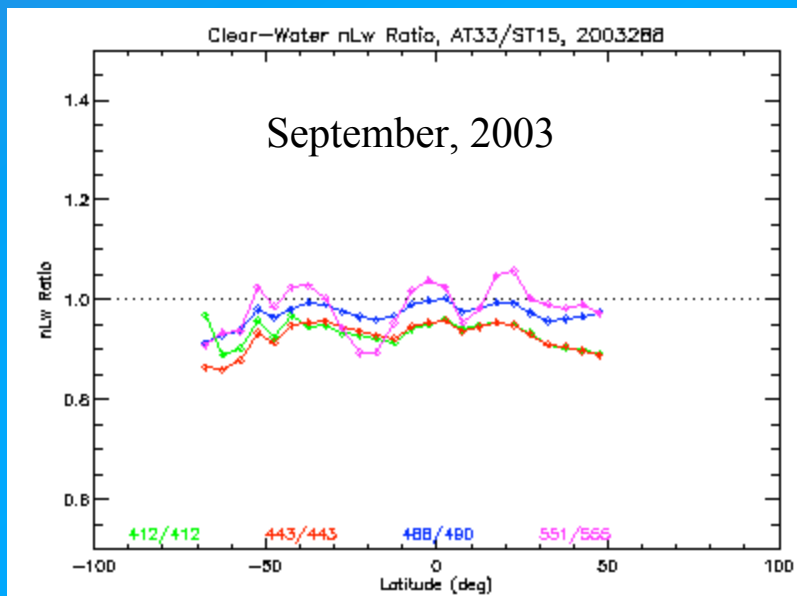
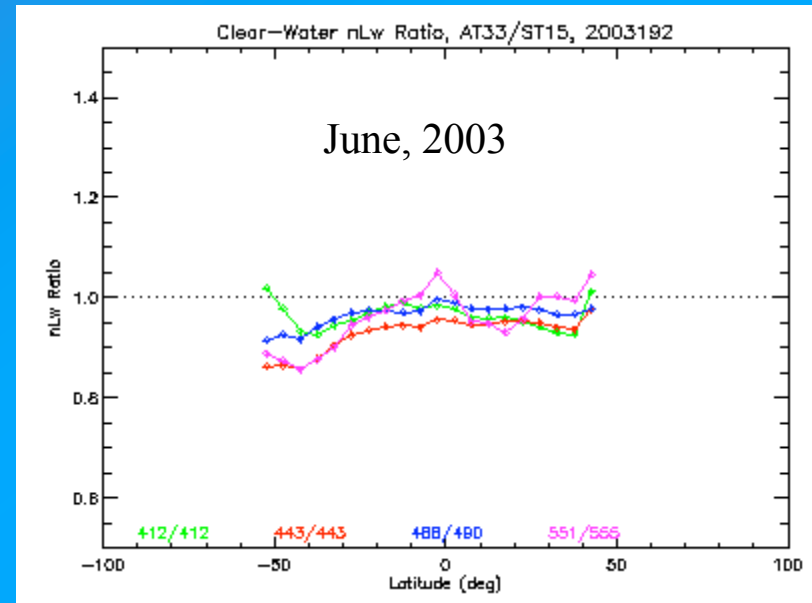
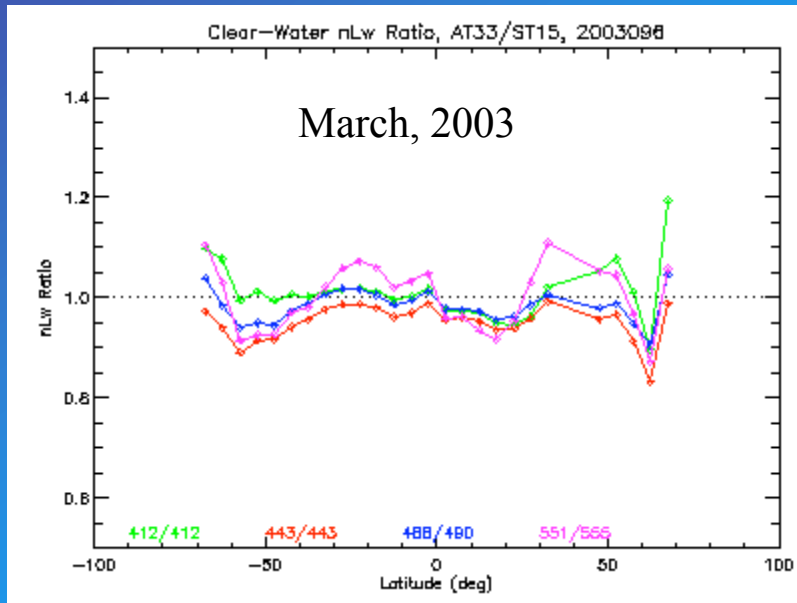
Deep-Water Lwn Comparisons
Solid Line: SeaWiFS
Dashed Line: MODIS/Aqua

Deep-Water Lwn Ratios

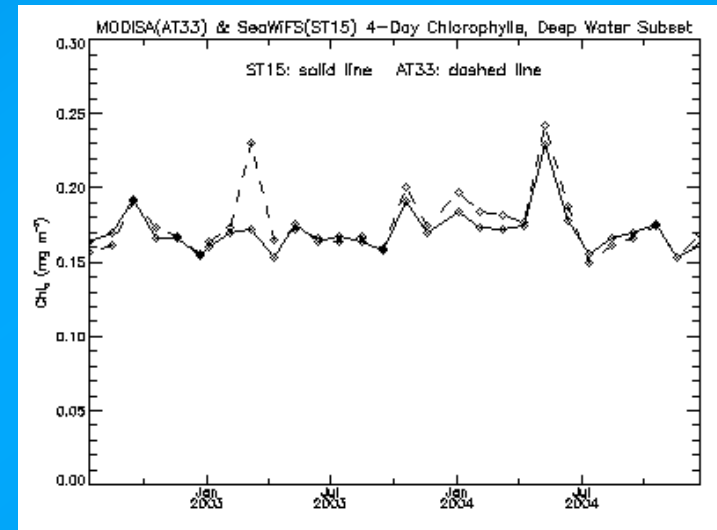
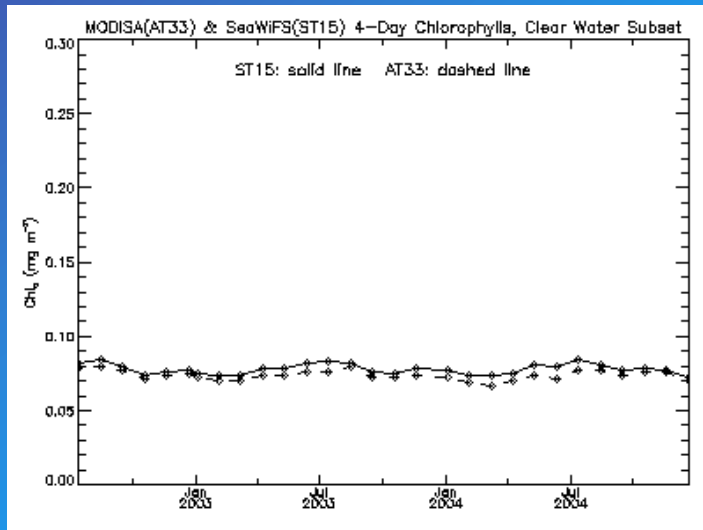
- Global averages very consistent.
- Average differences within $\pm 5\%$.



MODIS-Aqua/SeaWiFS Meridional Clear-Water Lwn Comparisons (Global Daily Mean)

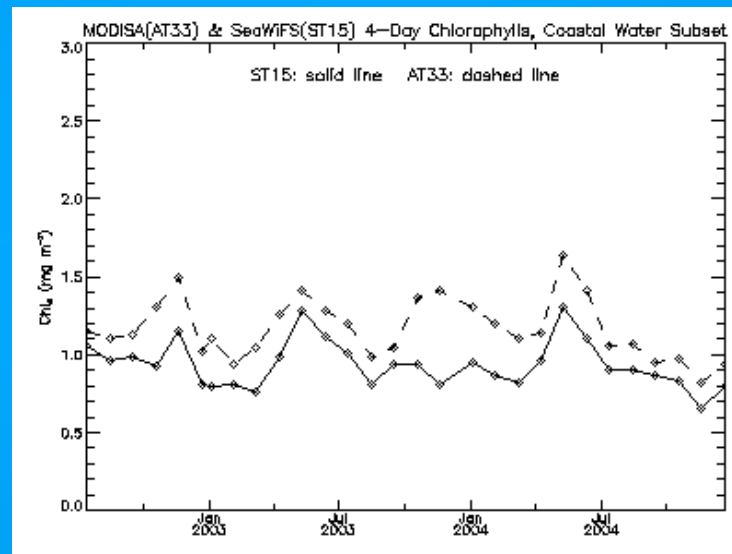


MODIS-Aqua & SeaWiFS Global Mean Chlorophyll Time Series



Clear-water:
 $\text{chl-a} < 0.15 \text{ mg/m}^3$

Deep-water:
depth $> 1000 \text{ m}$



Coastal: depth $< 1000 \text{ m}$
• Primarily chlorophyll-a algorithm difference at high concentrations

Dashed line: MODIS
Solid line: SeaWiFS

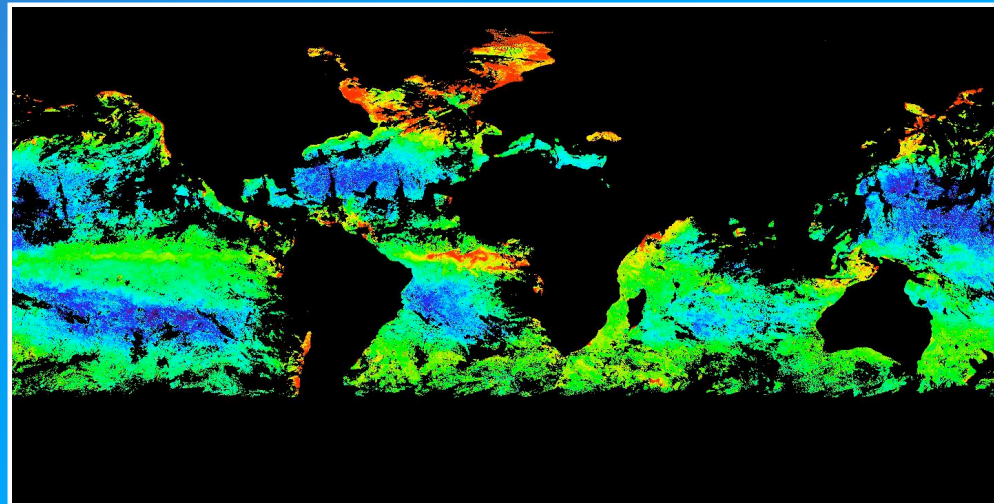
SeaWiFS & MODIS 4-Day Deep-Water Chlorophyll Images

4 day composites, Summer 2002

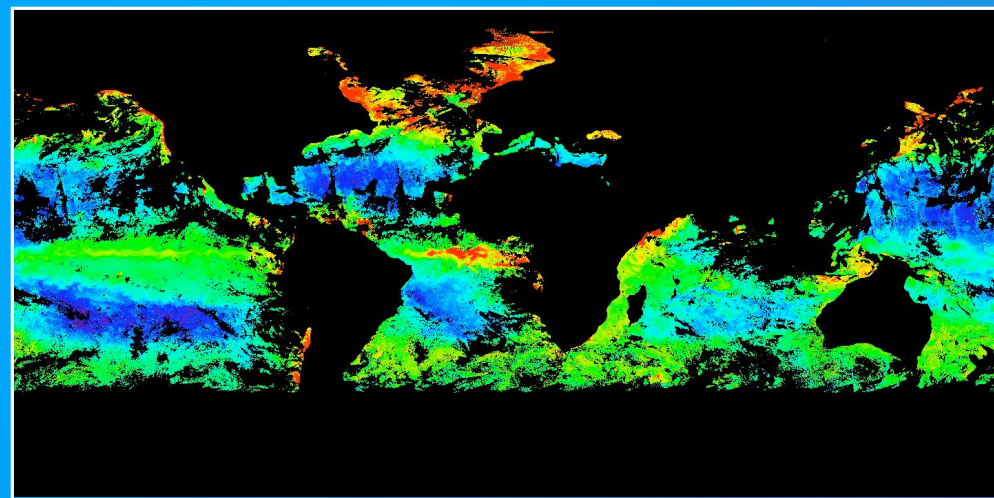


0.01-1 mg/m³

SeaWiFS



MODIS
(current operational
processing)

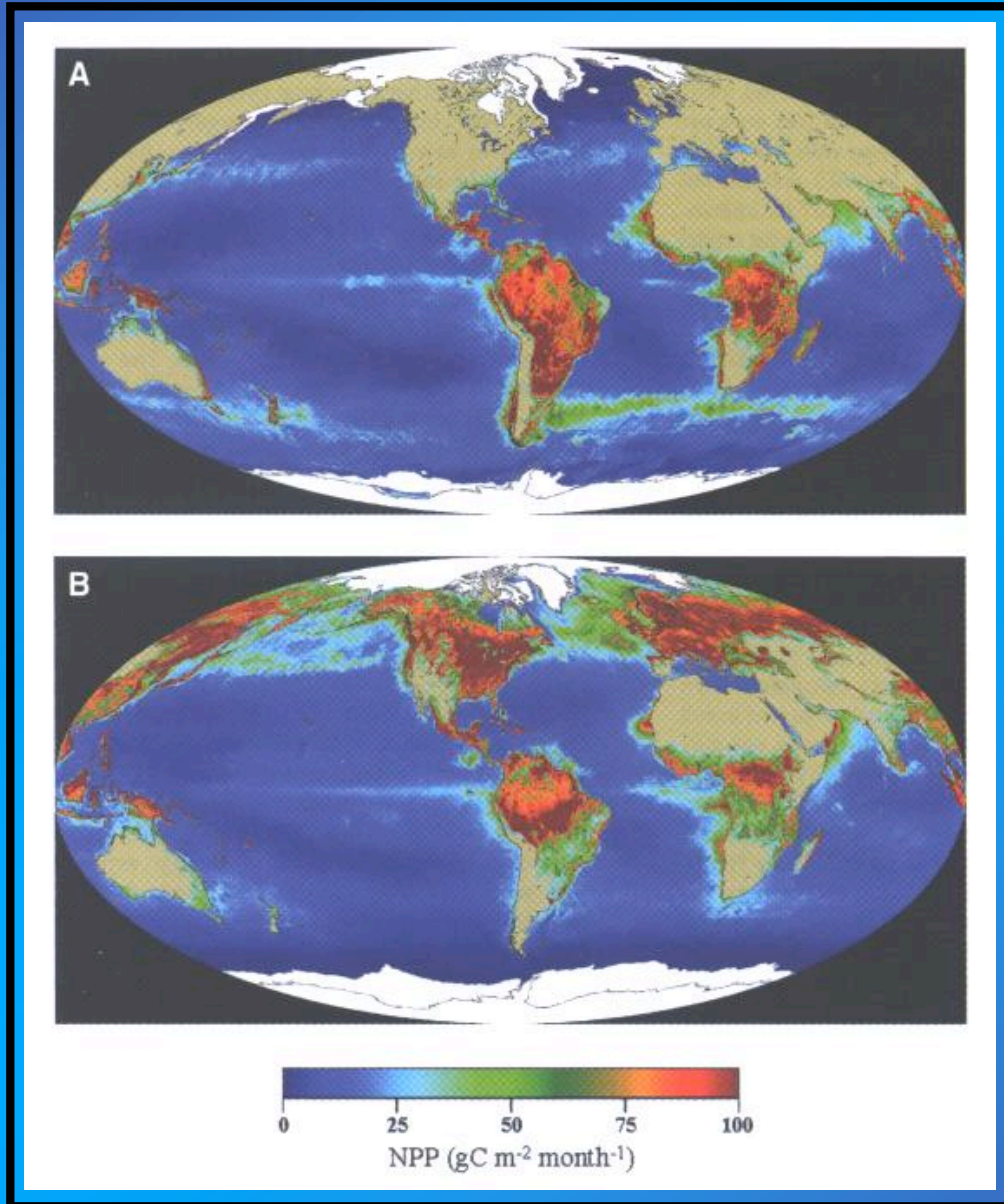


Global Ocean Color/Biogeochemistry

Trends: Recent Case Studies

- 1997-1998 El Niño-La Niña Transition in Ocean & Land Productivity: Behrenfeld et al., *Science*, 2001
 - Global marine productivity increased by 6 petagrams C/yr between Sept. 1997-August 2000
 - Global terrestrial productivity showed no significant change, only regional changes
- CZCS-SeaWiFS Decadal Primary Productivity Change: Gregg et al., *Geophys. Res. Lett.*, 2003
 - Marine productivity declined > 6% over past 2 decades
- Global Chlorophyll-a Trends During 1998-2003: Gregg et al., *Geophys. Res. Lett.*, , 2005
 - Ocean gyre chlorophyll concentrations decreasing with increasing SST
 - Most oligotrophic areas also expanding: McClain et al., *Deep-Sea Res.*, 2004

Global Patterns of Net Primary Production (NPP) & NPP Anomaly: 1998-2000



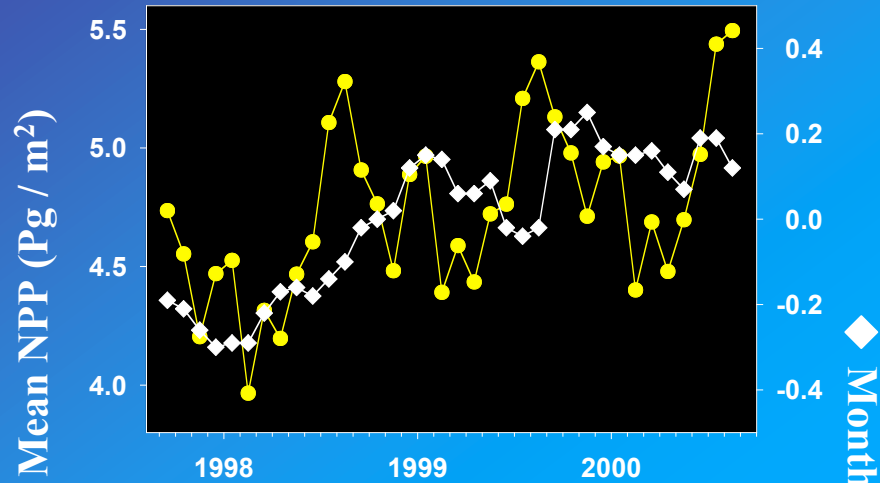
Boreal Winter

Boreal Summer

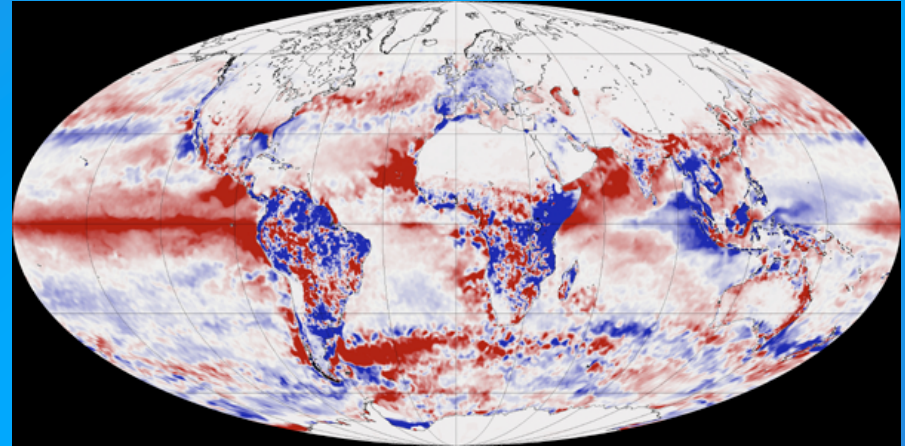
Behrenfeld, M., et al., Temporal changes in the photosynthetic biosphere, *Science*, 291, 2594-2597, 2001.

Global NPP Trends: 1997-2000

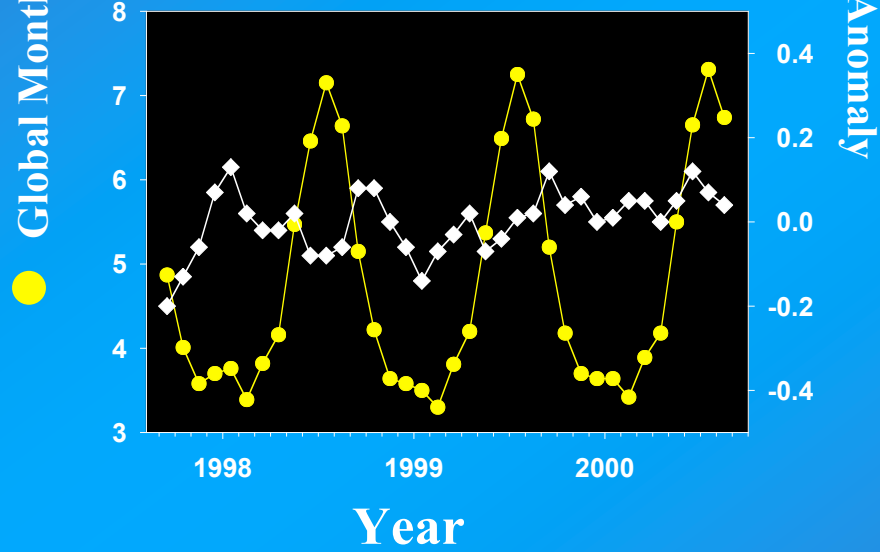
Oceans



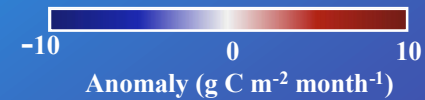
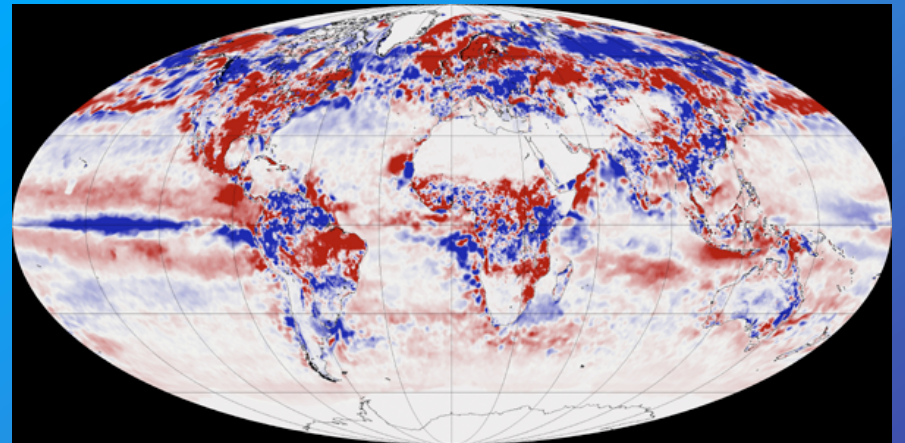
Boreal Winter



Land



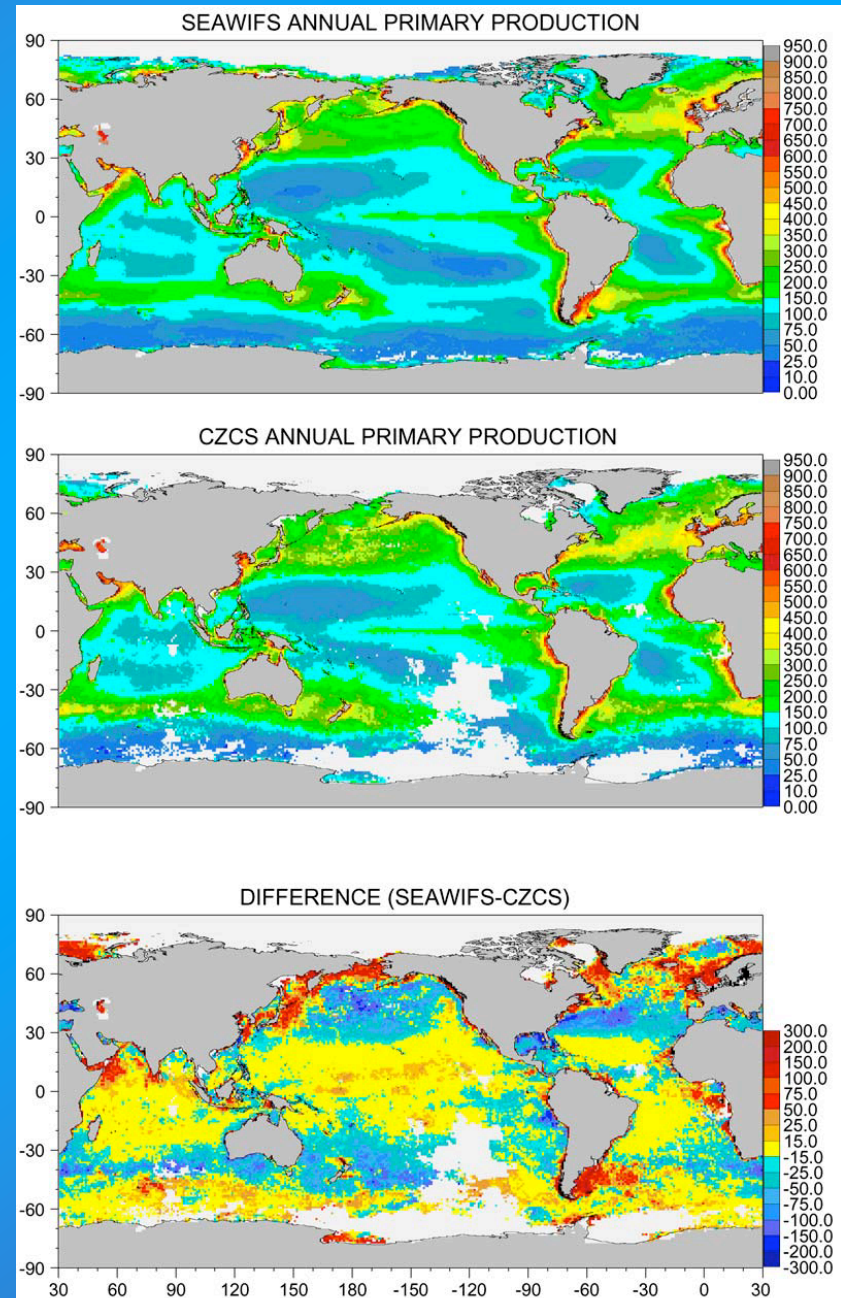
Boreal Summer



Decadal Scale Changes in Marine Productivity

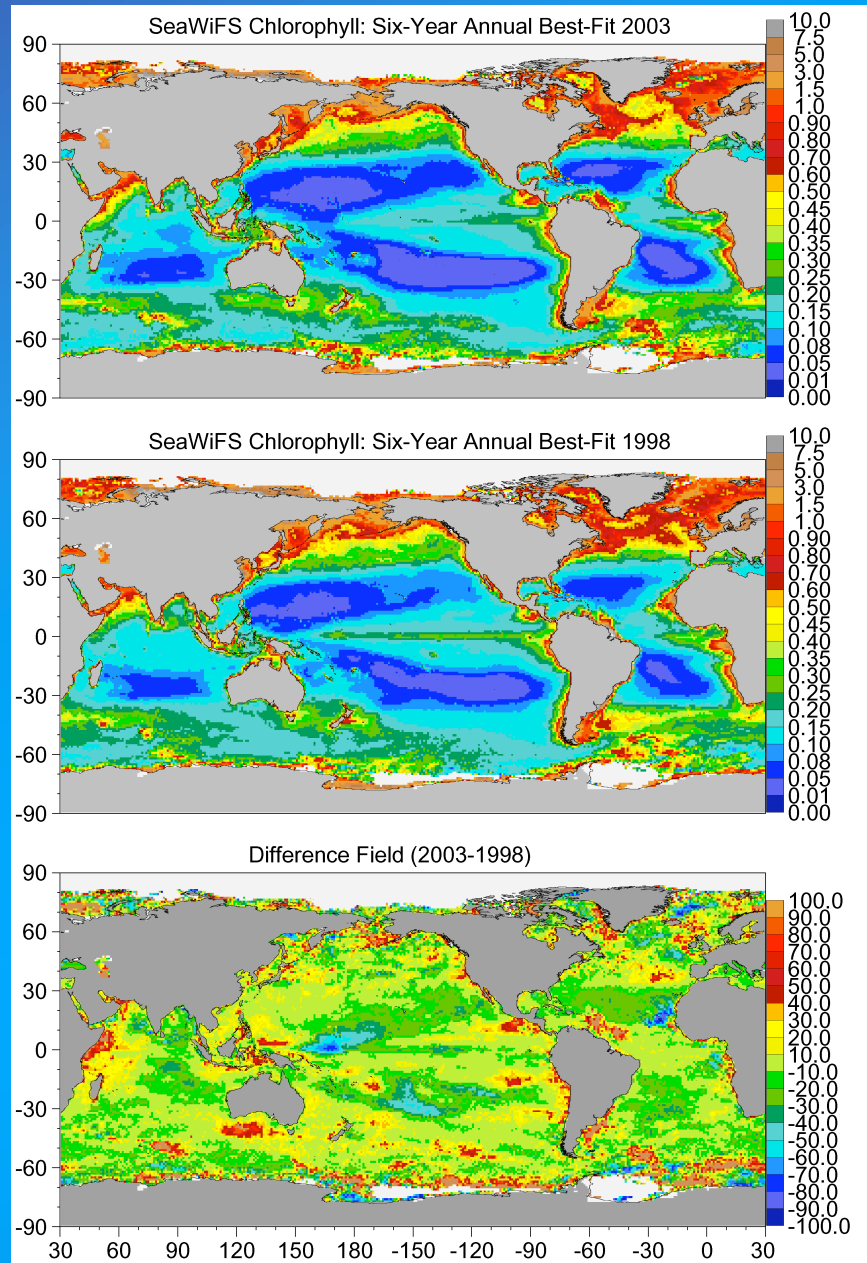
- 6% global decrease (2.8 Pg C/yr) in marine productivity based on CZCS (1978 -1986) & SeaWiFS (1997 - 2003) climatologies.
- 70% of change at high latitudes.
- Productivity tended to increase at low latitudes.

Gregg, W.W., et al., Ocean primary production & climate: Global decadal changes, *Geophys. Res. Lett.*, 15, doi: 10.1029/2003GL016889, 2003.



Locations of Most Significant Chlorophyll-a Change Based on SeaWiFS Time Series: 1998-2003

Patterns of Chlorophyll-a Change: 1998-2003



Gregg, W.W., et al., GRL, 2005

**Temporal Variations in Ocean
Central Gyre Chlorophyll-a &
SST Mean Values: 1998-2003**

Gregg, W.W., et al., GRL, 2005

Maintaining the Ocean Color CDRs: Data Set Reprocessings

- Historical Data Sets (REASoN-CAN, Watson Gregg, PI)
 - OCTS: Reprocessing scheduled for Spring 2005
 - CZCS: Reprocessing scheduled for CY 2005
- SeaWiFS: Reprocessing completed in March 2005 (4 km data @ 3700X)
- MODIS/Aqua: Reprocessing completed in March 2005 (1 km data @ 150X)

BACK-UP SLIDES

Ocean Color & Carbon Cycle/Ecosystems/Biogeochemistry: NASA Science Objectives

- Why do we care about ocean biogeochemistry?
 - The ocean is a primary sink for anthropogenic CO₂.
 - The ocean is the largest active reservoir of carbon.
 - Marine photosynthesis supports the entire marine foodweb (fisheries).
- Major Ocean Biogeochemistry Science Questions
 - Ocean biology interannual variability (e.g., El Niño/La Niña)
 - Impacts of climate change/warming on marine ecosystems
 - Marine CO₂ sequestration and role of “biological pump”
 - Impacts of population growth on coastal ecosystems
- Data Requirements
 - Long time series of global observations (from multiple sensors)
 - Consistent and accurate on-orbit sensor calibrations
 - Improved accuracy in data products (e.g., chlorophyll-a, primary productivity), particularly in coastal regions
 - Adequate field/laboratory calibration & validation program

Ocean Color Data Processing, Cal/Val, & Algorithm Development Functions

Algorithm Development & Field Data Collection

- Algorithms
 - Atmospheric correction
 - Quality masks & flags
 - Bio-optical
 - Sea surface temperature
 - Data merger (time/space)
- Bio-optical & atmos. field data collection
- Science leadership/coord
- New product specification
 - Definition/Development
 - Resource/Performance Evaluation
 - Selection

Sensor Calibration & Product Validation

- I/F with mission operations
 - Cal. strategies, schedules, and operations plans
- Round robins
 - Visible
 - Thermal IR
- Vicarious calibration
 - Data: MOBY, AERONET, ship
 - Data Analysis
- Protocol development for measurement and analysis
 - SST, OC, Atm. Corr.
- Instrument technology evaluation
- I/F with sensor/satellite mission calibration and characterization activities/groups (e.g., NCST)
- Q/C & archive in-situ data (product validation & algo. dev.)
- Product validation
 - Discipline Processing Group
 - Science Team

Data Processing

- I/F with IPO & NOAA
- I/F with NPP/CDMS
- Maintenance and infrastructure improvements within GSFC
- Climate data processing
 - Continuity data sets & data merger (historical/existing)
 - VIIRS
 - Simulated data develop.
 - End-to-end testing
- Data storage
 - RDRs, Level-1, EDRs
 - Ocean & ancillary data
- Algorithm testing & implementation (inc. new products)
- Quality control/assurance
 - Continuity data sets
 - VIIRS

Distribution & Outreach

- Real-time ground station support
- Data archive & distribution
- Community processing S/W (SeaDAS)
- Data Synthesis
- Science campaign support
 - Autonomous support
 - User services
 - Interface and data processing capability
 - RT data distribution
- Publication support
 - Science writer/editor
- Education outreach

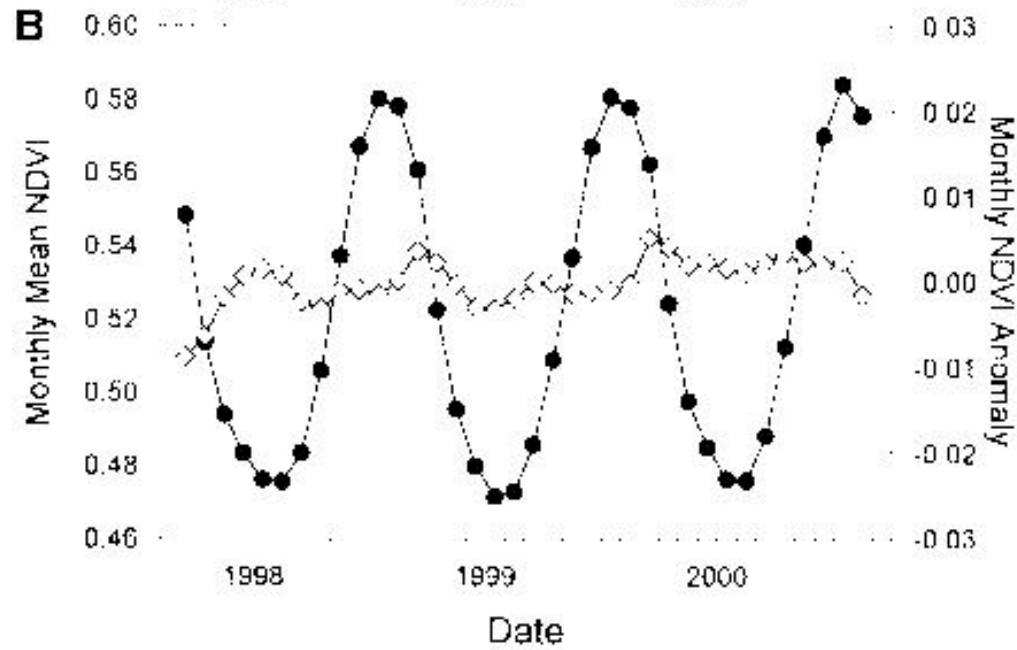
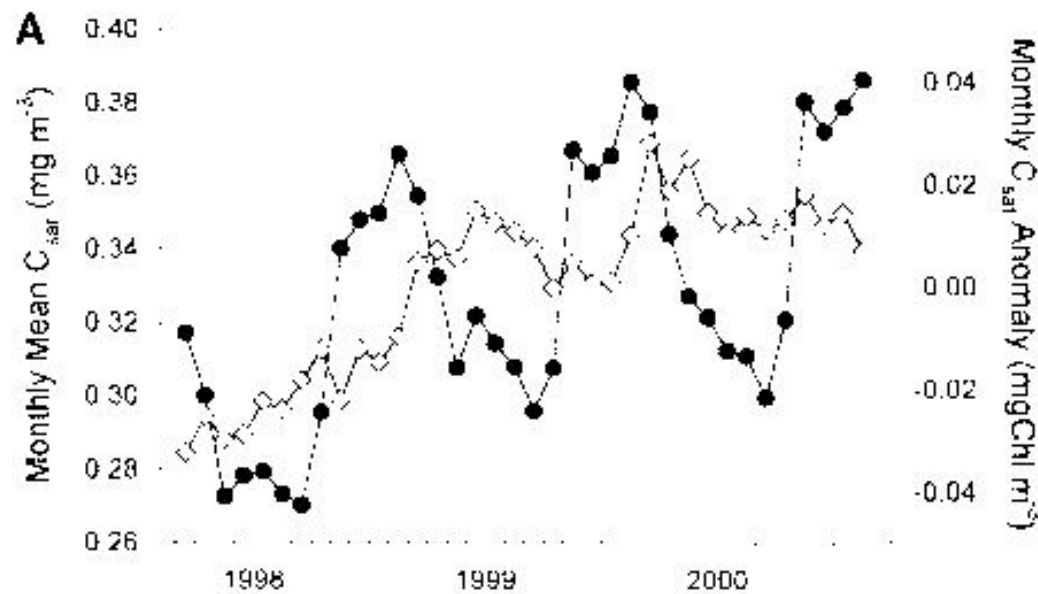
Functions supported under NRAs

Discipline processing functions

Functions assumed by a NASA flight project, HQ, or another agency (NOAA)

Ocean Color 865 nm Band: No Vicarious Calibration

- 865 nm measurements are used provide aerosol amounts in the atmospheric correction algorithm
 - SeaWiFS, MODIS, OCTS, VIIRS
- Comparisons for SeaWiFS suggest that band 8 calibration may be 5-10% too high
 - Southern Ocean band 8 gain study (~5-6%)
 - Comparisons with University of Arizona ground measurements (within 10%)
 - Comparisons with aerosol optical thickness data (AERONET & cruise data)
 - Scatter in results is large
 - SeaWiFS appears high



Time Series of Global Ocean Chl-a & Chl-a Anomaly, 1998-2000

Time Series of Global NDVI & NDVI Anomaly, 1998-2000

Behrenfeld, M., et al., Temporal changes in the photosynthetic biosphere, *Science*, 291, 2594-2597, 2001.