Satellite Ocean Color/Biogeochemistry Climate Data Records

Chuck McClain
Ocean Biology Processing Group

NASA MODIS Science Team Meeting

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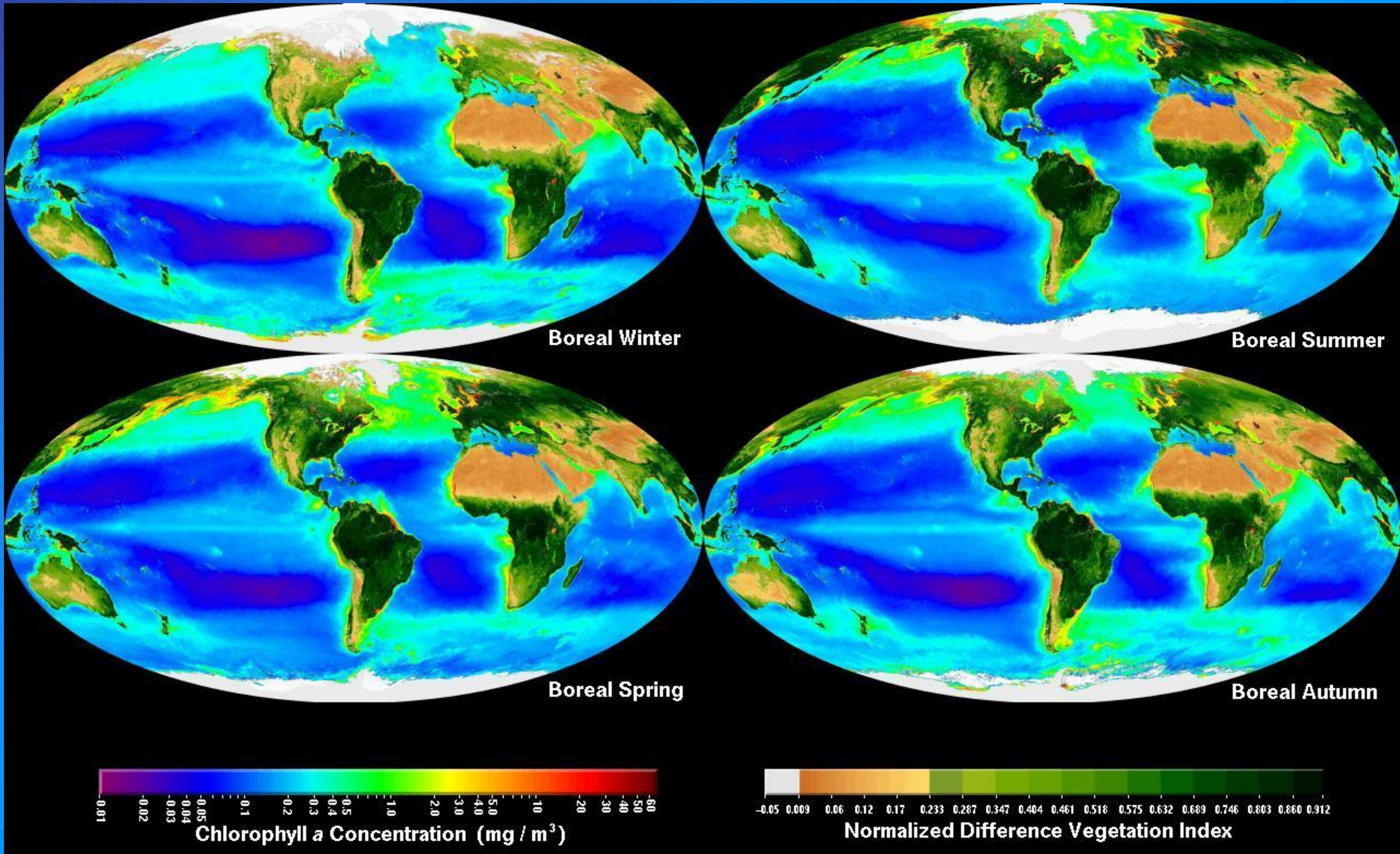
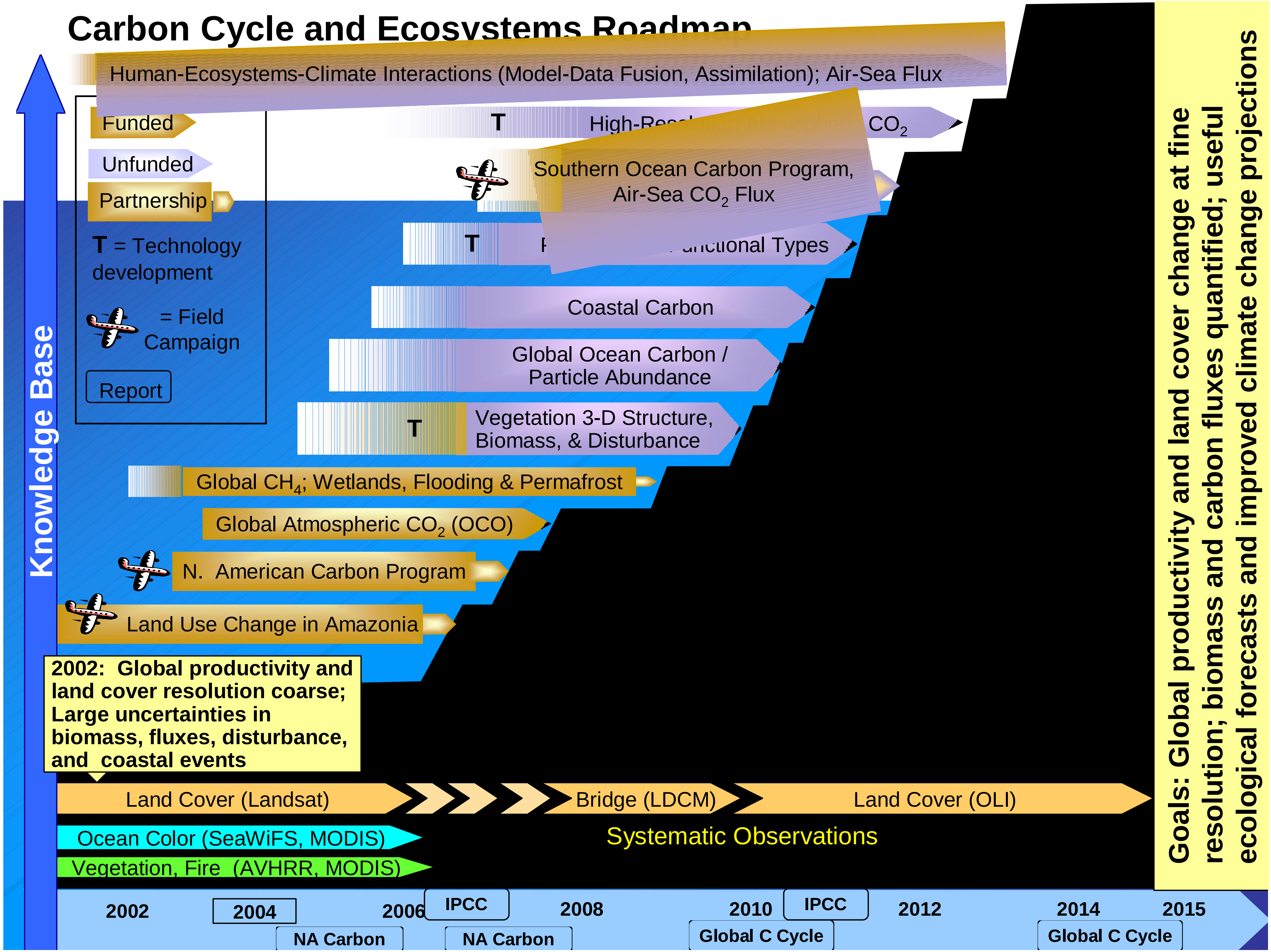
Seasonal Biosphere

Ocean Chlorophyll-a & Terrestrial NDVI



Data from SeaWiFS

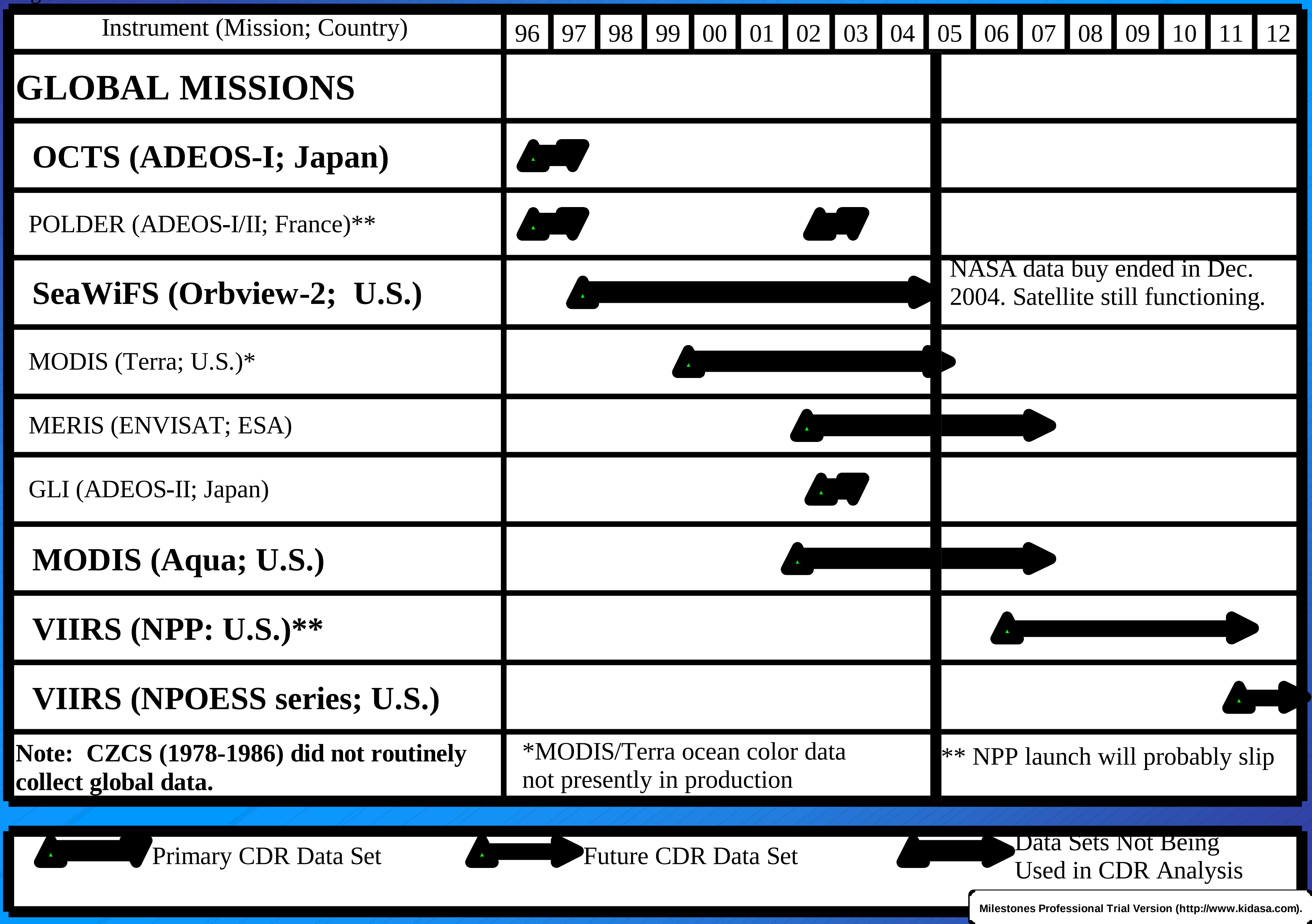


Carbon Cycle and Ecosystems Roadmap
Human-Ecosystems-Climate Interactions (Model-Data Fusion, Assimilation); Air-Sea Flux
Funded
Unfunded
Partnership
T = Technology development
= Field Campaign
Report
T
CO_2
Southern Ocean Carbon Program, Air-Sea CO_2 Flux
T
Functional Types
Coastal Carbon
Global Ocean Carbon / Particle Abundance
T
Vegetation 3-D Structure, Biomass, & Disturbance
Global CH_4; Wetlands, Flooding & Permafrost
Global Atmospheric CO_2 (OCO)
N. American Carbon Program
Land Use Change in Amazonia
Knowledge Base
2002: Global productivity and land cover resolution coarse; Large uncertainties in biomass, fluxes, disturbance, and coastal events
Land Cover (Landsat)
Bridge (LDCM)
Land Cover (OLI)
Ocean Color (SeaWiFS, MODIS)
Systematic Observations
Vegetation, Fire (AVHRR, MODIS)
Goals: Global productivity and land cover change at fine resolution; biomass and carbon fluxes quantified; useful ecological forecasts and improved climate change projections
2002
2004
2006
IPCC
2008
2010
IPCC
2012
2014
2015
NA Carbon
NA Carbon
Global C Cycle
Global C Cycle

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 ccean 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



Historical Ocean Color Accuracy Goals

- **Sensor radiometric calibration**
  - ±5% absolute
  - ±1% band-to-band relative
- **Water-leaving radiances**
  - ±5% absolute
- **Chlorophyll-a**
  - ±35% over range of 0.05-50.0 mg/m^3

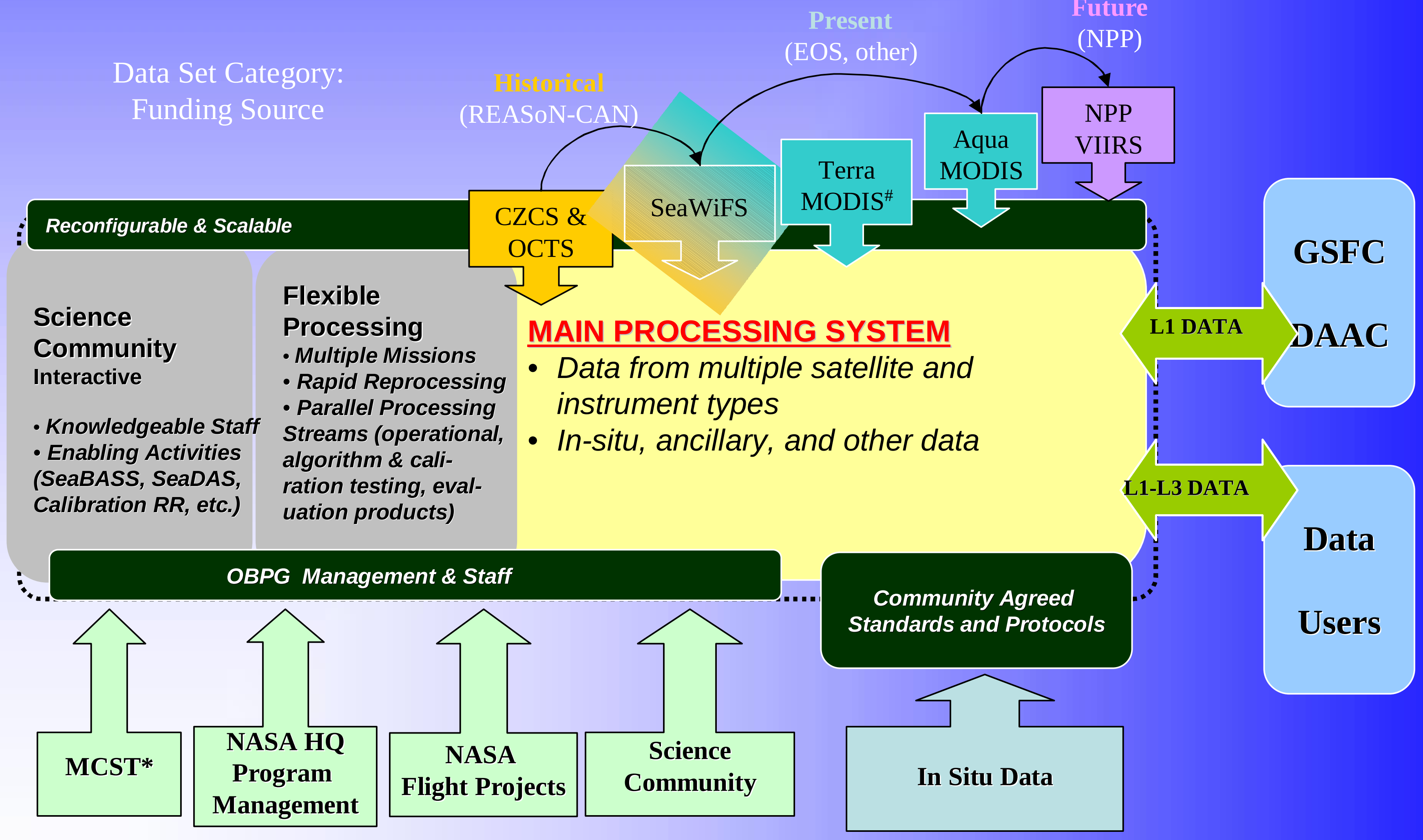
Current Ocean Biogeochemistry CDRs. Community presently revising product suite & CDR requirements.

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

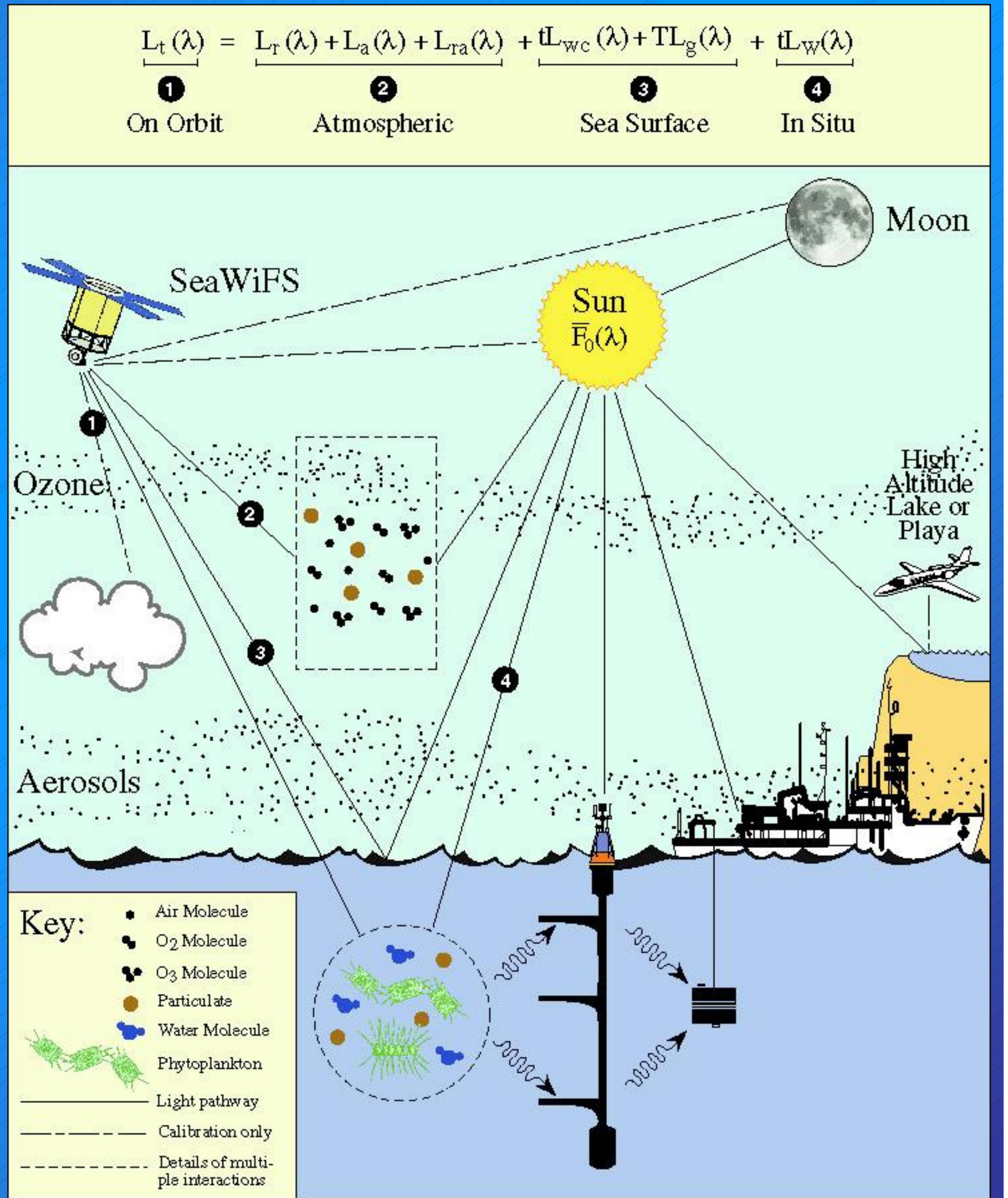


* MODIS Characterization Support Team (NASA/GSFC)
# Terra MODIS OC processing suspended in Jan. 2004

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

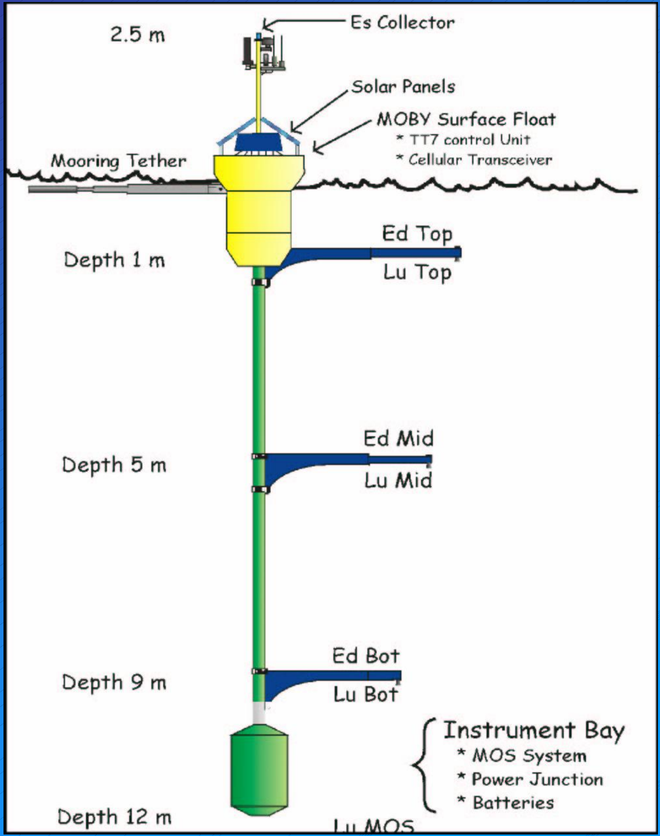
Original Protocols:

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

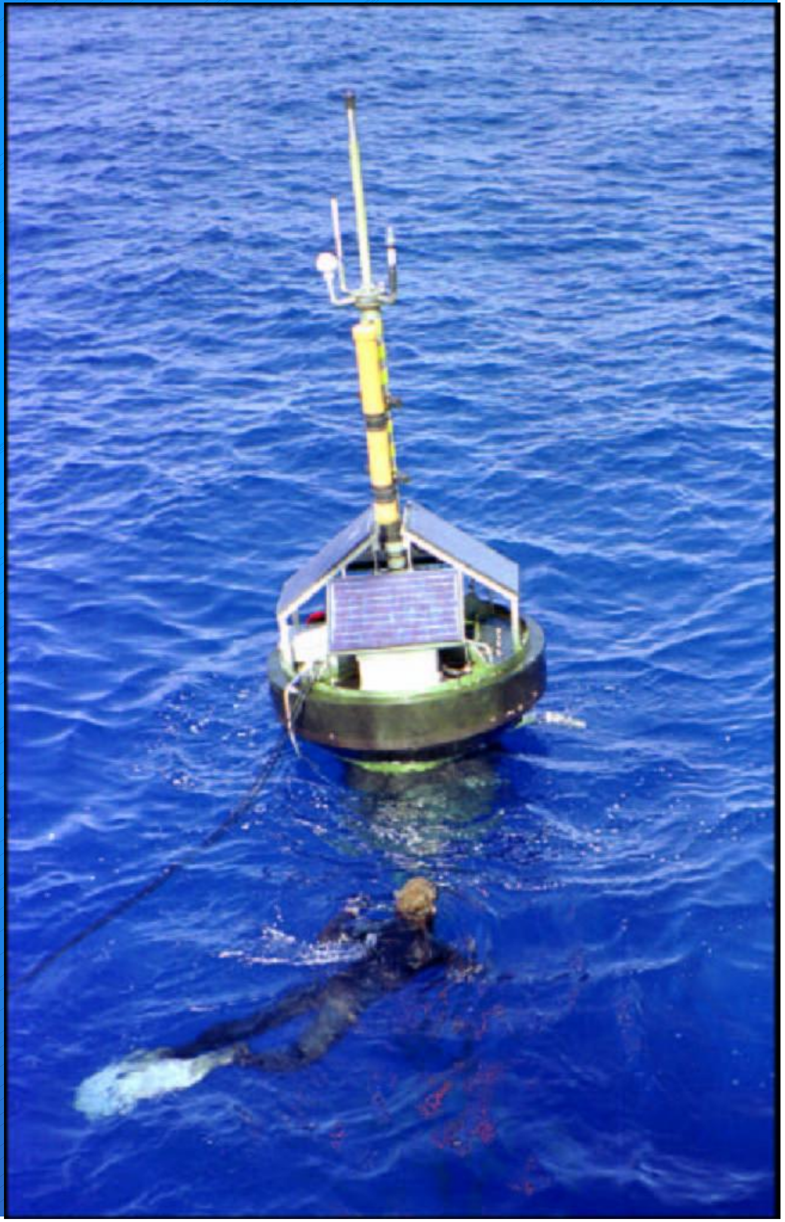
Revisions and Other Protocols:

- 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).

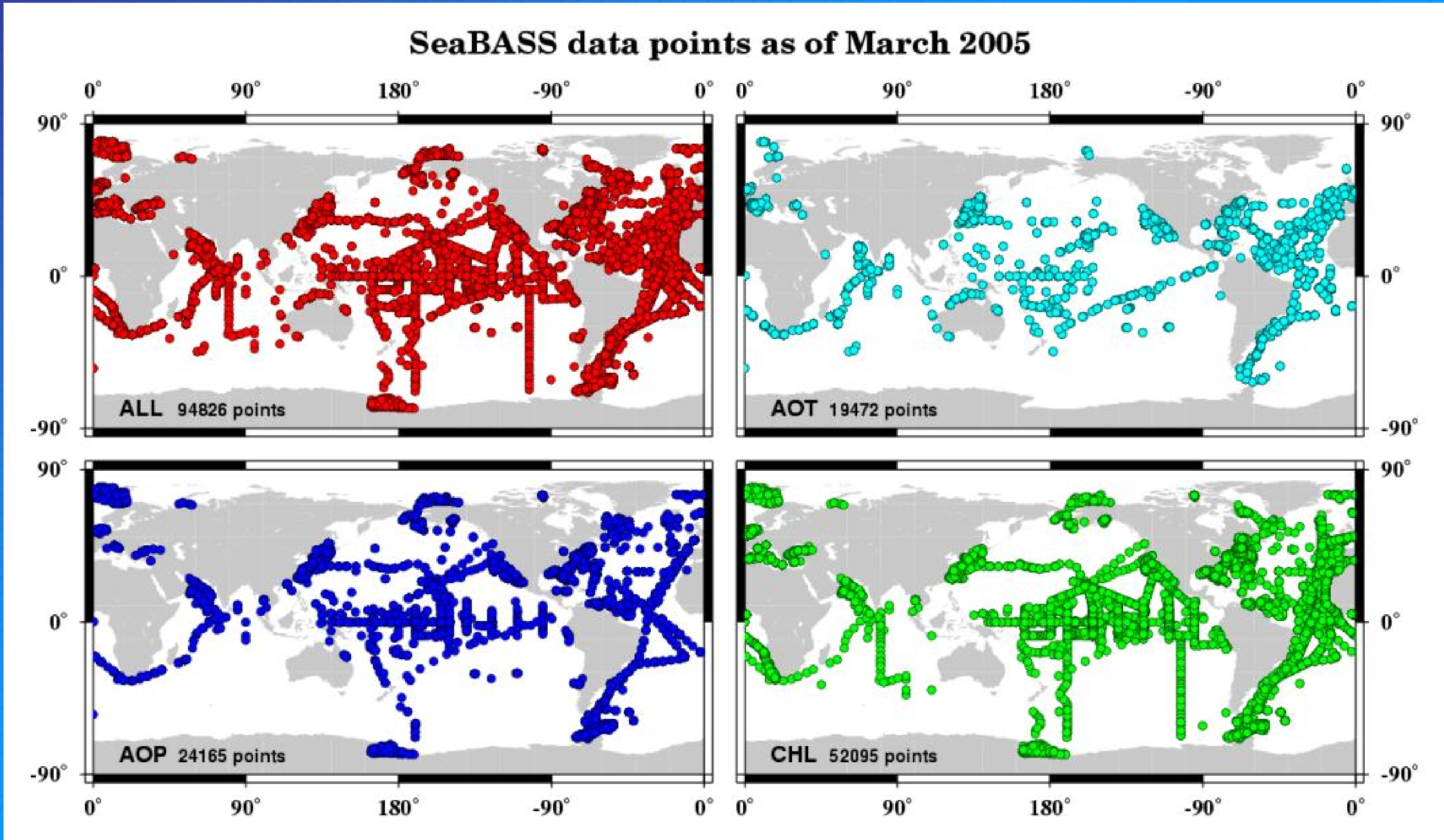
MOBY: Vicarious Calibration



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



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



Data from over 1360 cruises

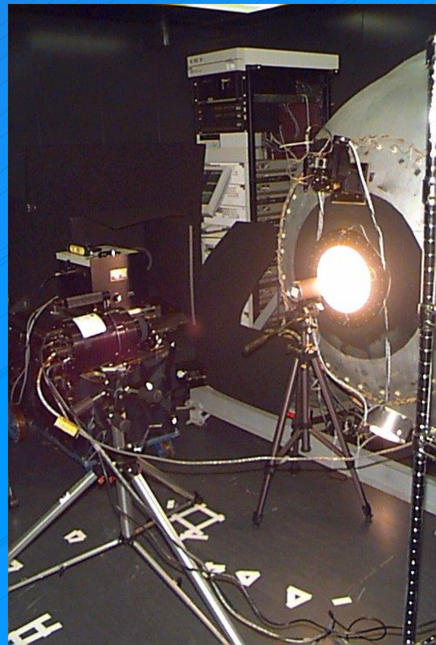
Apparent Optical Property (AOP); Chlorophyll-a (CHL); Aerosol Optical Thickness (AOT)

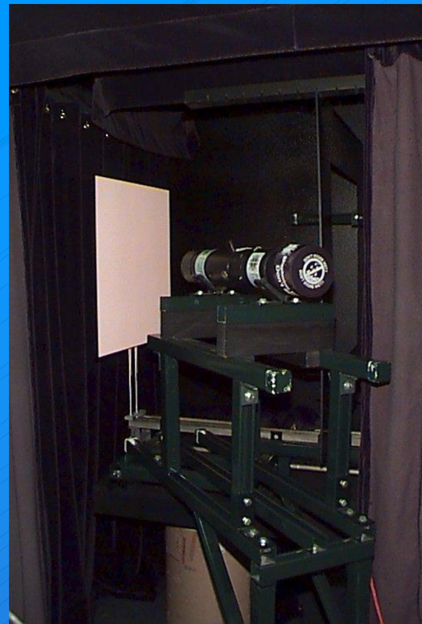
SeaWiFS & SIMBIOS Calibration Round Robins

(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



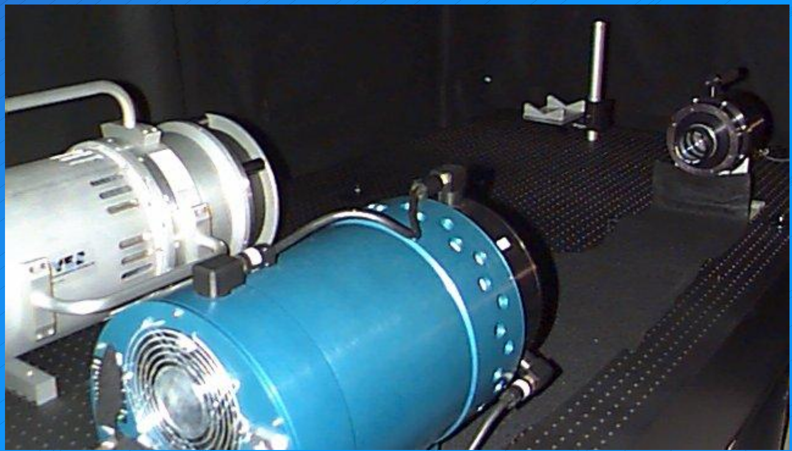


Radiance Calibrations (spheres & plaques)

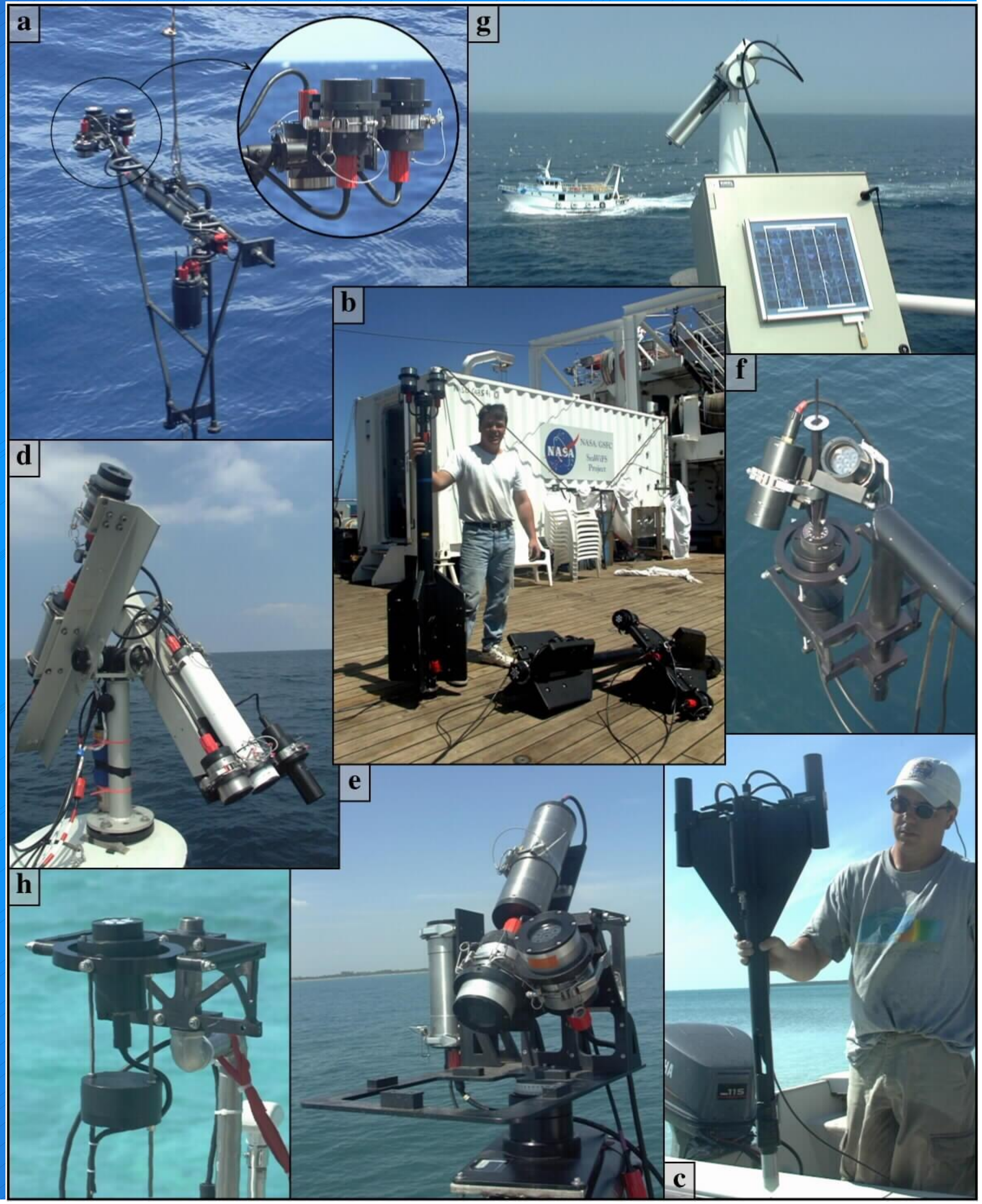
SeaWiFS Transfer Radiometer (SXR-1 & -2)

Field Measurement Technology Development

Various in-water & above water radiometers



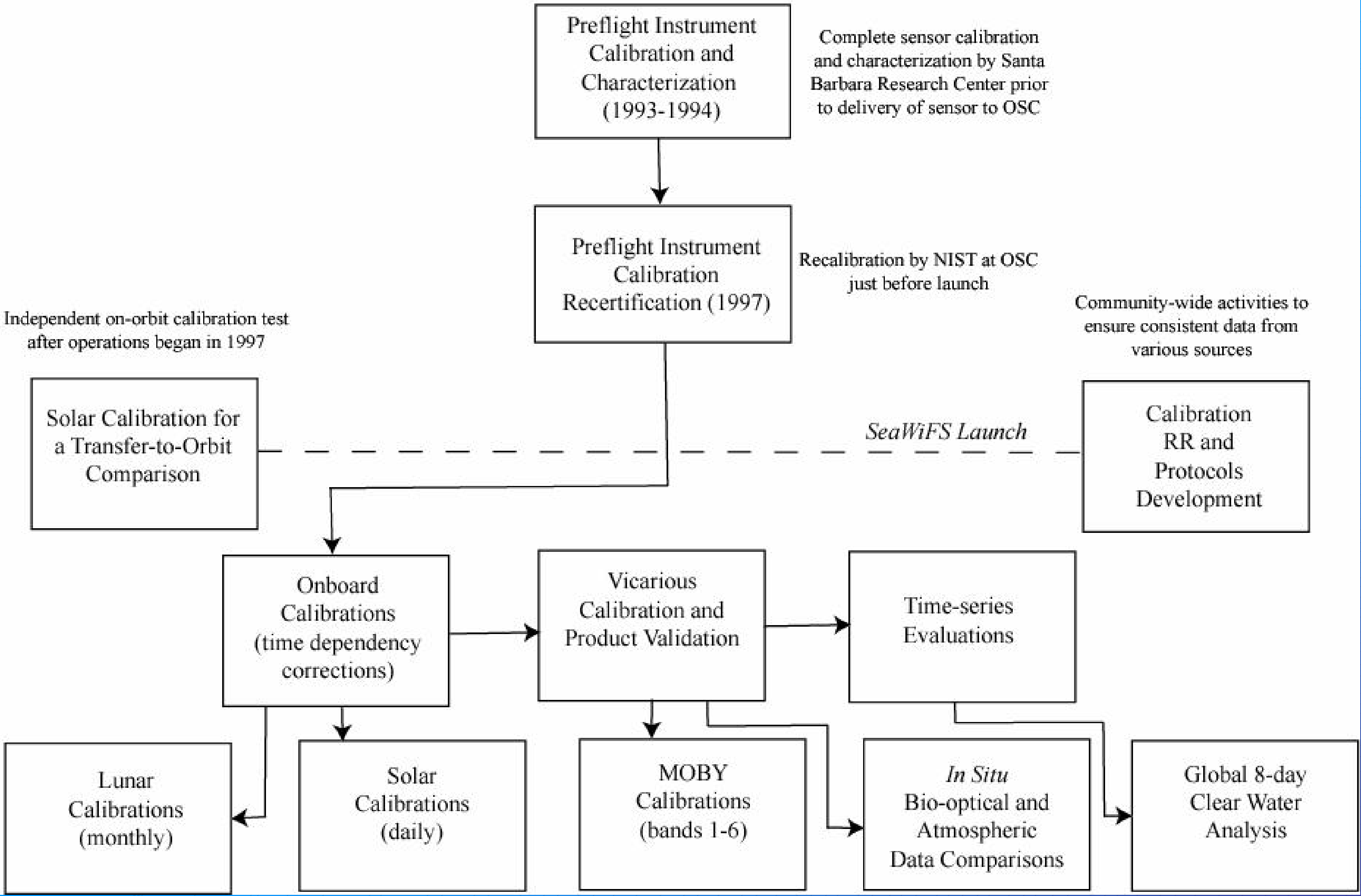
SeaWiFS Quality Monitor (SQM)
(NIST/NASA-developed portable field source for stability monitoring)



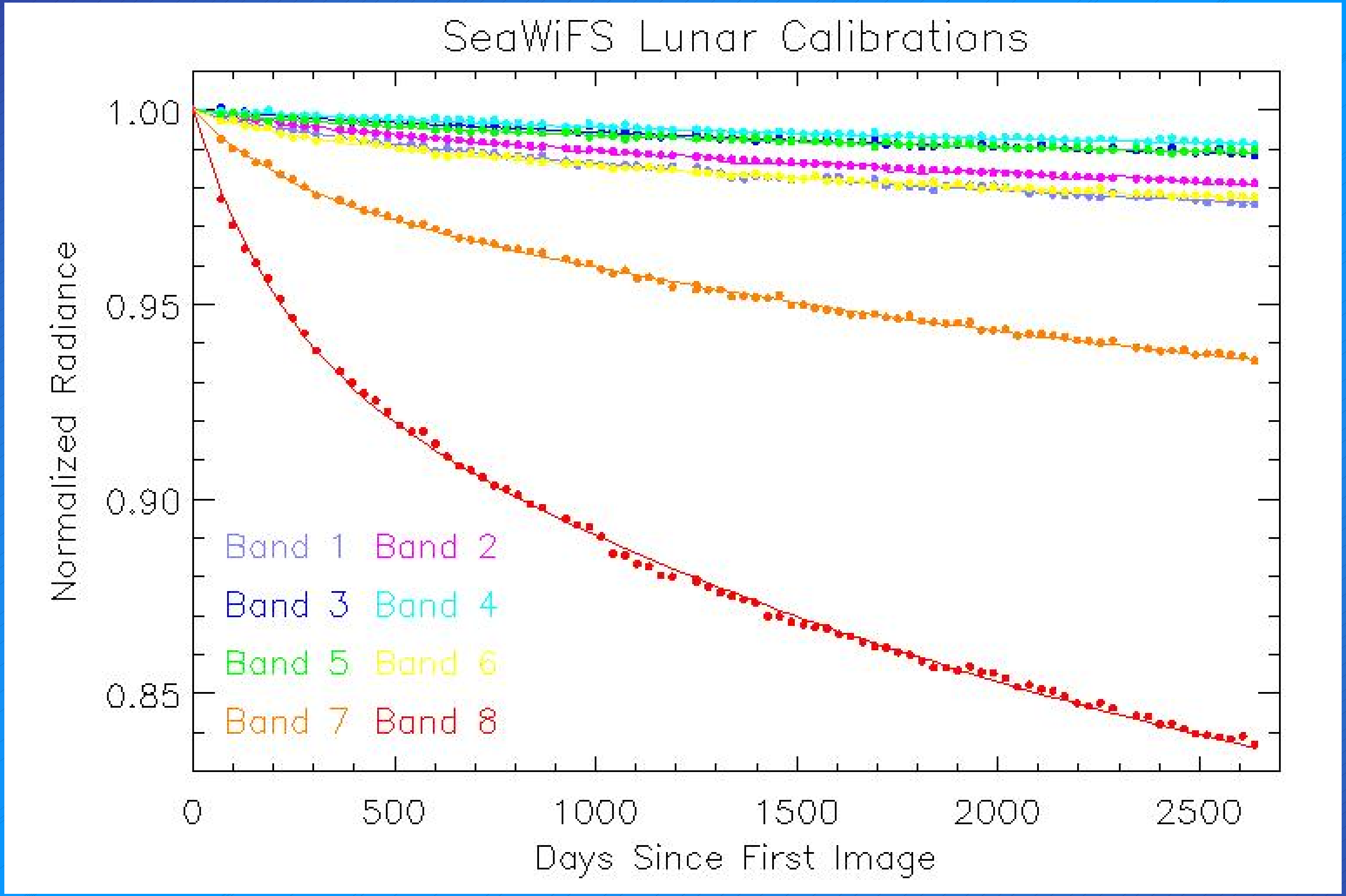
SeaWiFS, MODIS, & VIIRS

- **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

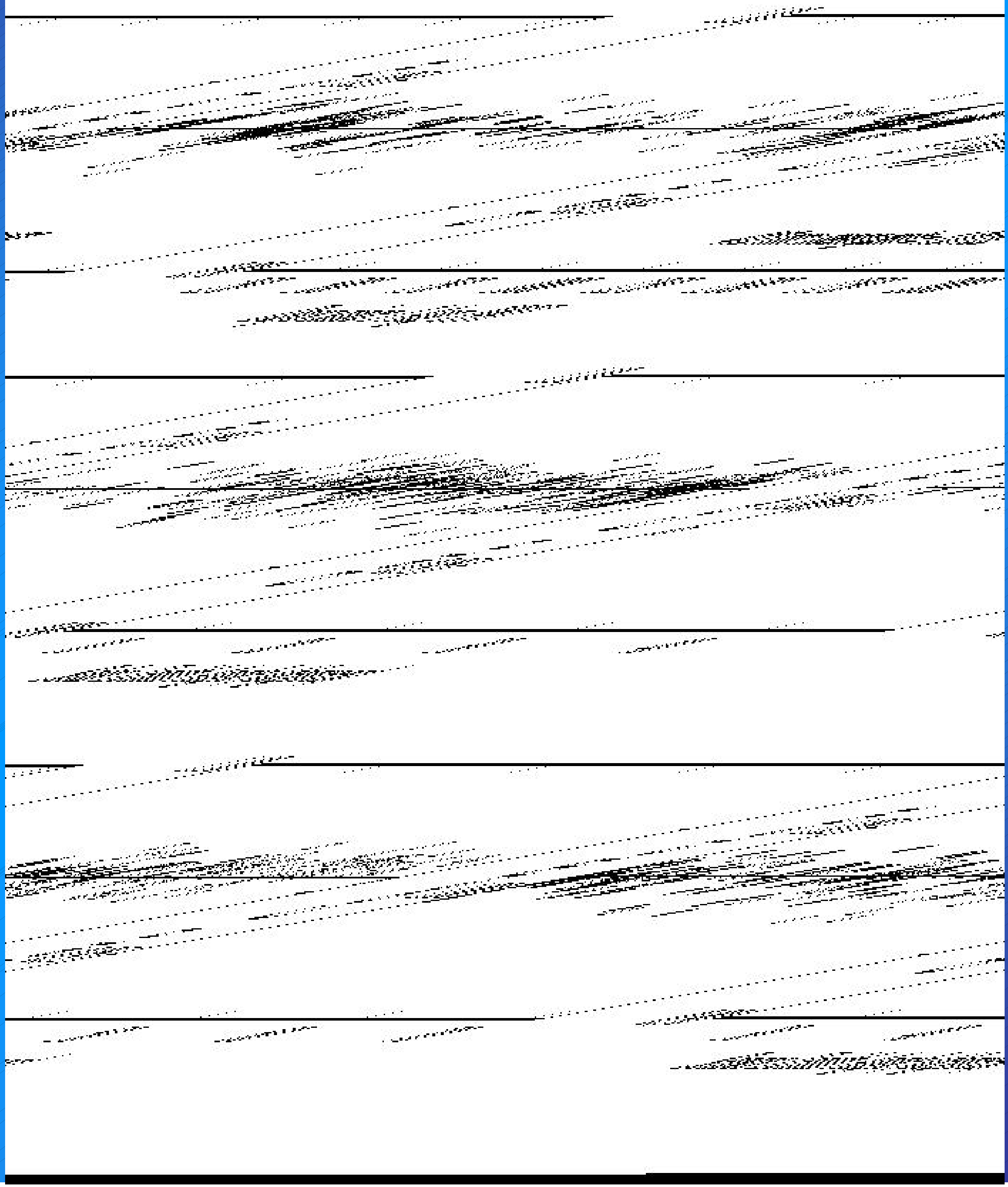


Lunar calibration: Monthly views of the moon at ~ 7° phase angle.
Gradual monotonic degradation primarily in NIR bands.

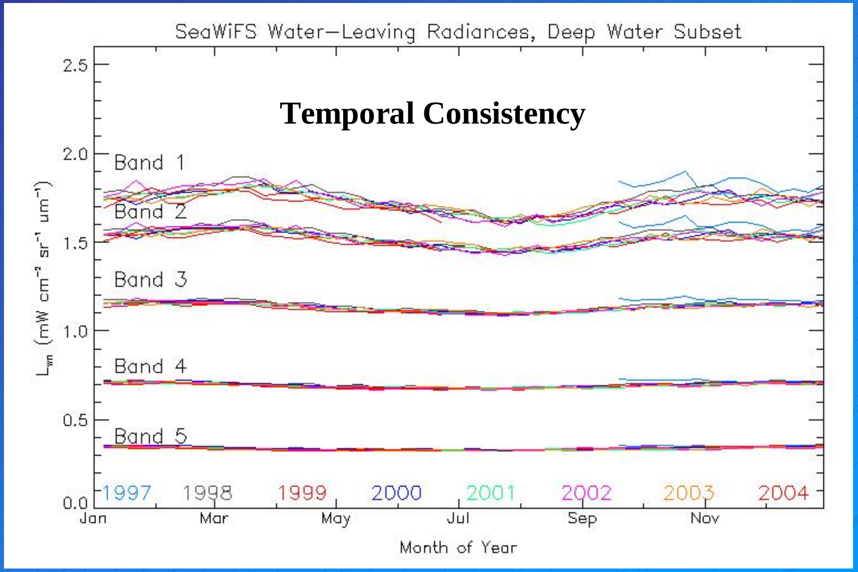
MOBY-based Vicarious Band 1 Gain Factors

- Overpasses used in operational gain determination

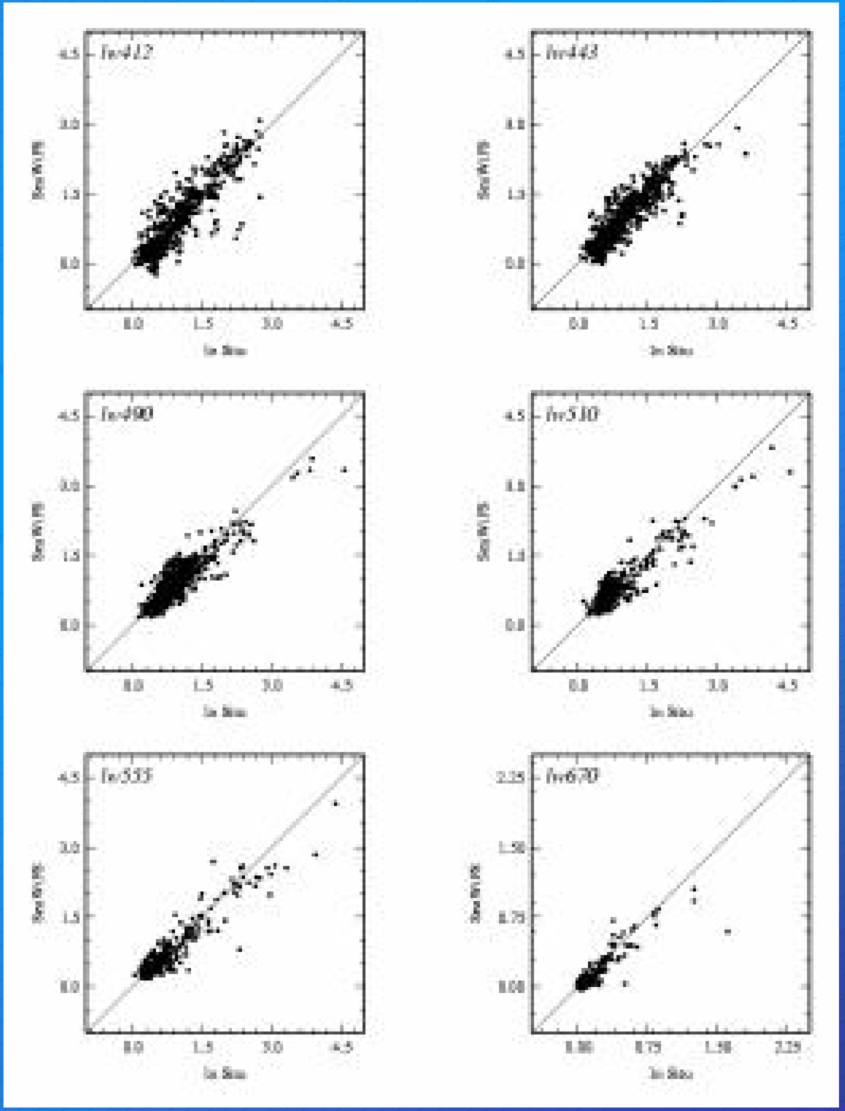
¡ Overpasses that failed gain analysis Q/C criteria



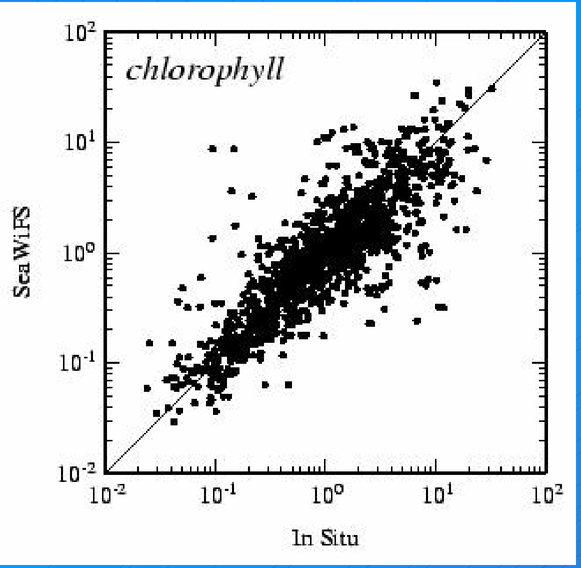
SeaWiFS Data Quality:
Global Consistency & In Situ Verification



Field Validation: Lwn's

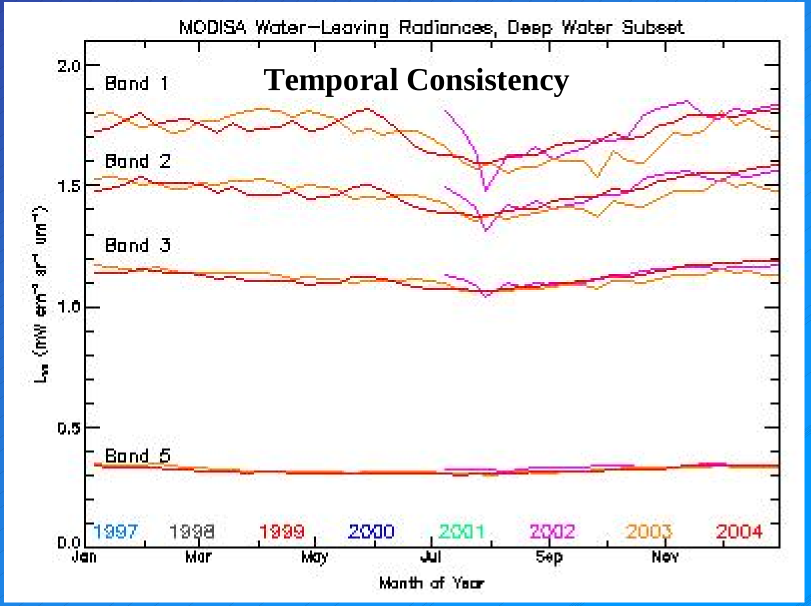


Field Validation: Chl-a

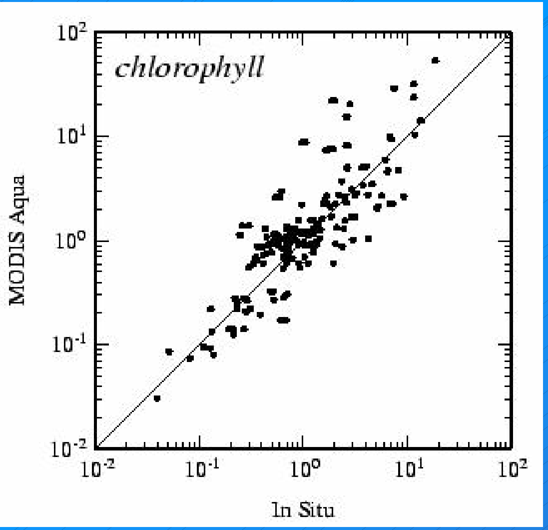


*** Lwn: Normalized Water-leaving Radiance**

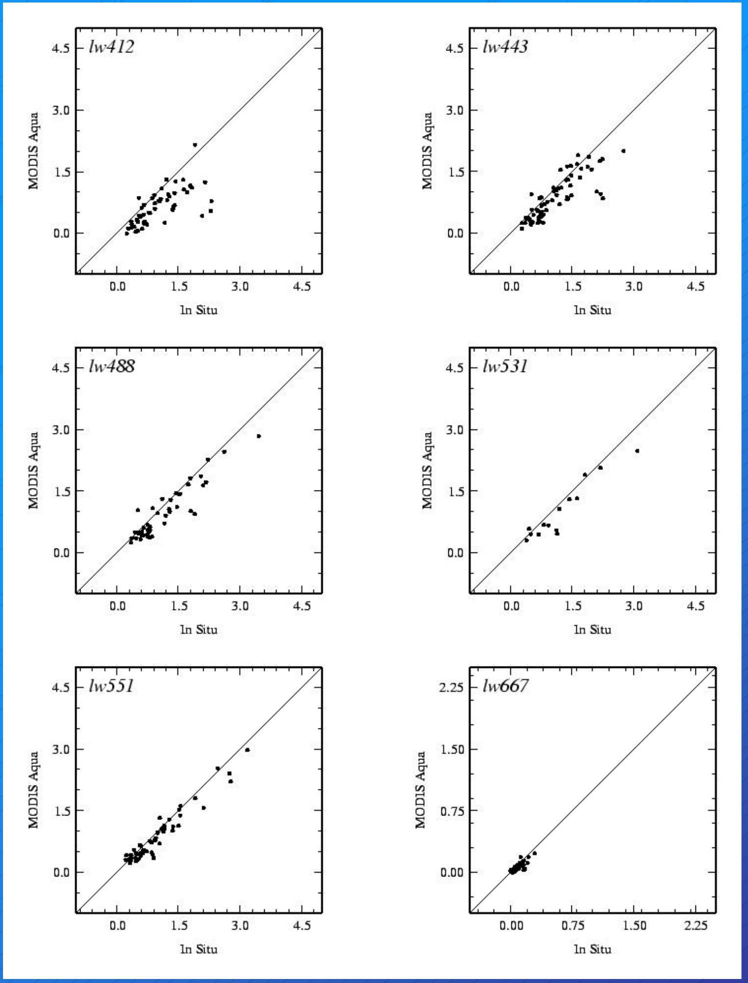
MODIS/Aqua Data Quality:
Global Consistency & In Situ Verification



Field Validation: Chl-a

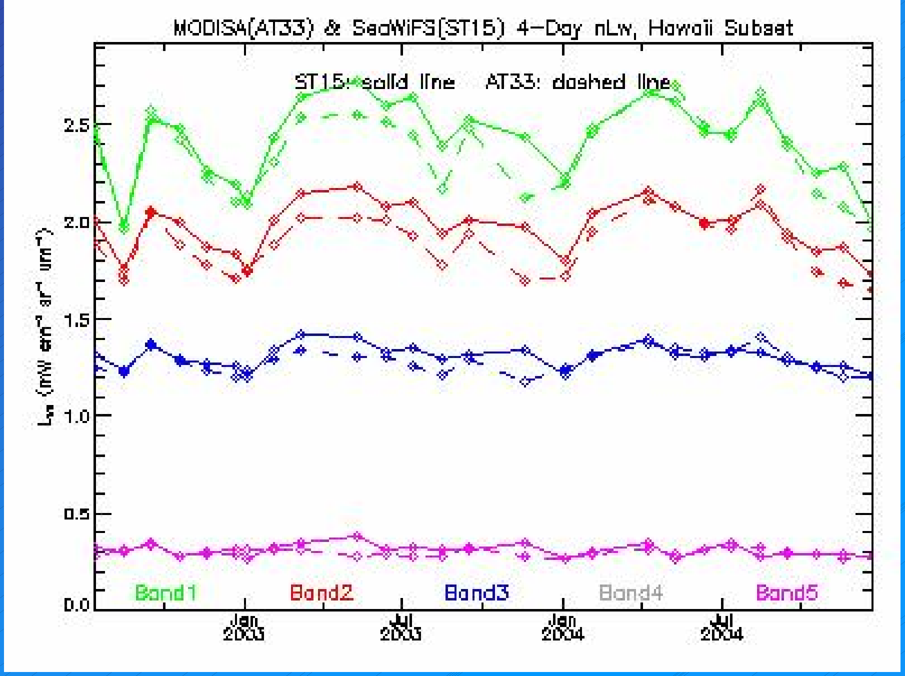


Field Validation: Lwn's

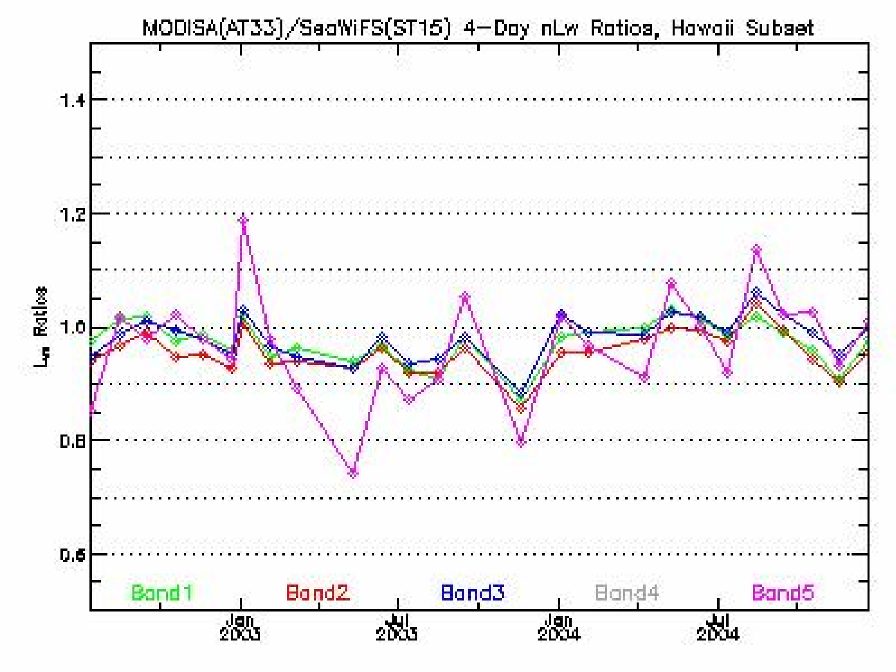


*** Lwn: Normalized Water-leaving Radiance**

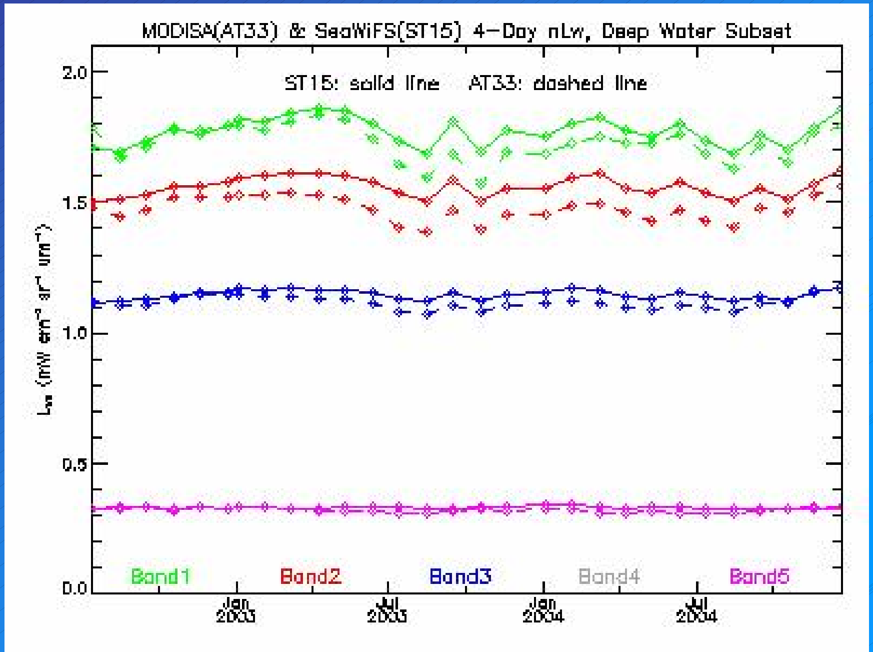
MODIS(Aqua)/SeaWiFS Lwn Ratios (Hawaii):
Vicarious Calibration Region



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

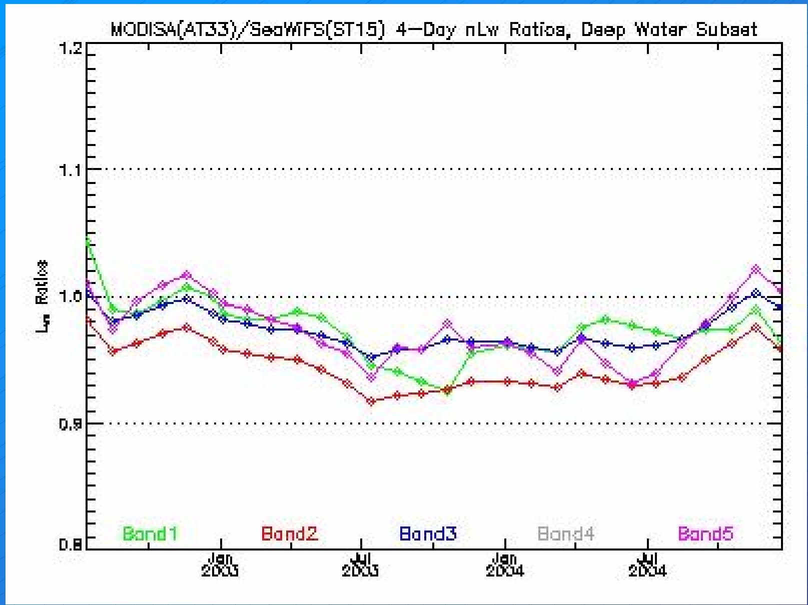


MODIS/Aqua-SeaWiFS Global Lwn’s



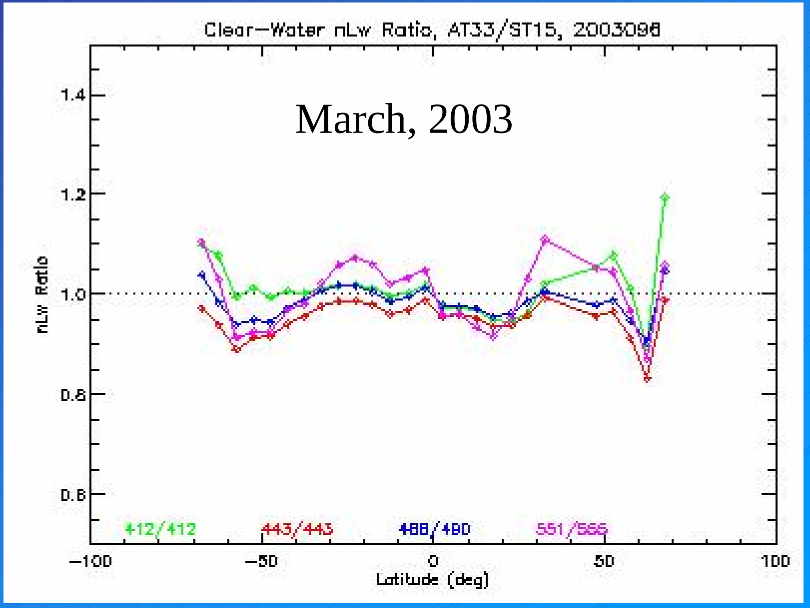
Deep-Water Lwn Comparisons
Solid Line: SeaWiFS
Dashed Line: MODIS/Aqua

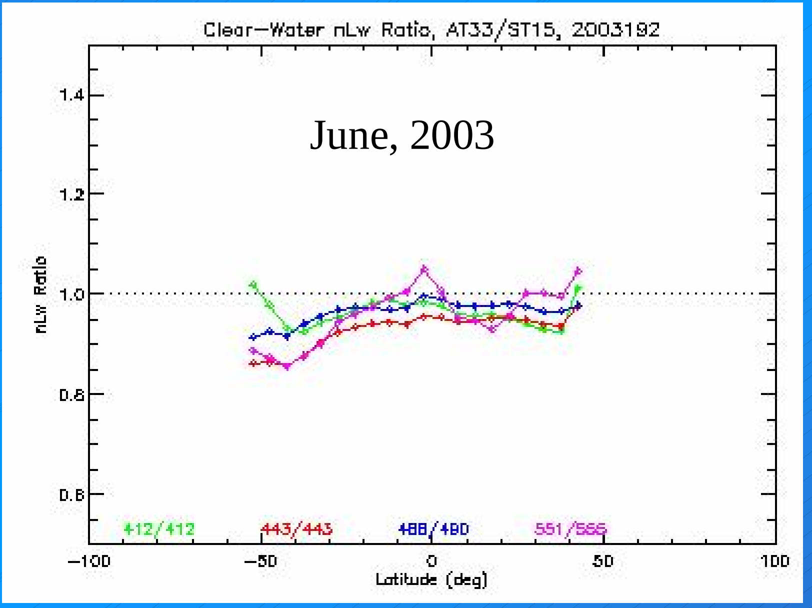
- Global averages very consistent.
- Average differences within ±5%.

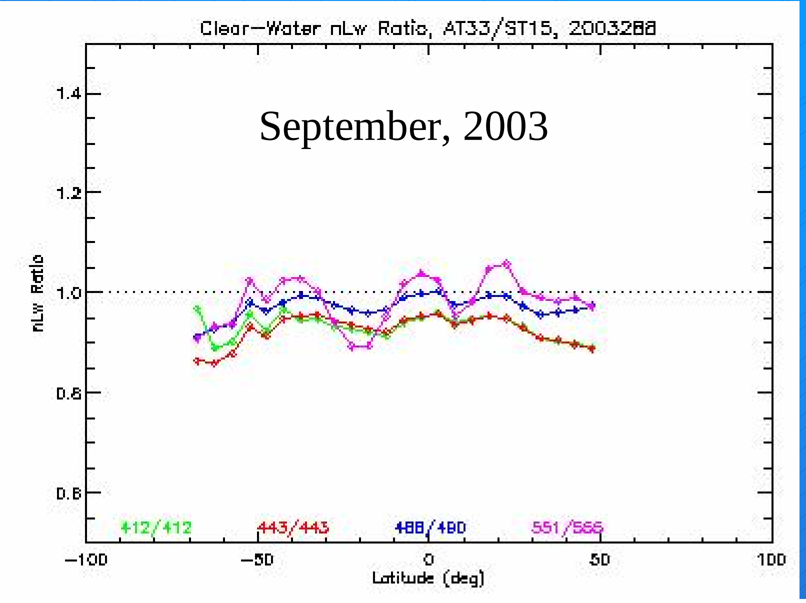


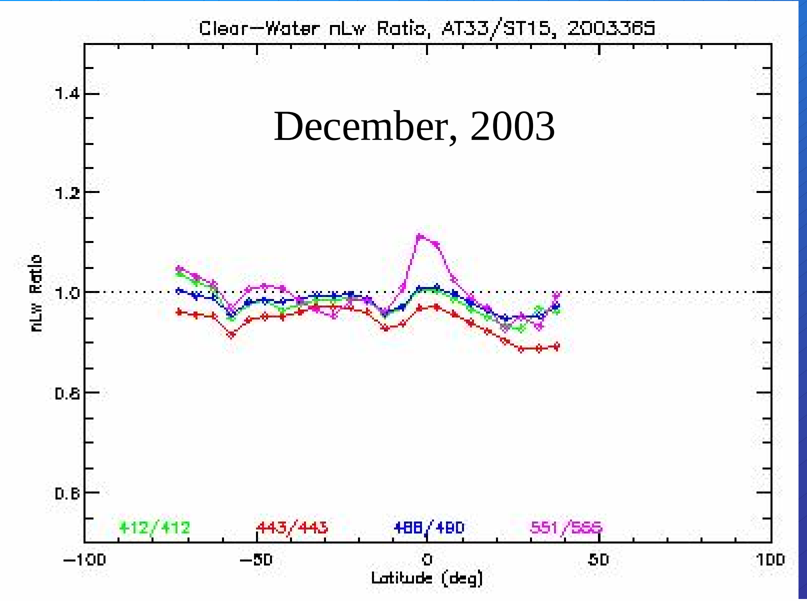
Deep-Water Lwn Ratios

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

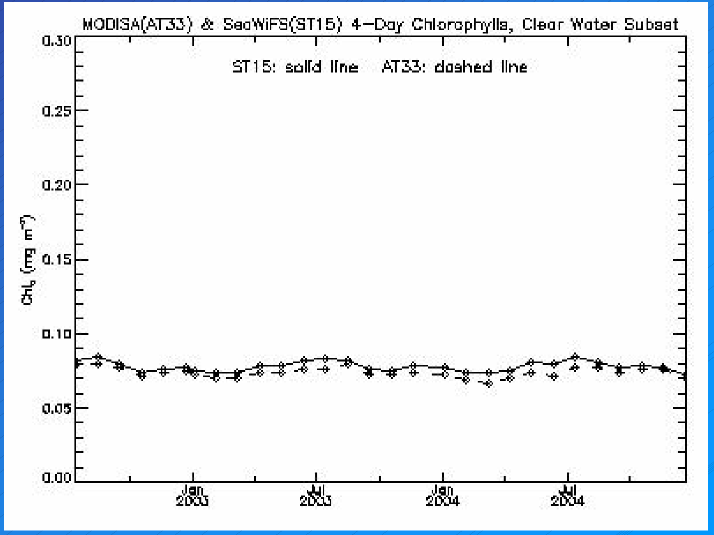


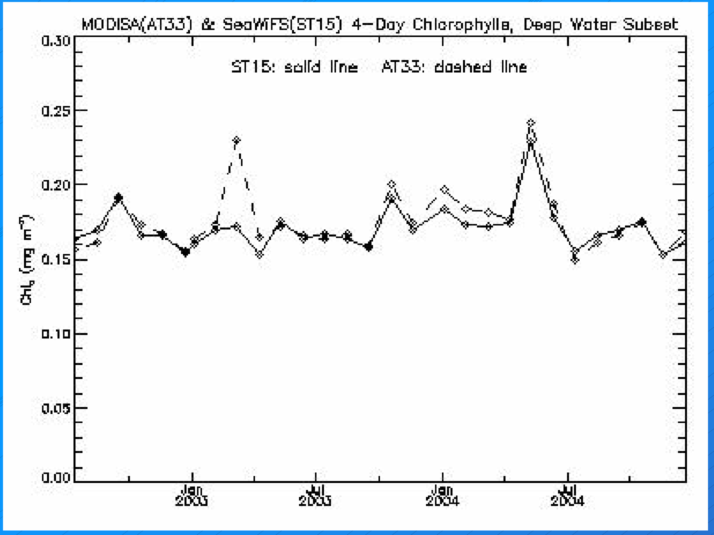




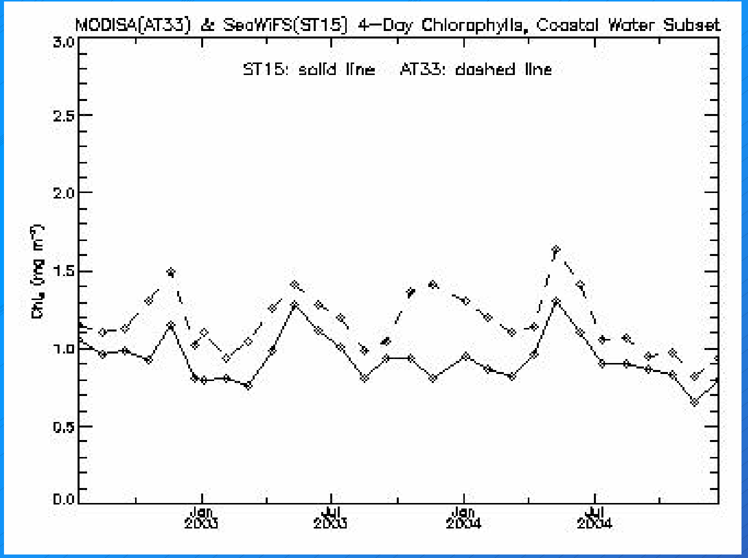


MODIS-Aqua & SeaWiFS Global Mean Chlorophyll Time Series





Clear-water:
chl-a < 0.15 mg/m^3



Deep-water:
depth > 1000 m

Coastal: depth < 1000 m
- Primarily chlorophyll-a algorithm difference at high concentrations

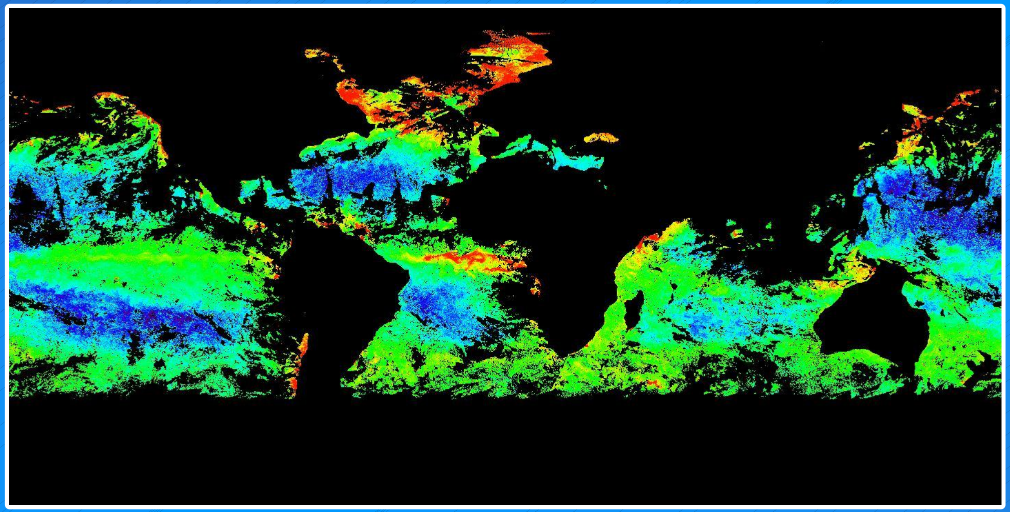
Dashed line: MODIS
Solid line: SeaWiFS

SeaWiFS & MODIS 4-Day Deep-Water Chlorophyll Images

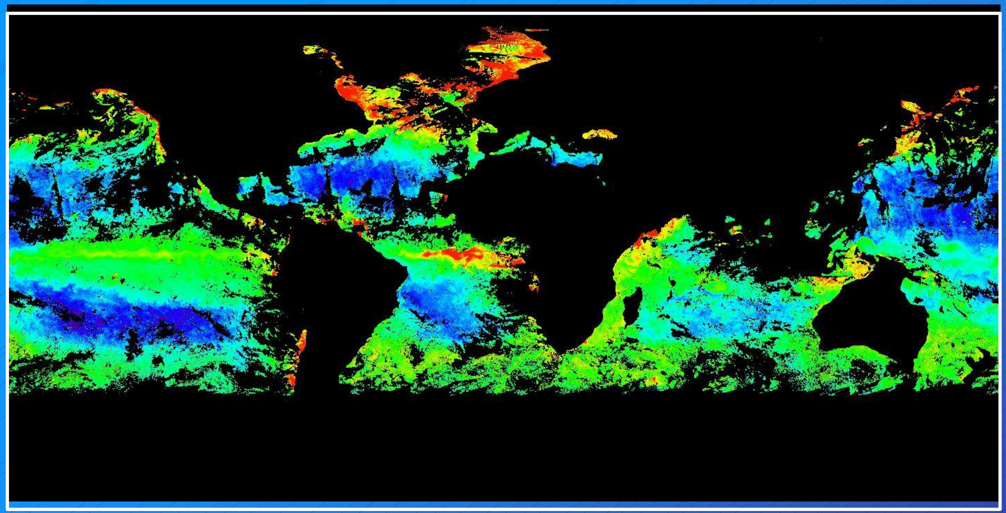
4 day composites, Summer 2002

0.01-1 mg/m^3

SeaWiFS



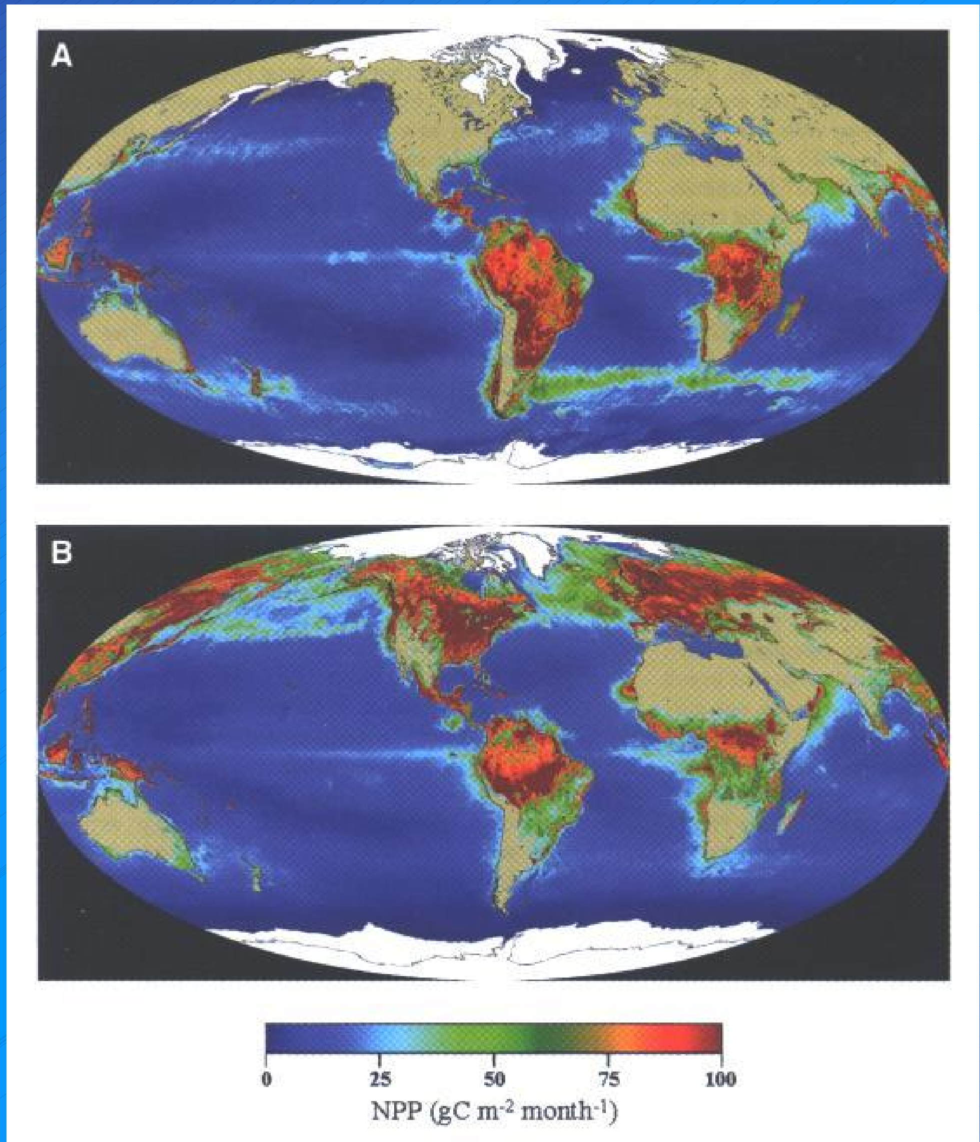
MODIS
(current operational processing)



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 oligiotropic areas also expanding: McClain et al., *Deep-Sea Res.*, 2004

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

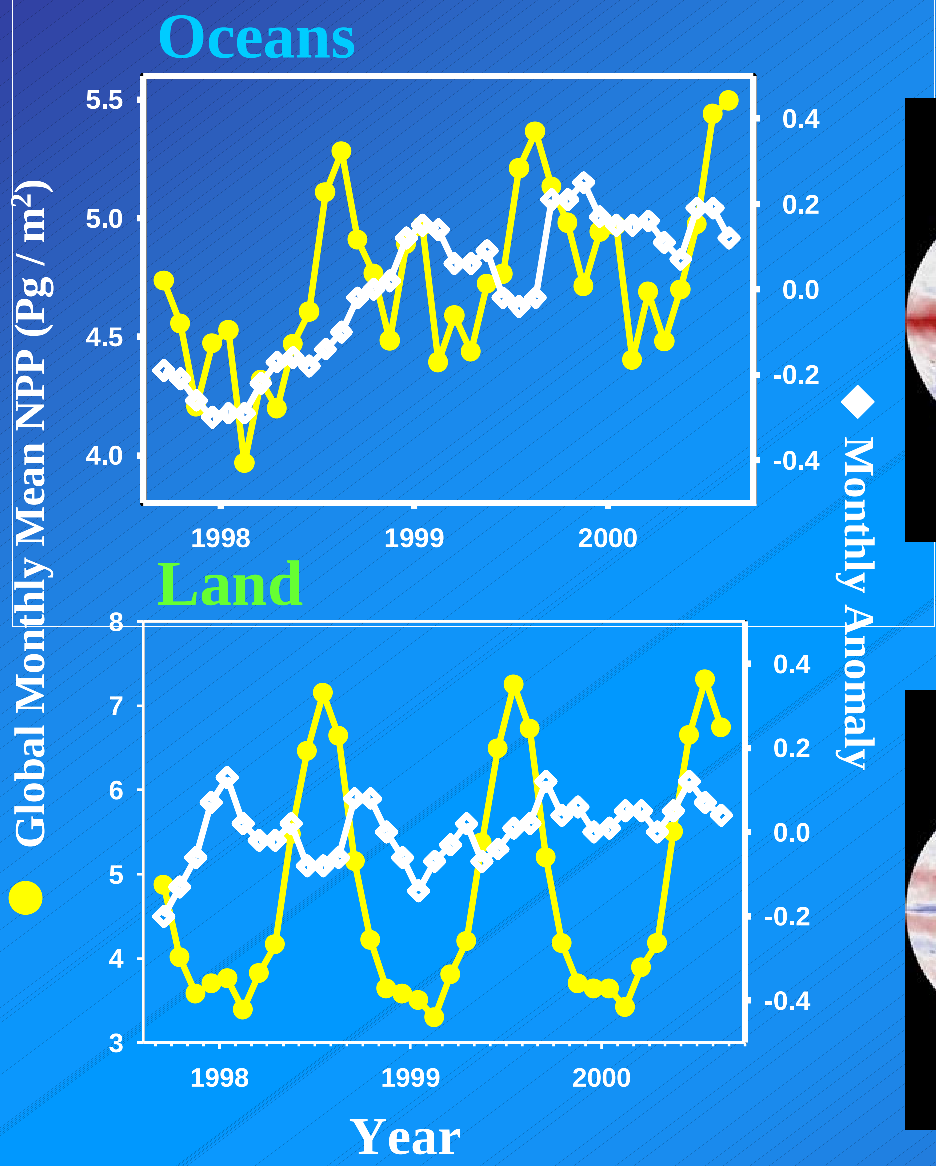


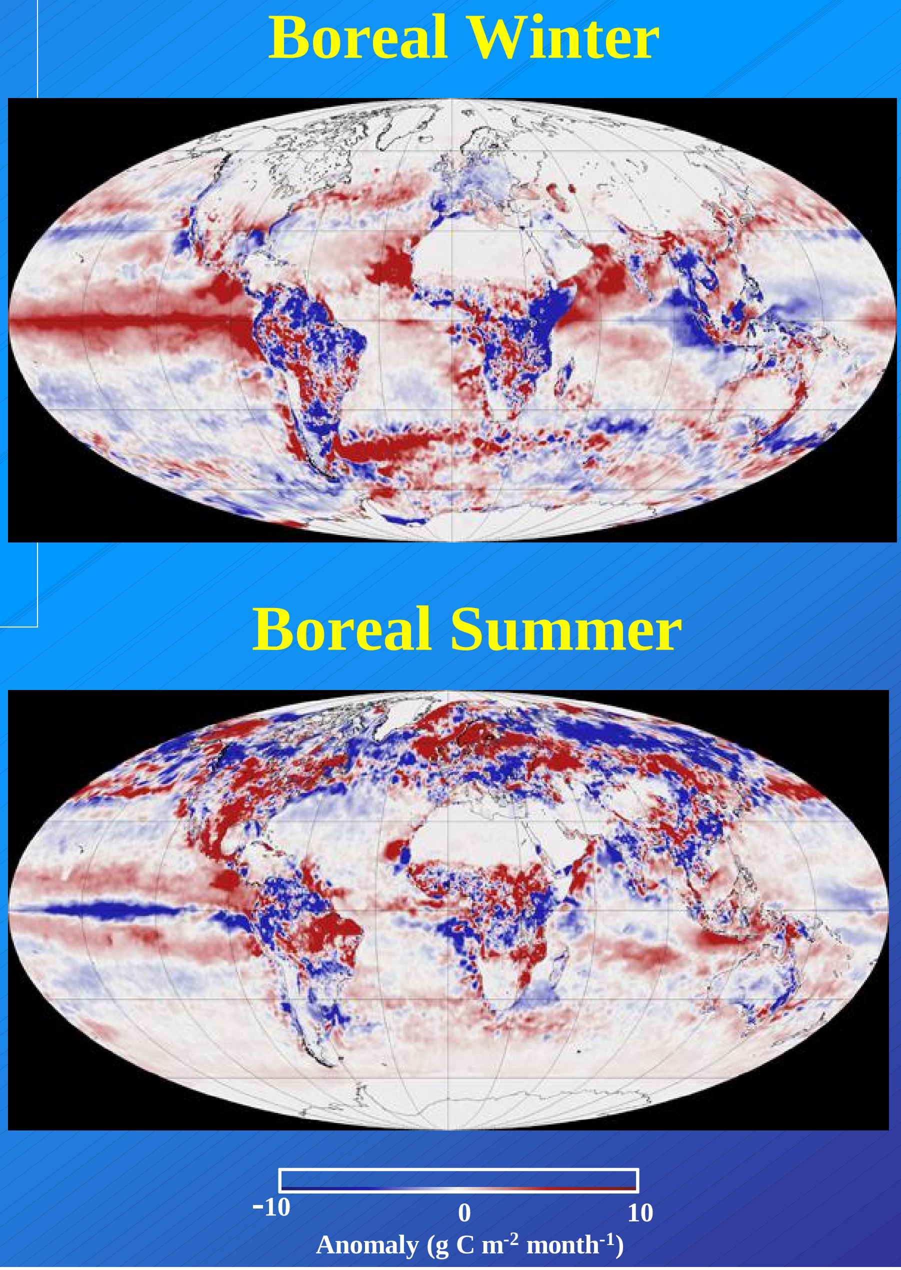
Boreal Winter

Boreal Summer

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

Global NPP Trends: 1997-2000

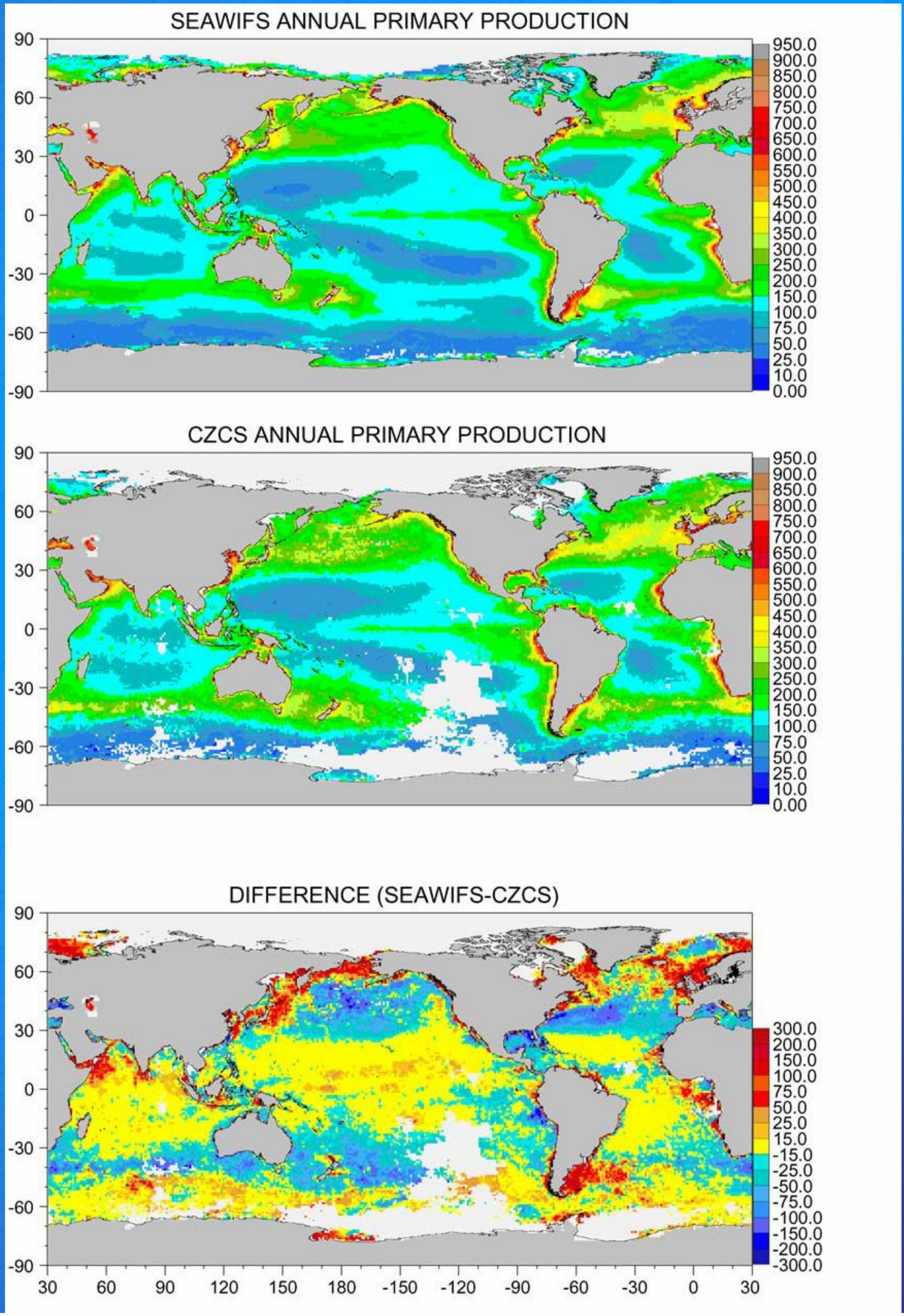




Behrenfeld, M., et al., *Science*, 2001.

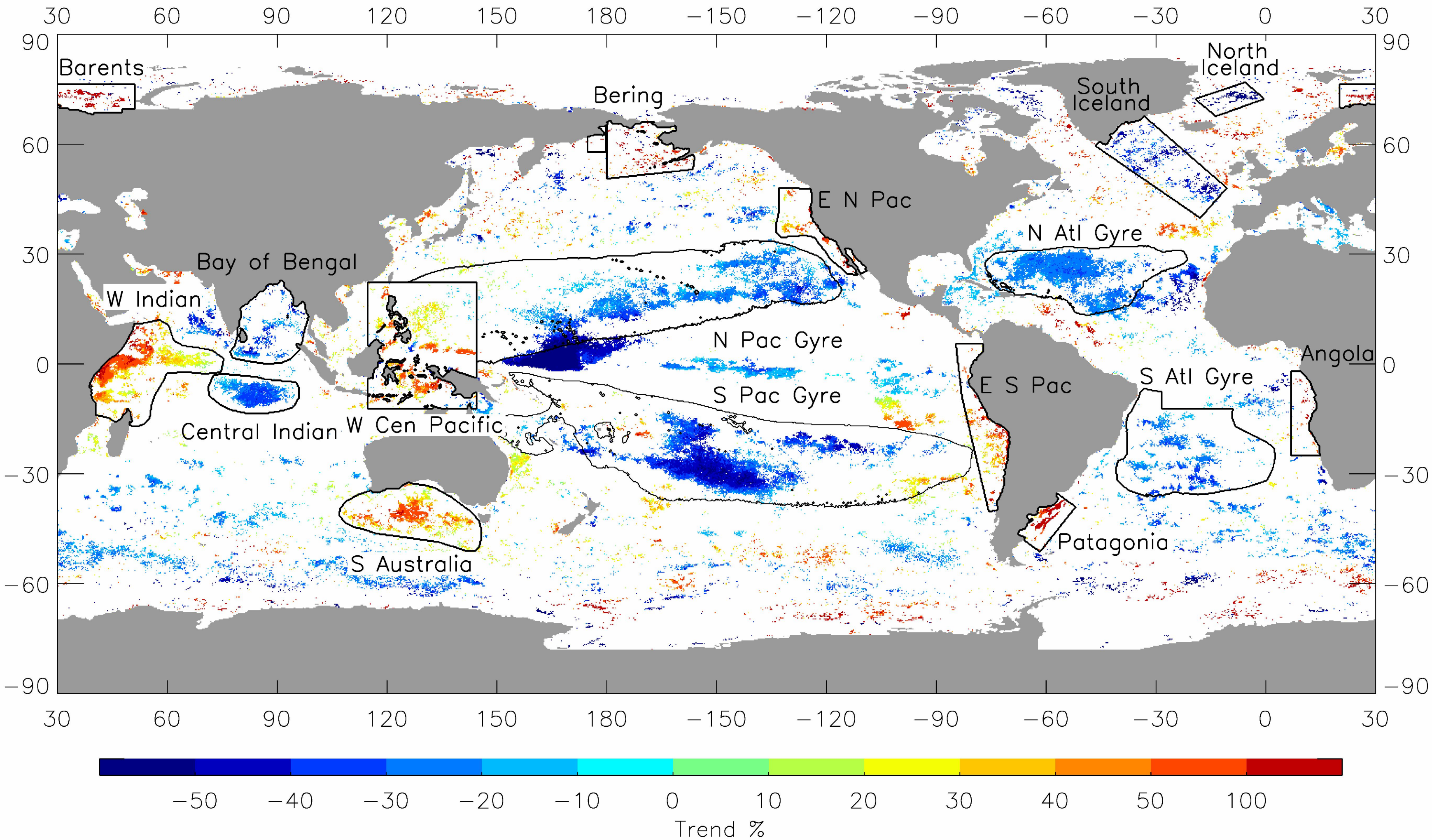
Decadal Scale Changes in Marine Productivity

- 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.



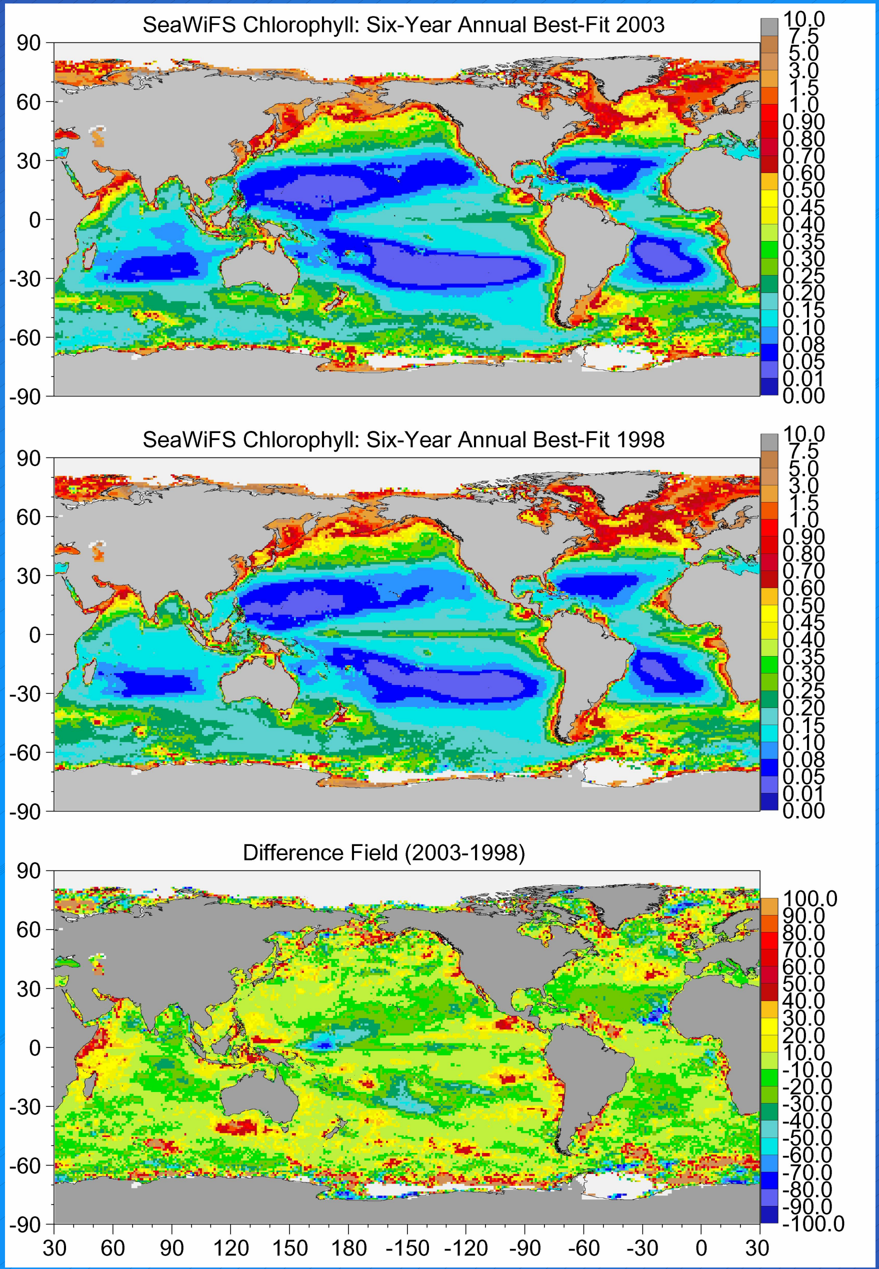
Gregg, W.W., et al., Ocean primary production & climate: Global decadal changes, *Geophys. Res. Lett*., 15, doi: 10.1029/2003GL016889, 2003.

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

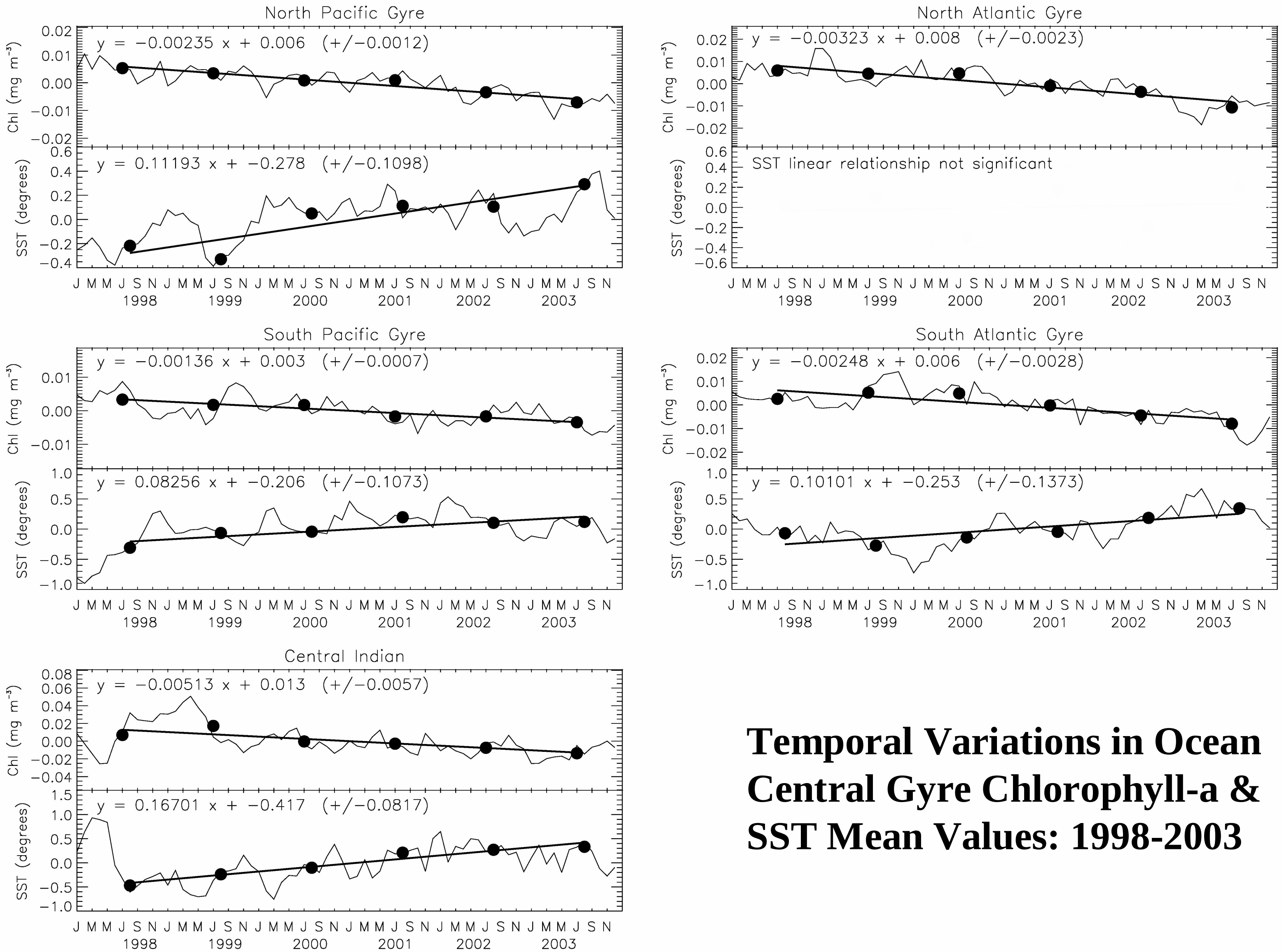


Gregg, W. W., et al., GRL, 2005.

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 CO_2.
  - 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 CO_2 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

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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

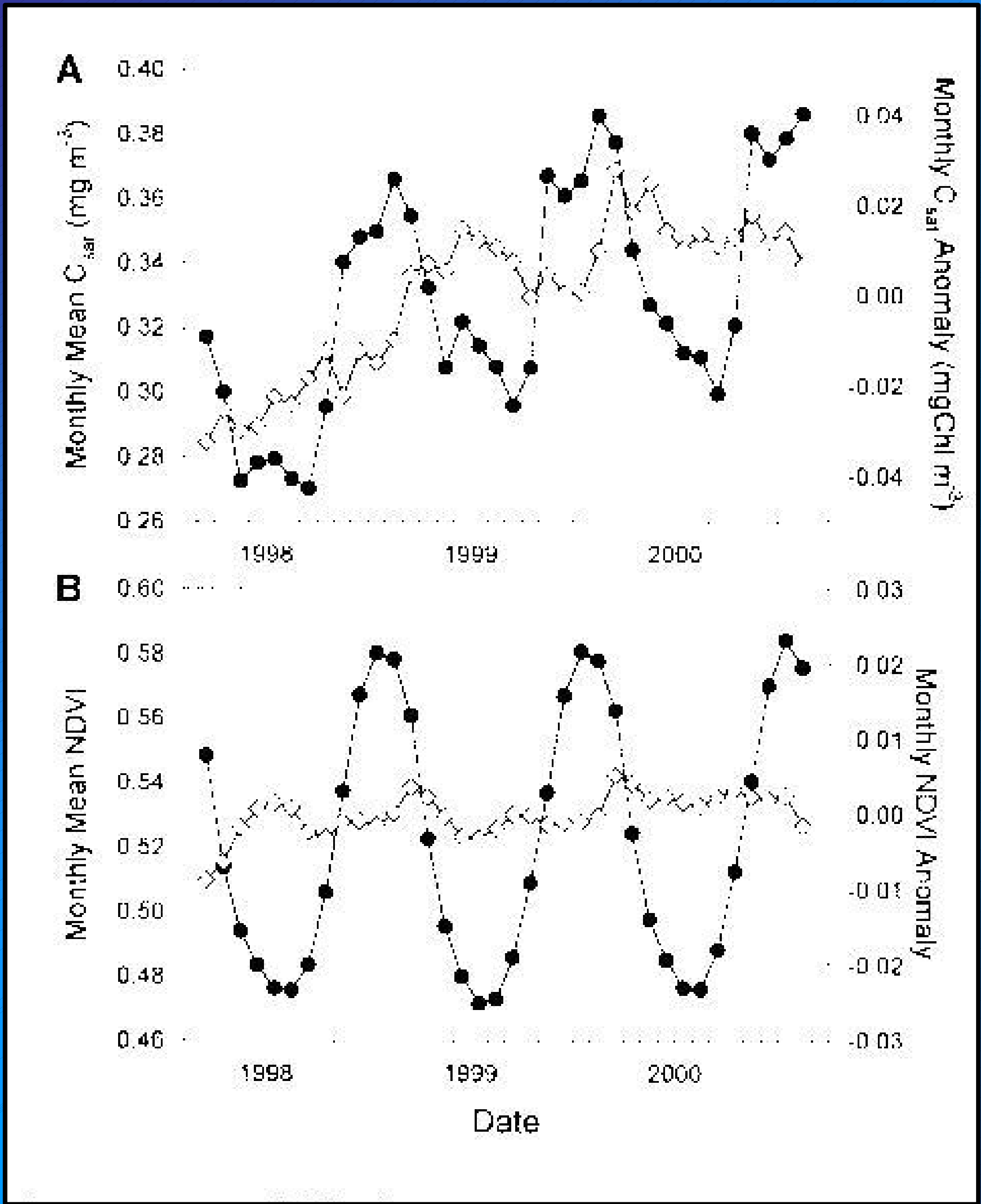
Distribution & Outreach

- 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.