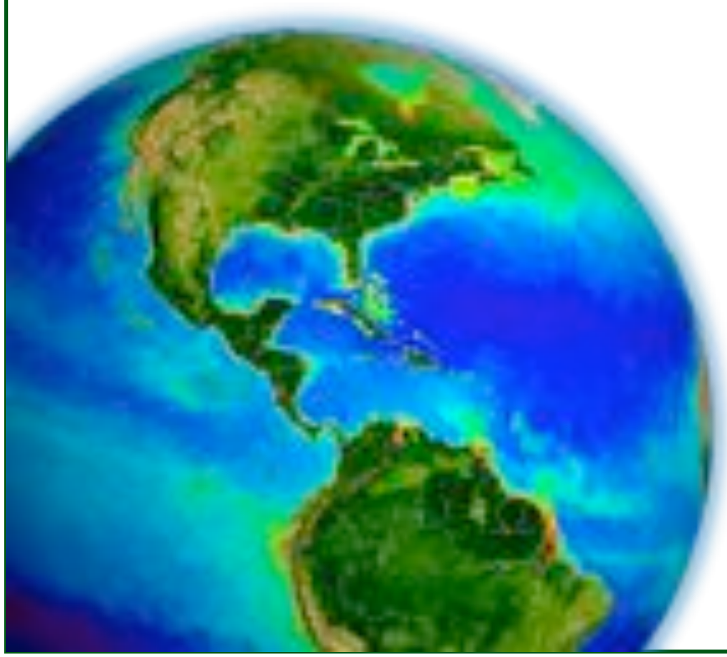
Advances in the Processing and Retrieval of Ocean Color from MODIS and SeaWiFS



Bryan Franz

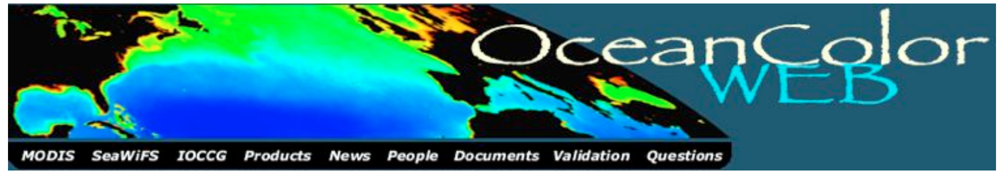
and the

Ocean Biology Processing Group

MODIS Science Team Meeting
January 2010

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
  - –Data archive and distribution
  - –Product validation (SeaBASS)
  - –Algorithm development (NOMAD)
  - –User processing and display (SeaDAS)
  - –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: 42 million files OC

  since 2004: 12 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)

Ocean Color Reprocessing

Scope: SeaWiFS, MODISA, MODIST, OCTS, CZCS

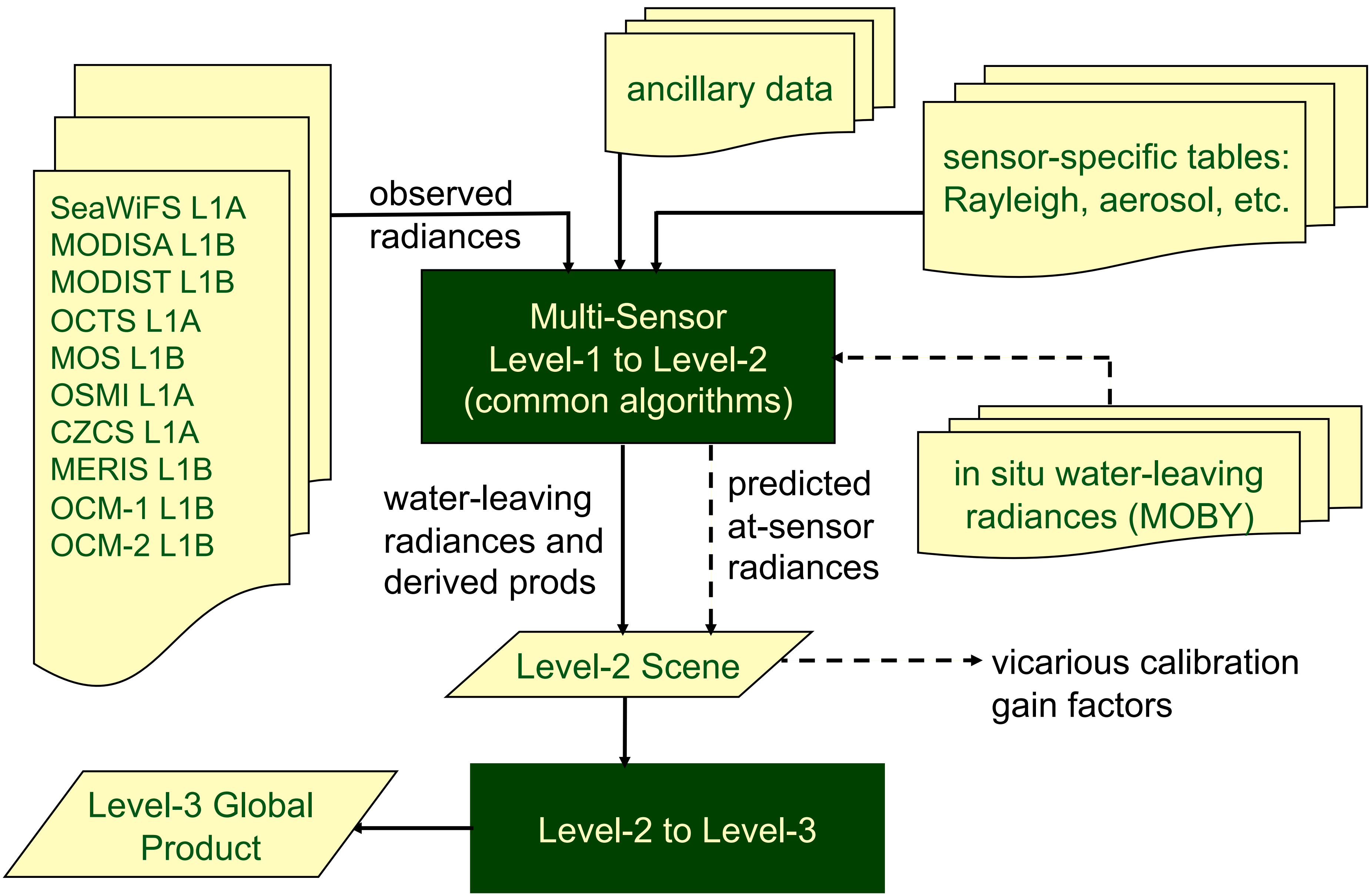
Status:

- SeaWiFS reprocessing completed November 2009
- MODISA to begin next week, completed in February-March

Highlights:

- sensor calibration updates
- regeneration of all sensor bandpass quantities
- new aerosol models based on AERONET
- improved turbid-water atmospheric correction algorithm
- accounting for atmospheric NO2 absorption
- expanded product suite

Sensor-Independent Approach



Expanded MODIS Product Suite

<table>
<tr><th>OLD</th><th>NEW</th><th></th><th></th></tr>
<tr><td>nLw(λ)</td><td>$R_{rs}(\lambda)$ →</td><td>$R_{rs}(412)$</td><td></td></tr>
<tr><td>Chlorophyll *a*</td><td>Chlorophyll *a*</td><td>$R_{rs}(443)$</td><td></td></tr>
<tr><td>$K_d(490)$</td><td>$K_d(490)$</td><td>$R_{rs}(469)$</td><td>land bands</td></tr>
<tr><td>Ångstrom</td><td>Ångstrom</td><td>$R_{rs}(488)$</td><td></td></tr>
<tr><td>AOT</td><td>AOT</td><td>$R_{rs}(531)$</td><td></td></tr>
<tr><td>Epsilon</td><td>POC</td><td>$R_{rs}(547)$</td><td>revised band center</td></tr>
<tr><td></td><td>PIC</td><td>$R_{rs}(555)$</td><td></td></tr>
<tr><td></td><td>CDOM_index</td><td>$R_{rs}(645)$</td><td></td></tr>
<tr><td></td><td>PAR</td><td>$R_{rs}(667)$</td><td></td></tr>
<tr><td></td><td>iPAR</td><td>$R_{rs}(678)$</td><td></td></tr>
<tr><td></td><td>Fluorescence LH</td><td></td><td></td></tr>
<tr><td></td><td>Fluorescence QY</td><td></td><td></td></tr>
</table>

$$R_{rs}(\lambda) = \frac{nL_w(\lambda)}{F_0(\lambda)}$$

Expanded Product Suite

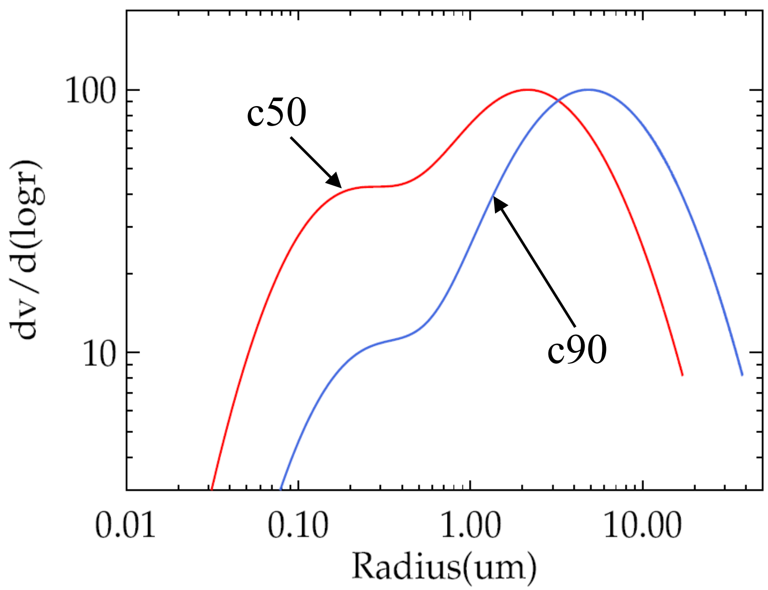
- particulate organic carbon (POC)
  - Stramski et al. 2008
- particulate inorganic carbon (PIC)
  - Balch et al. 2005, Gordon et al. 2001
- colored disolved organic matter index (CDOM_index)
  - Morel & Gentili 2009
- photsynthetically available radiation (PAR)
  - Frouin et al. 2003
- fluorescence quantum yield (FLH, iPAR,FQY)
  - Behrenfeld et al. 2009

Common Algorithm Changes

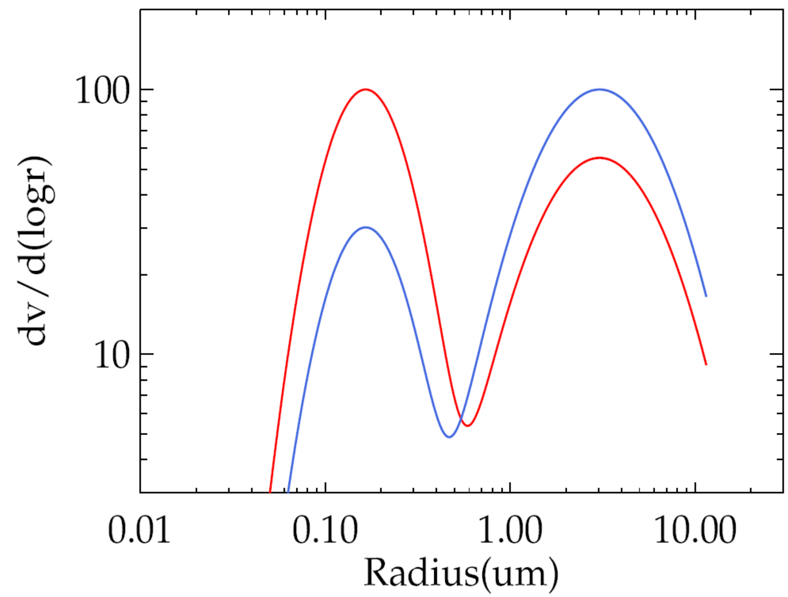
New Aerosol Models

- based on AERONET size distributions & albedos
- vector RT code accounting for polarization (Ahmad-Fraser)
- 80 models (8 humidities x 10 size fractions)
- model selection now descriminated by relative humidity
- revised vicarious calibration assumption (α=0.65 at Tahiti)

Old S&F Size Distributions

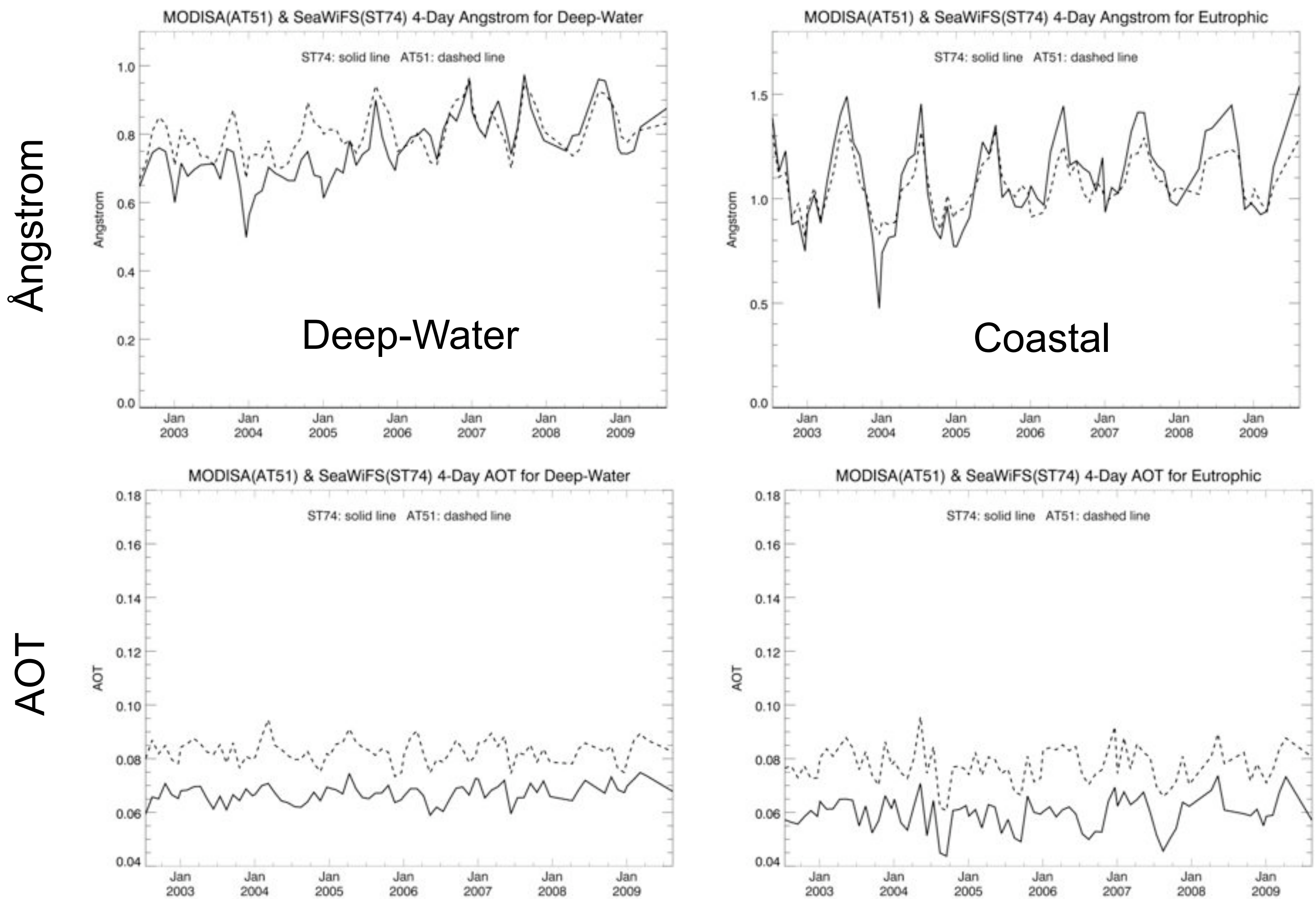


New AERONET-based Size Distributions

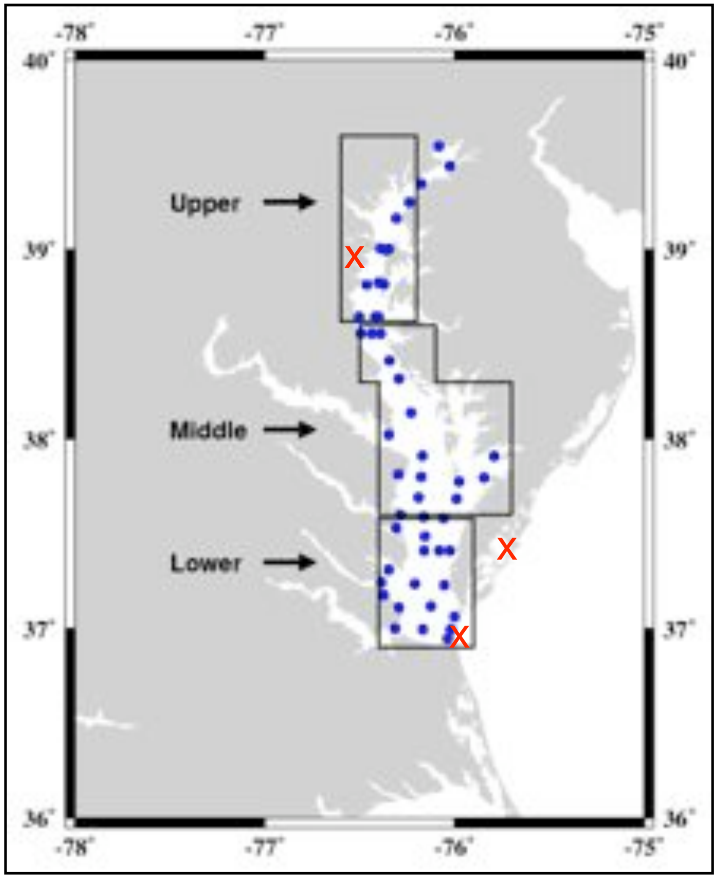


Ahmad, Z., B. A. Franz, C. R. McClain, E. J. Kwiatkowska, J. Werdell, E. Shettle, and B. N. Holben (2010). New aerosol models for the retrieval of aerosol optical thickness and normalized water-leaving radiances from the SeaWiFS and MODIS sensors over coastal regions and Open Oceans (drafted).

MODISA and SeaWiFS Aerosol Comparison



Coastal Environments



Chesapeake Bay serves as proxy for evaluating geophysical retrievals in a coastal environment.

CBP monthly chlorophyll measurements at 49 stations since 1984.

AERONET sites at SERC, COVE, and Wallops collecting aerosol properties.

. Chesapeake Bay Program

x AERONET

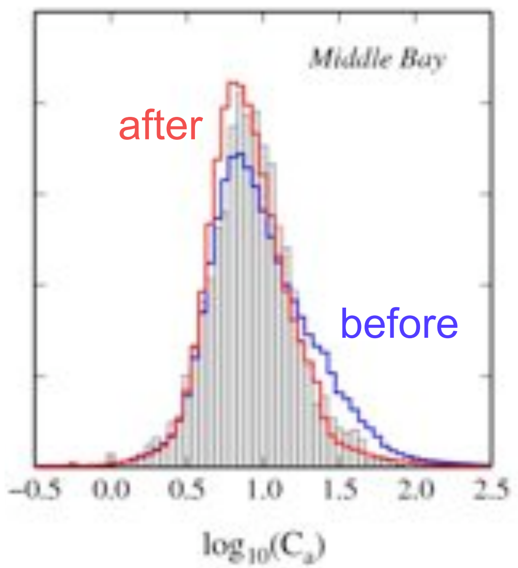
Werdell,P.J., B.A. Franz, and S.W. Bailey (2010). Evaluation of shortwave infrared atmospheric correction for ocean color remote sensing of Chesapeake Bay, submitted to Rem. Sens. Env.

Werdell, P.J., S.W. Bailey, B.A. Franz, L,W. Harding Jr., G.C. Feldman, C.R. McClain (2009). Regional and seasonal variability of chlorophyll-a in Chesapeake Bay as observed by SeaWiFS and MODIS-Aqua, Rem. Sens. Env., 113(6), 1319-1330.

Revised Turbid-Water Atmospheric Correction

- atmospheric correction in high-scattering water requires an iterative procedure to model and remove the water contribution in the NIR

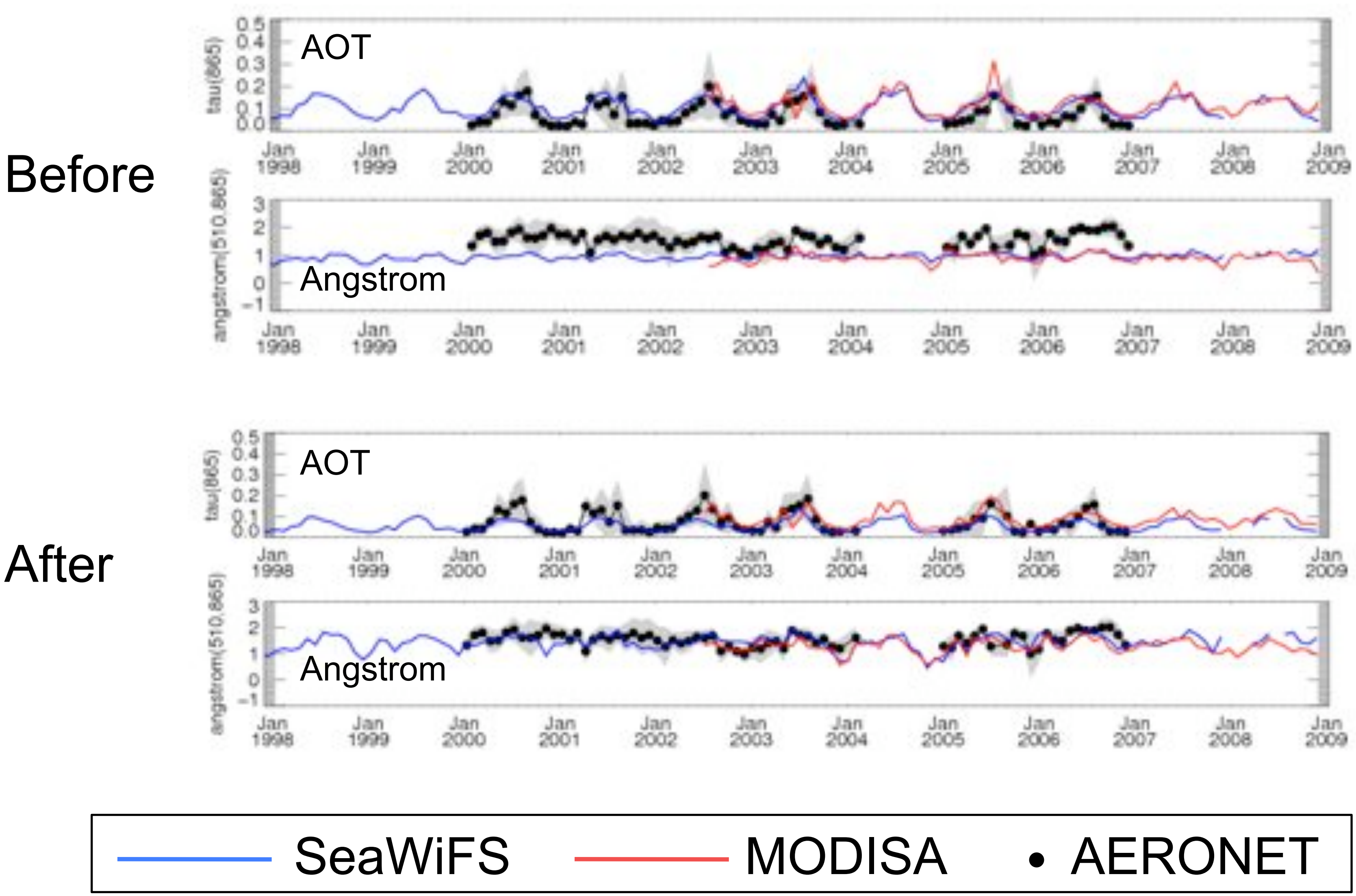
- bio-optical model updated, and results substantially improved



Bailey, S.W.., Franz, B.A., and Werdell, P.J. (2010). Estimation of near-infrared water leaving reflectance for satellite ocean color data processing, Opt. Exp., submitted.

Improved Aerosol Retrievals Relative to AERONET

Upper Chesapeake Bay



MODISA Calibration Changes

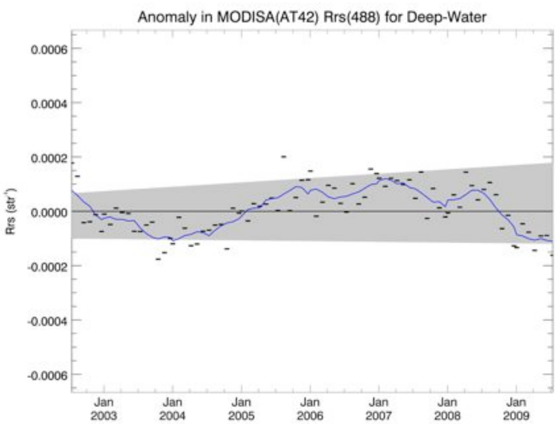
Updated MODISA Instrument Calibration

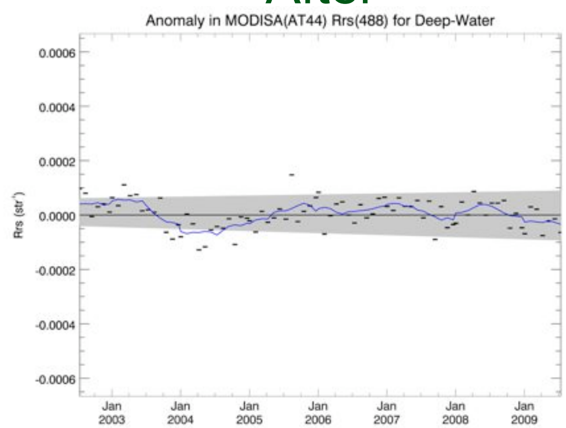
Latest MCST calibration (collection 6) applied

- updated fit to lunar and solar calibrator trends
- adds change in RVS over time for bands 667, 678, 748, 869
- result is enhanced temporal stability in water-leaving reflectance

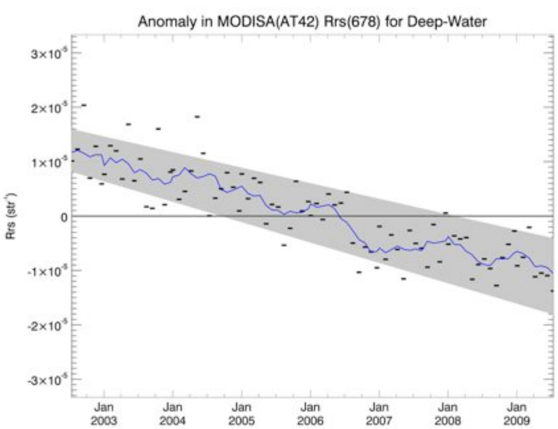
Before | After

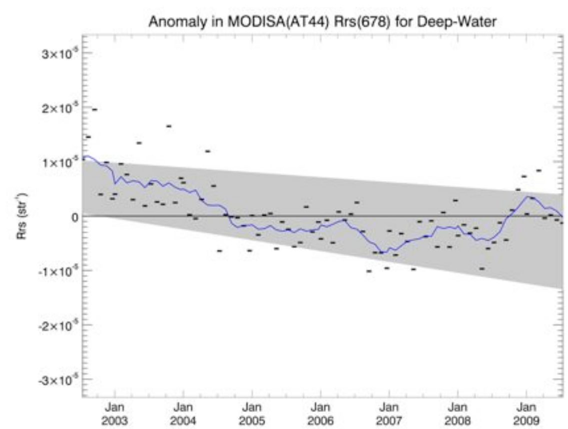
Rrs(488)





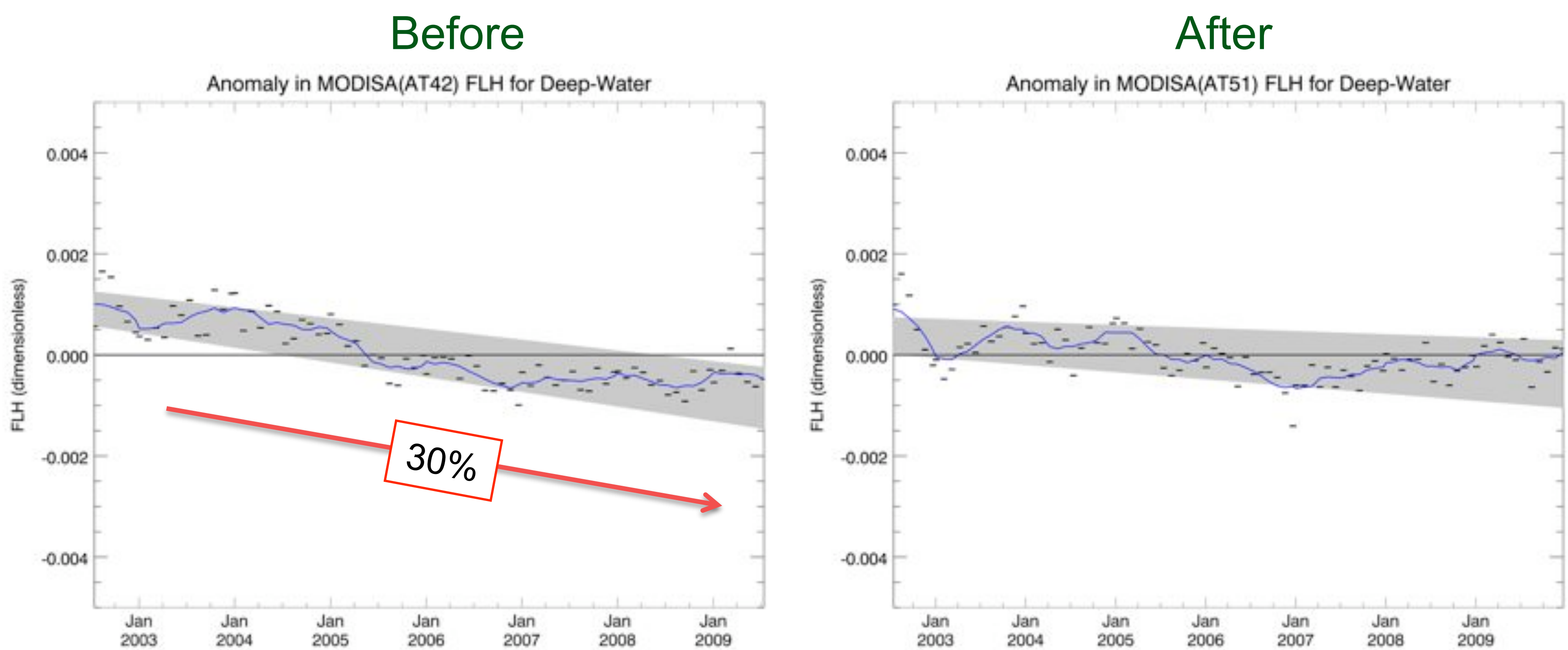
Rrs(678)



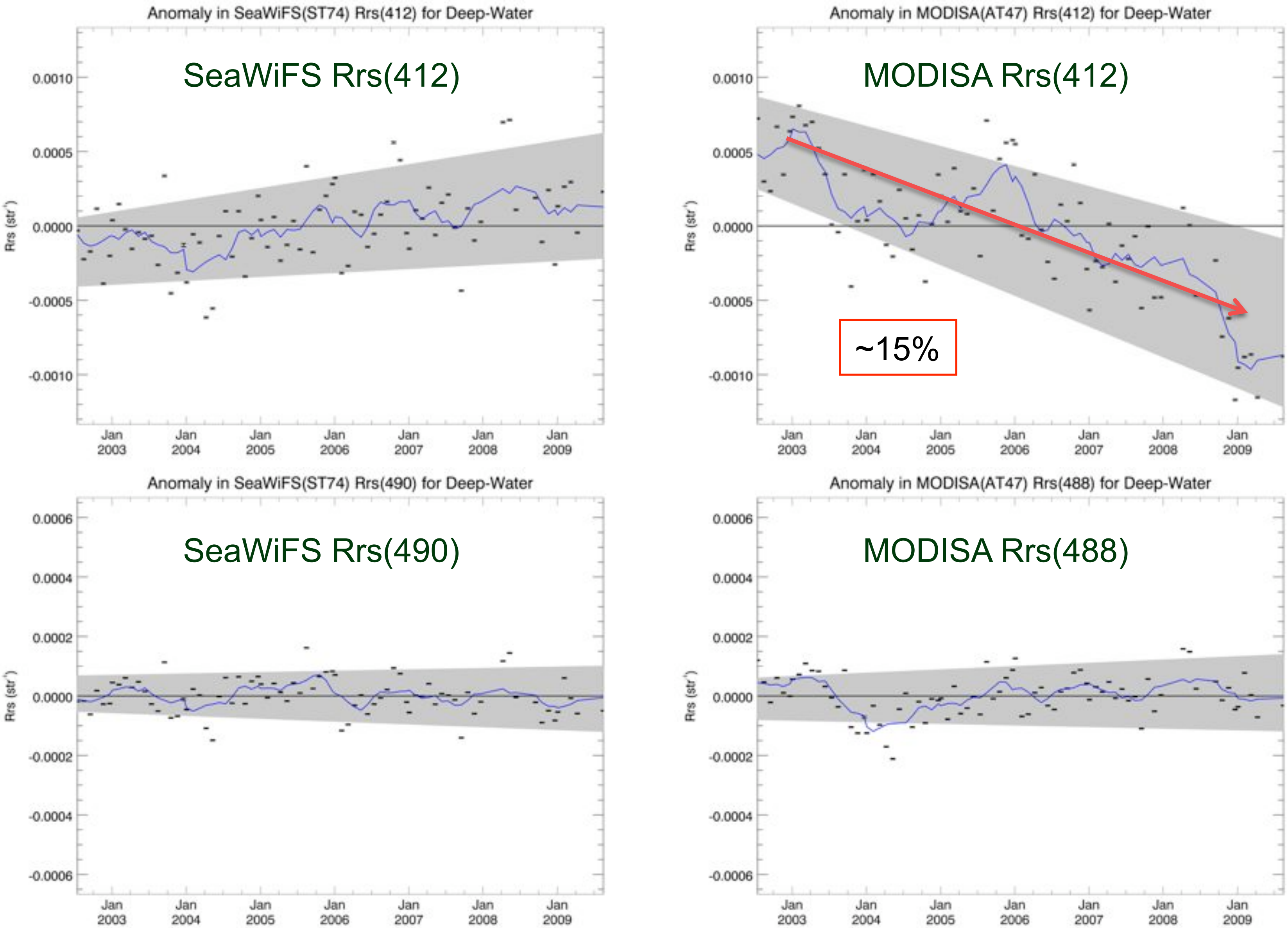


MODISA Chl_a Fluorescence Trends

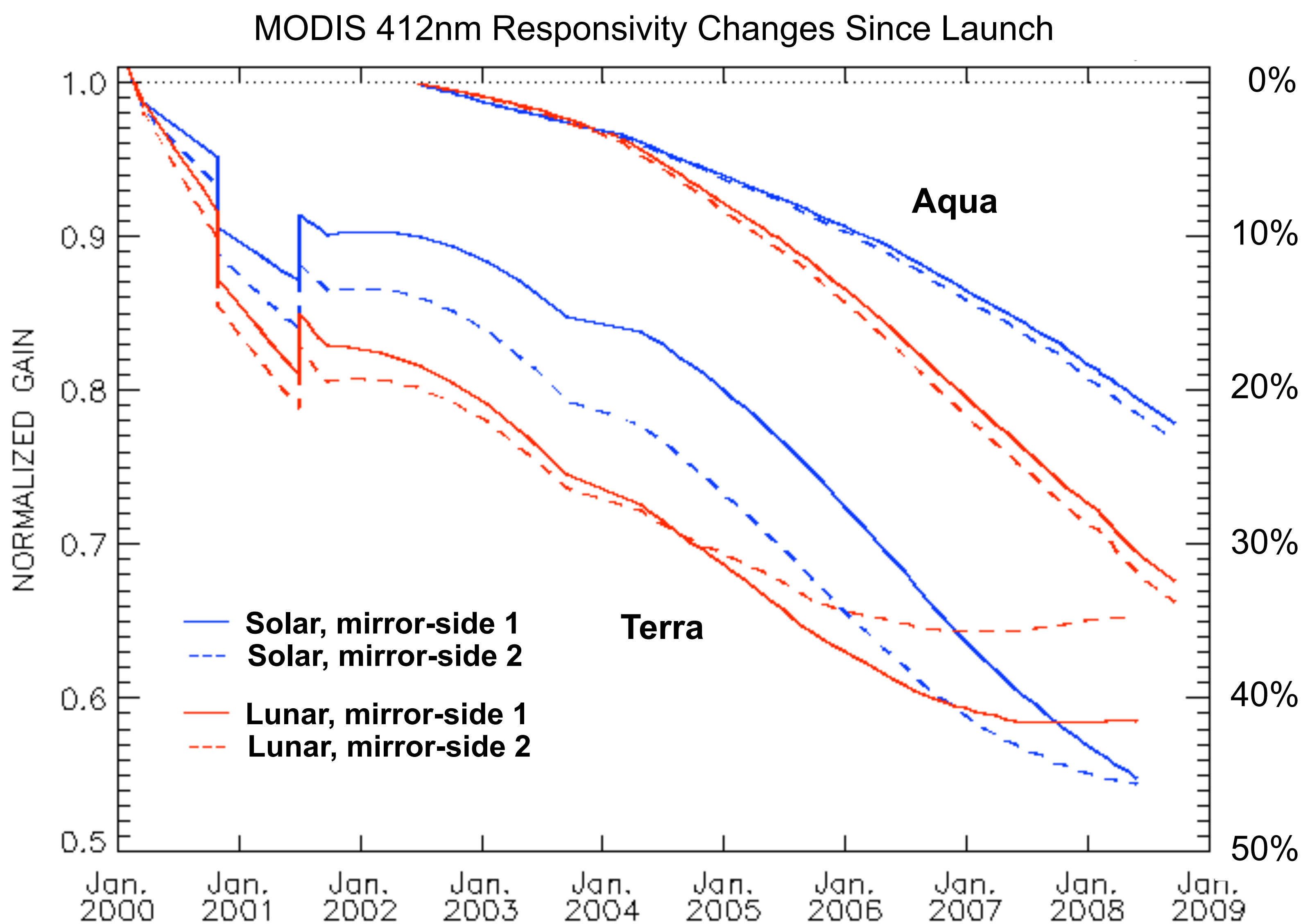
- MODIS fluorescence can provide data on phytoplankton physiology
  - e.g., Behrenfeld et al. 2009
- Past results showed significant (non-physical) trend in clear water
- MCST collection 6 calibration reduces trend fluorescence line height



Anomalous Trends in MODISA "after" C6 Calibration



MODIS Lunar and Solar Calibration Trends

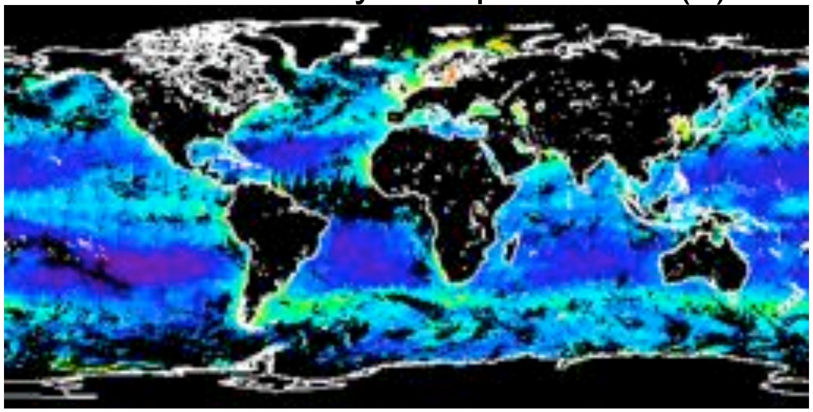


Vicarious Instrument Recharacterization

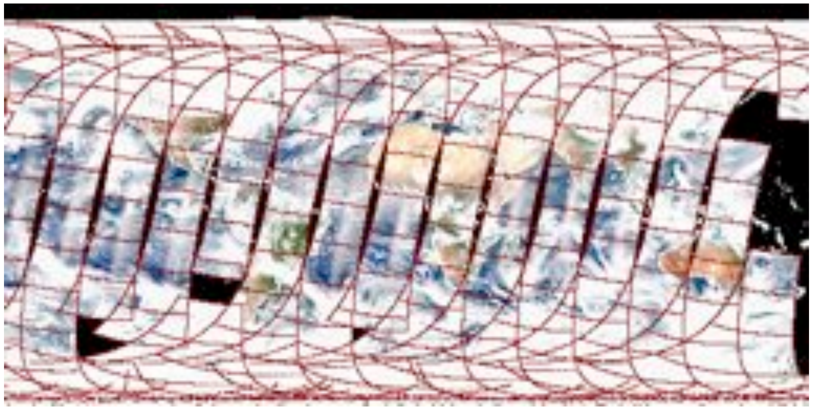
to assess change in RVS shape and polarization sensitivity

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

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:

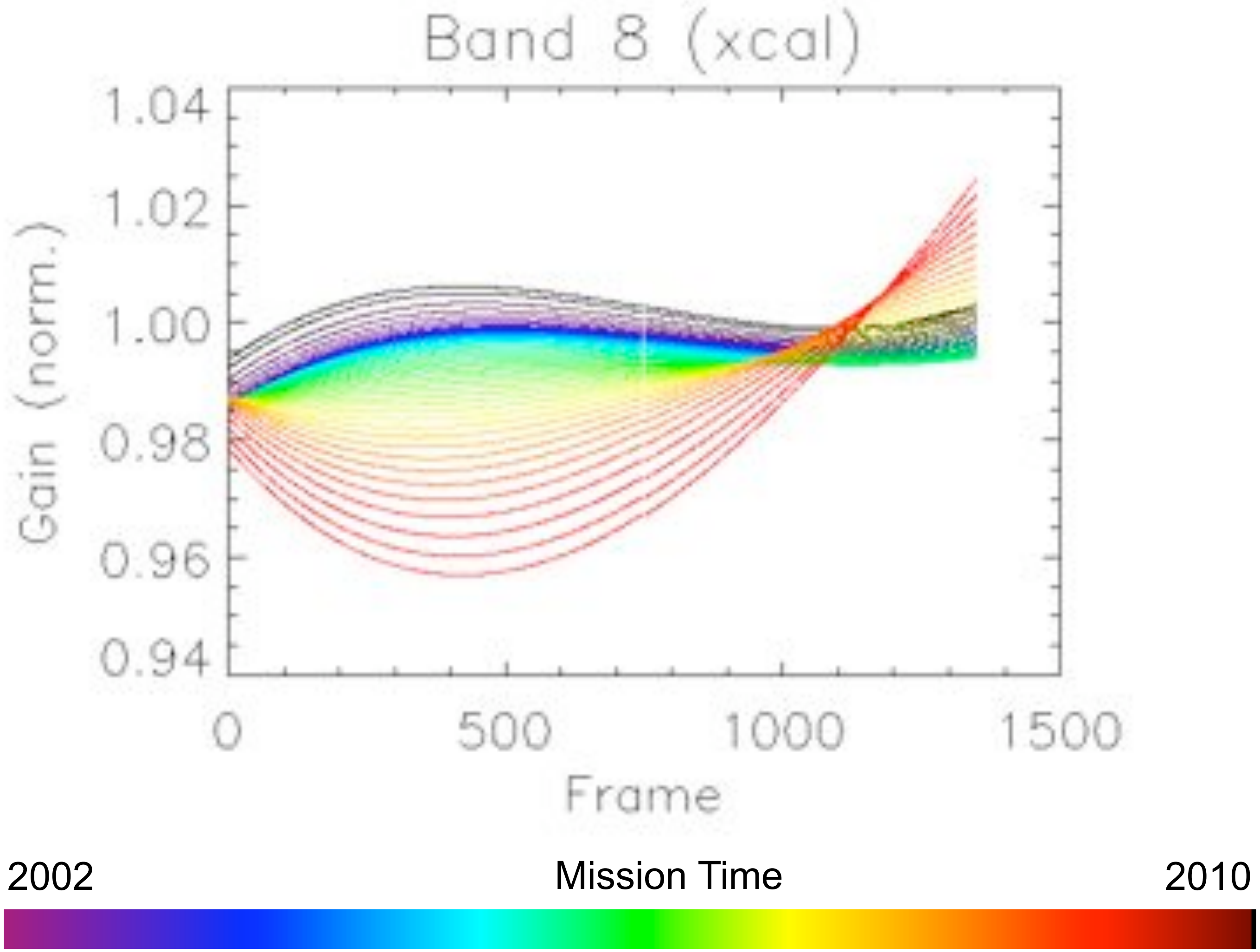
find best fit M_{11}, M_{12}, M_{13} to relate $L_m(\lambda)$ to $L_t(\lambda)$

where M_{xx} = fn(mirror aoi)

per band, detector, and m-side

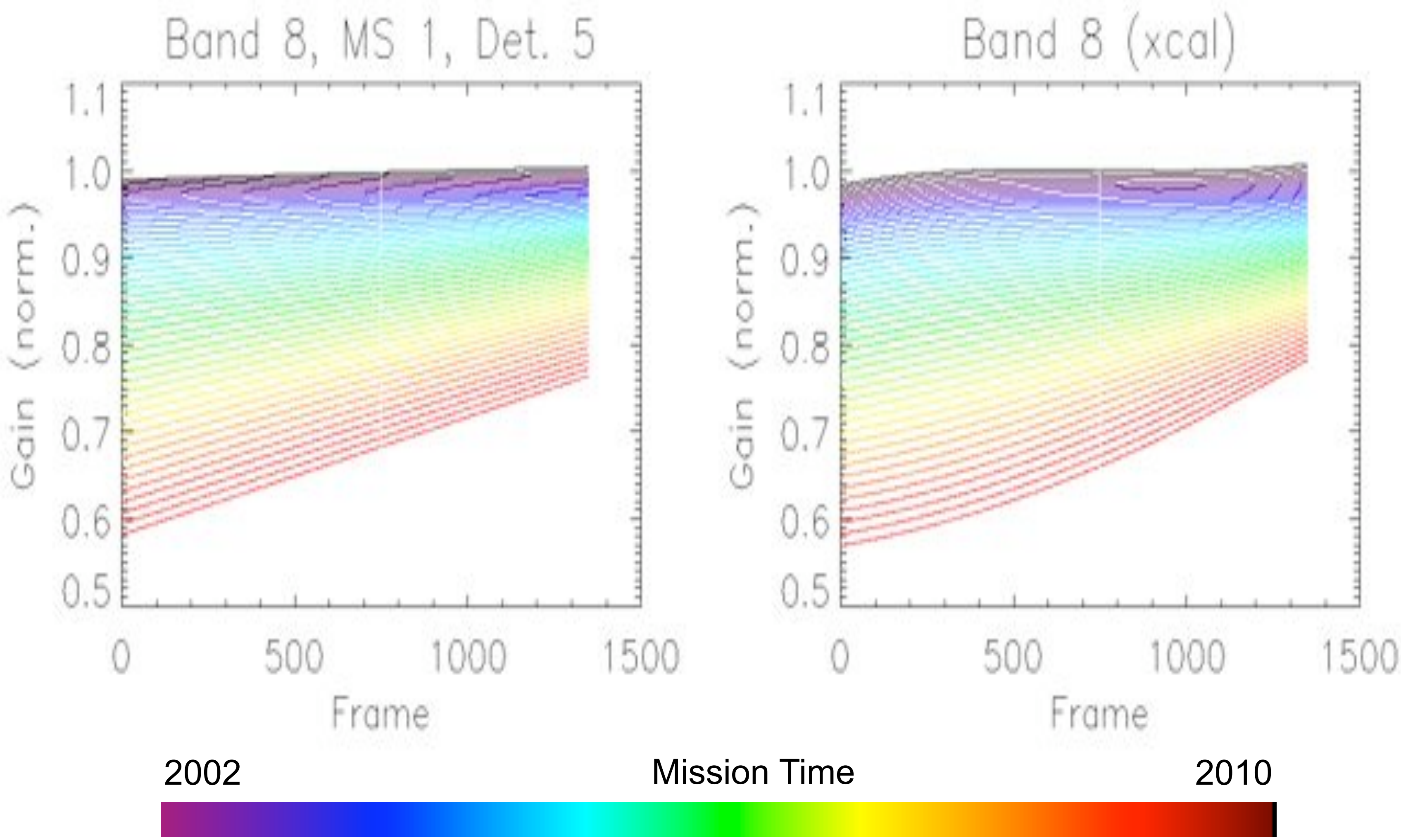
MODISA RVS Shape Change at 412 nm

derived from vicarious recharacterization of instrument model

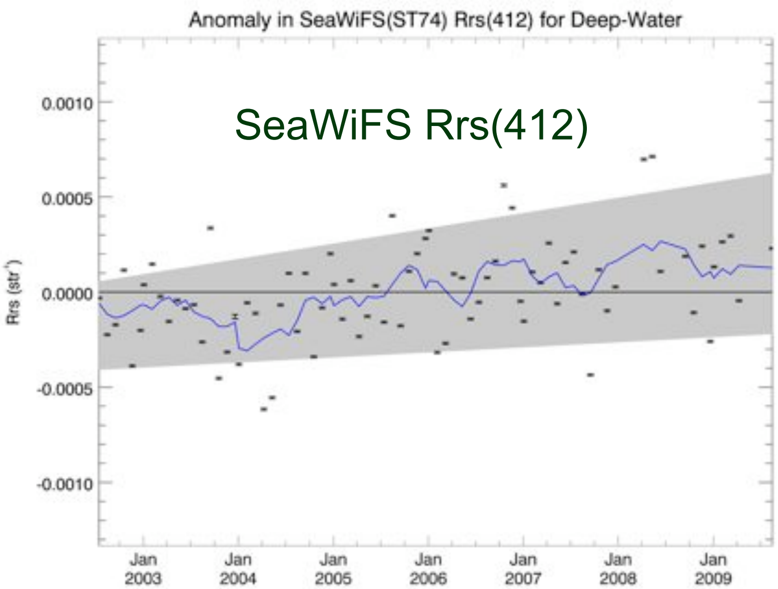


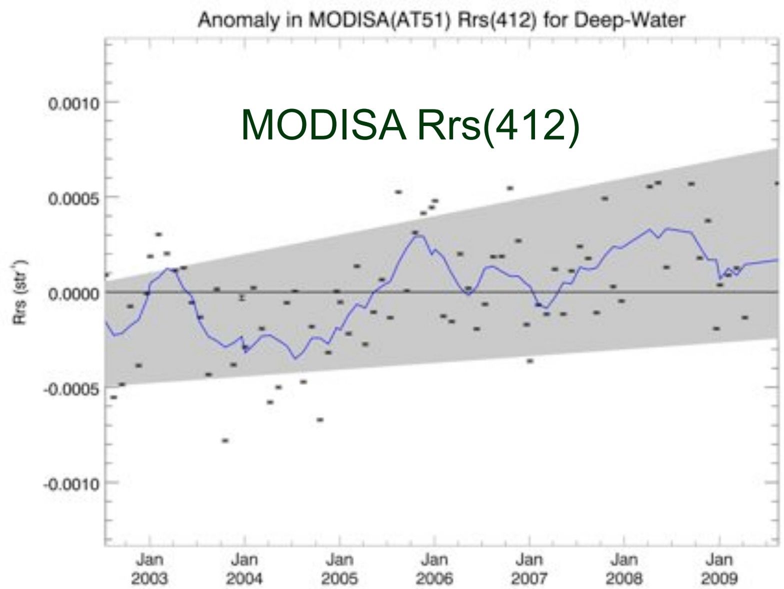
Total RVS Change at 412 nm

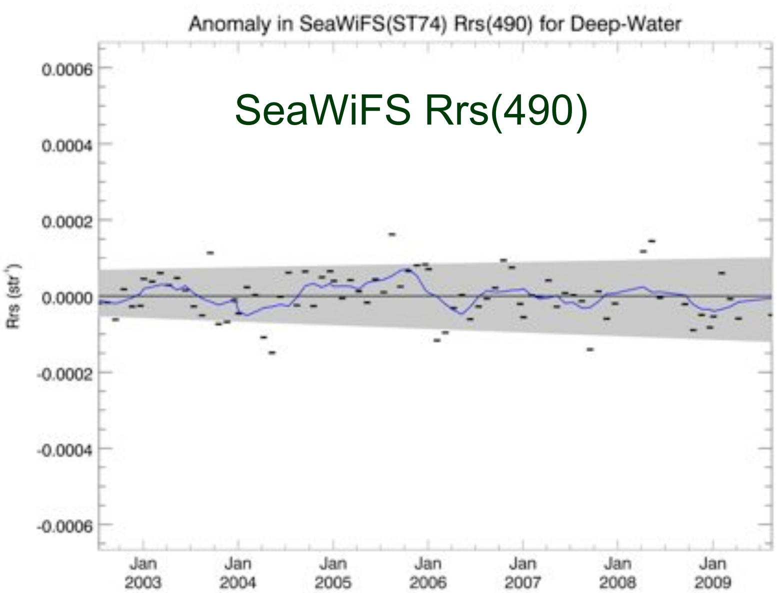
MCST results + OBPG vicarious characterization of shape change

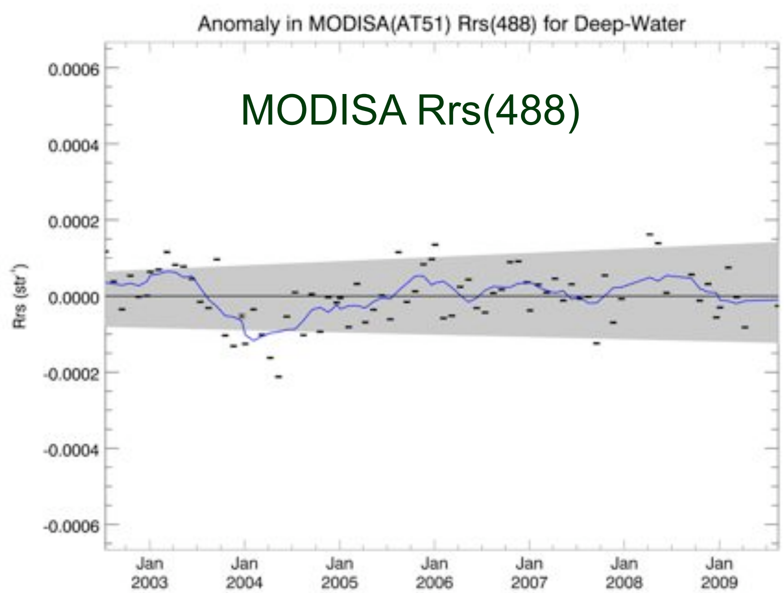


Revised RVS Shape in 412 Removes Trend





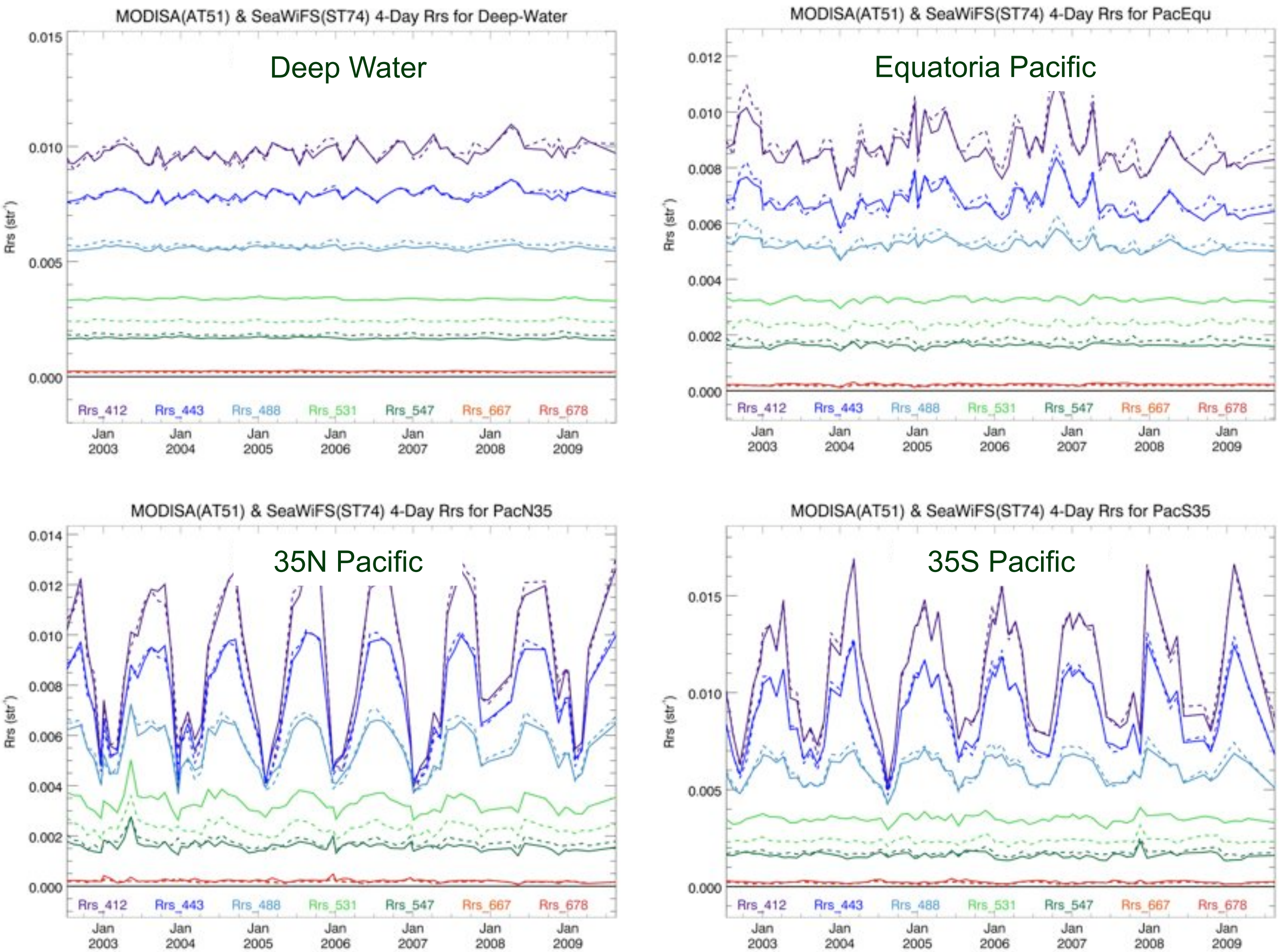




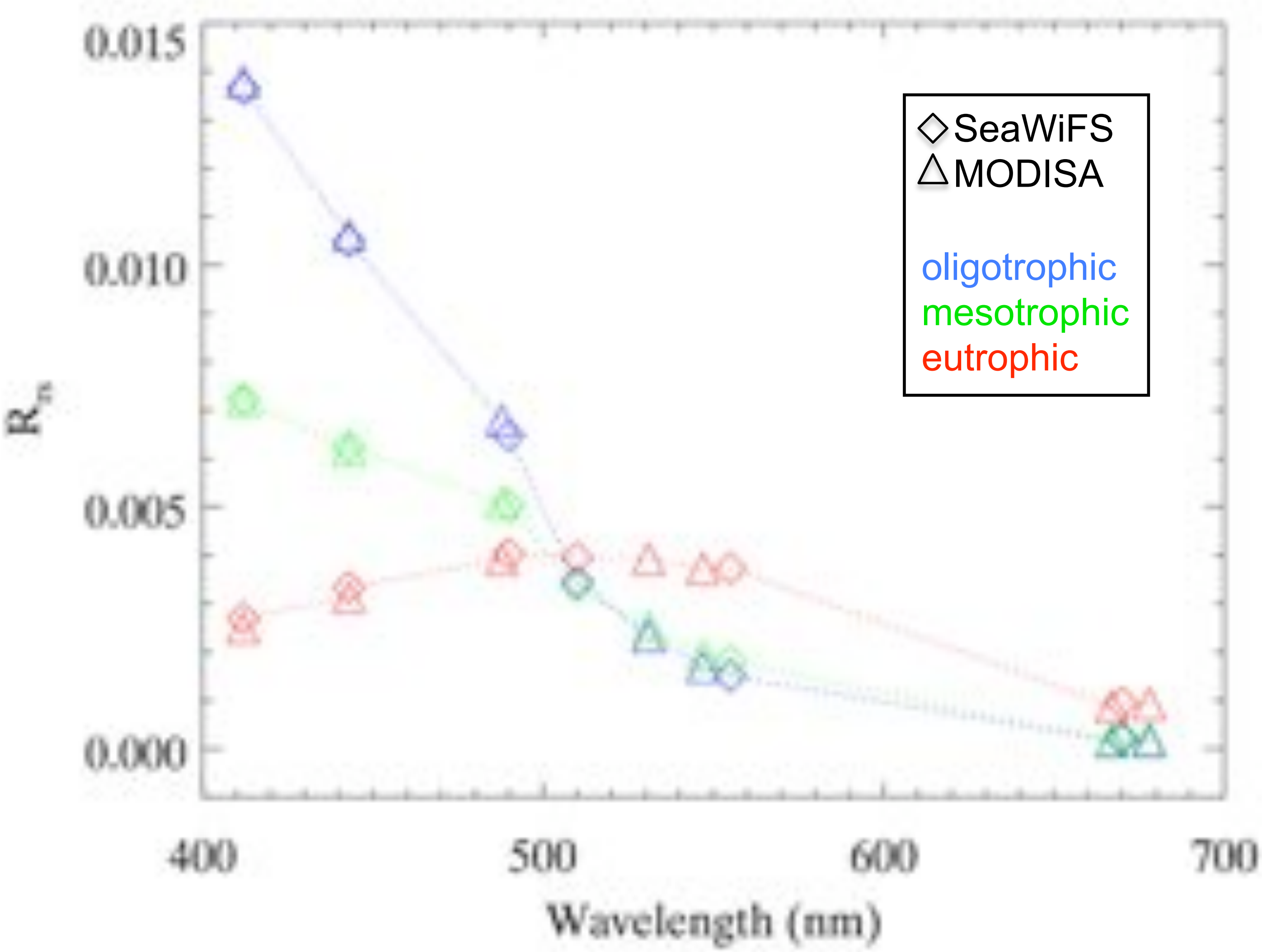
Global Results

Good Agreement in Water-Leaving Reflectance

over duration of SeaWiFS and MODISA mission overlap



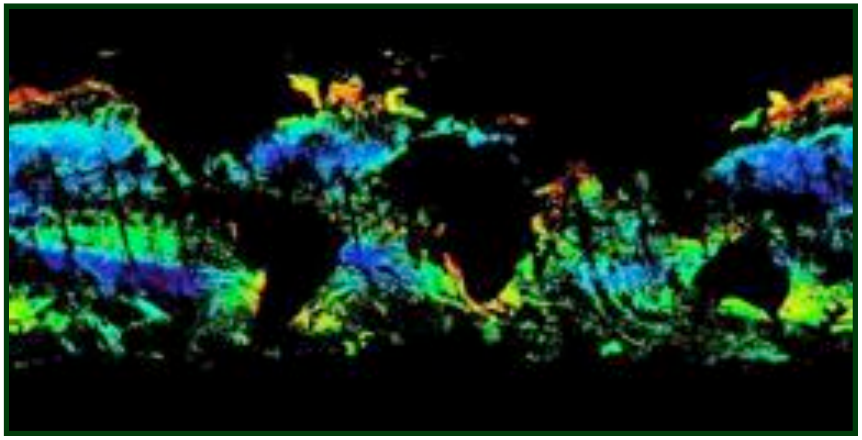
Mean Spectral Differences Agree With Expectations



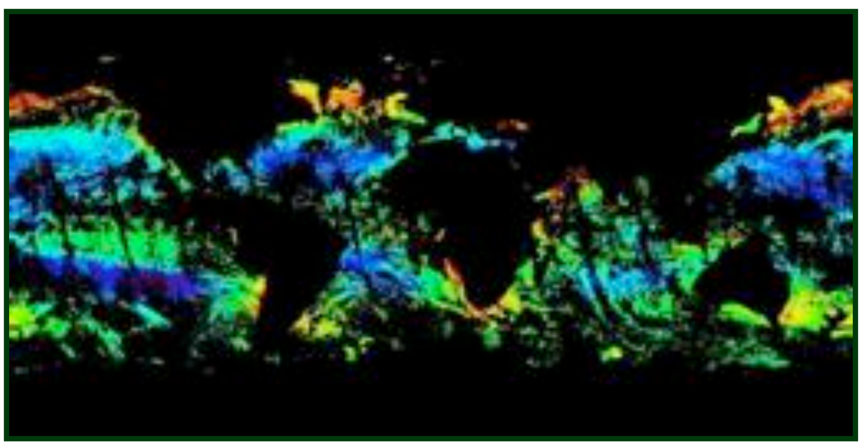
Good Agreement in Derived Chlorphyll

2002 289

SeaWiFS

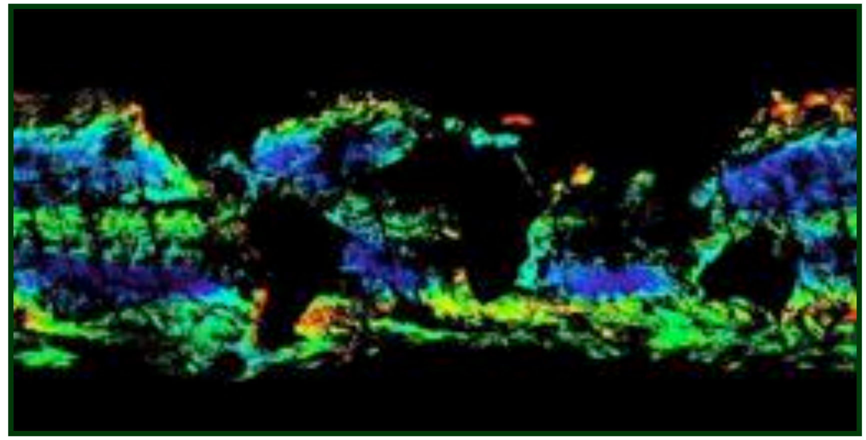


MODISA

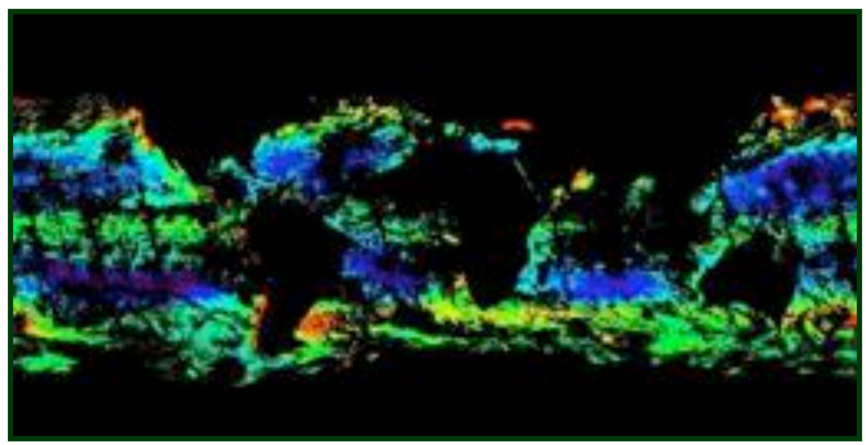


2008 289

SeaWiFS



MODISA

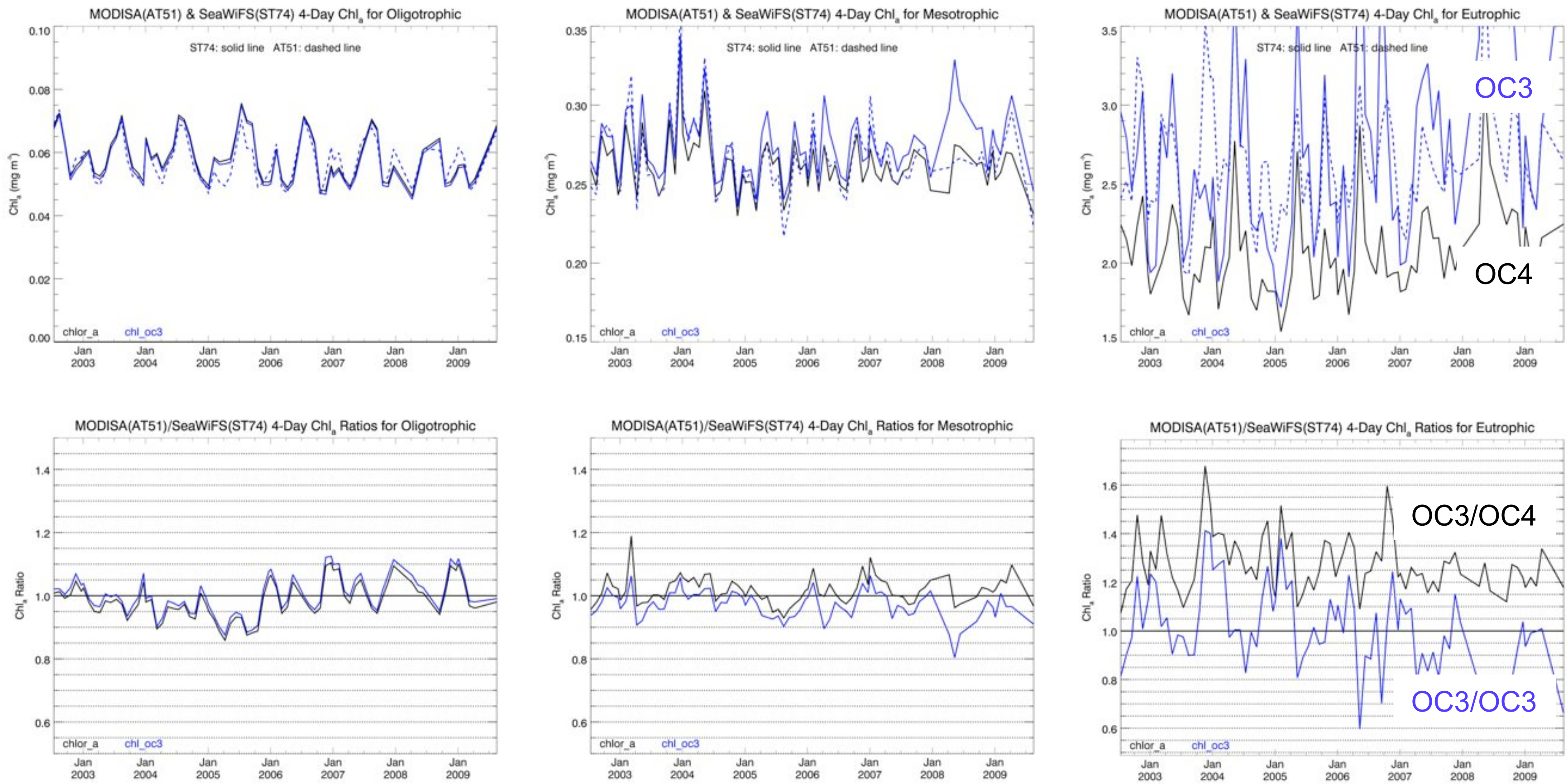


MODISA and SeaWiFS Chl_a Comparison

Oligotrophic | Mesotrophic | Eutrophic

Comparison

Ratio

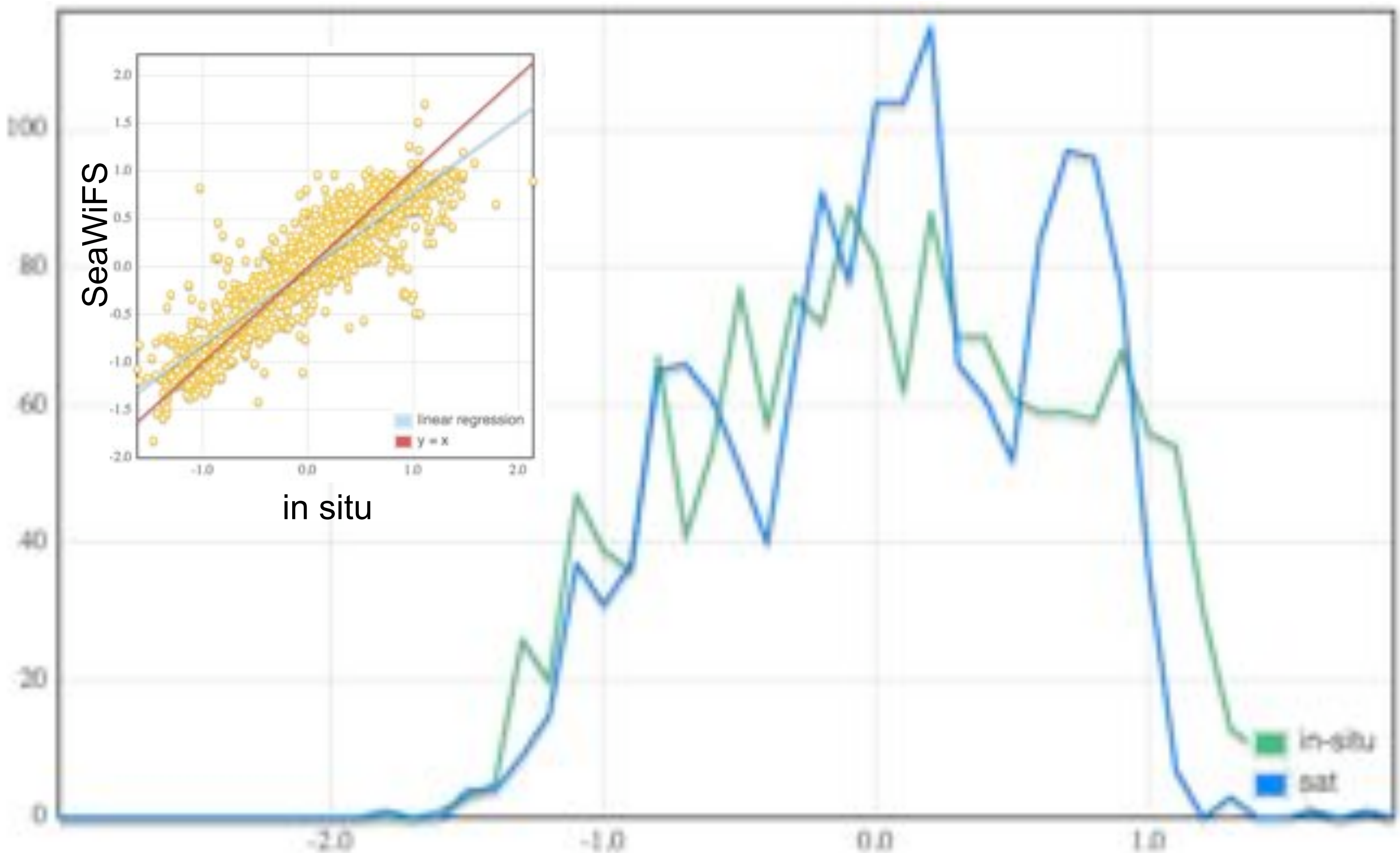


<Ratio>	Std Dev
0.99	0.058
1.00	0.060

<Ratio>	Std Dev
1.02	0.042
0.97	0.045

<Ratio>	Std Dev
1.28	0.12
1.01	0.17

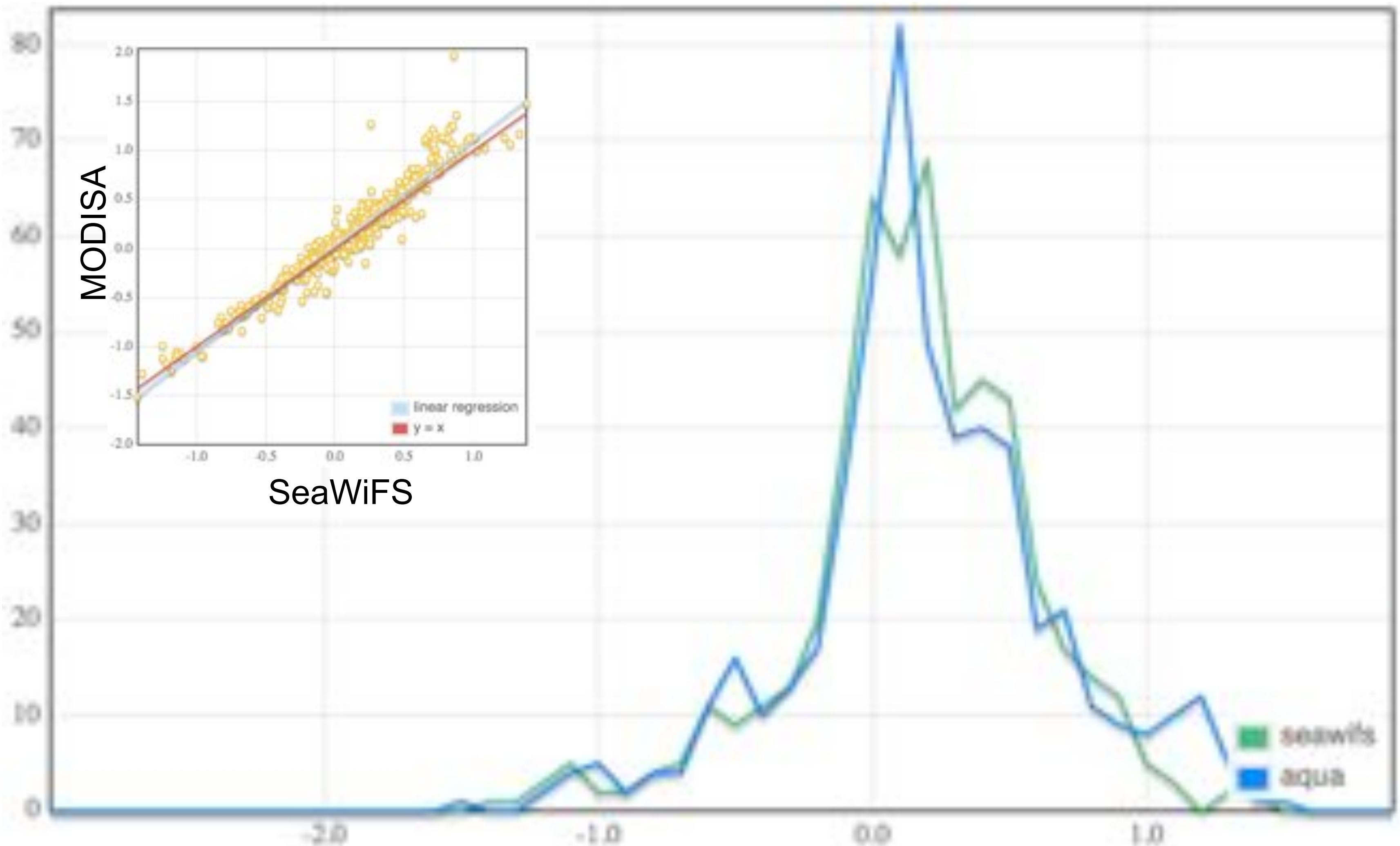
SeaWiFS Chl_a: Good Agreement with Global In situ



In-Situ Range	Sat Range	N	Slope	Intercept	R Squared	Median Ratio	Abs % Difference
(-1.61979, 2.14003)	(-1.81612, 1.70704)	1560	0.79275	-0.0152278	0.81477005	0.98005764	36.67182

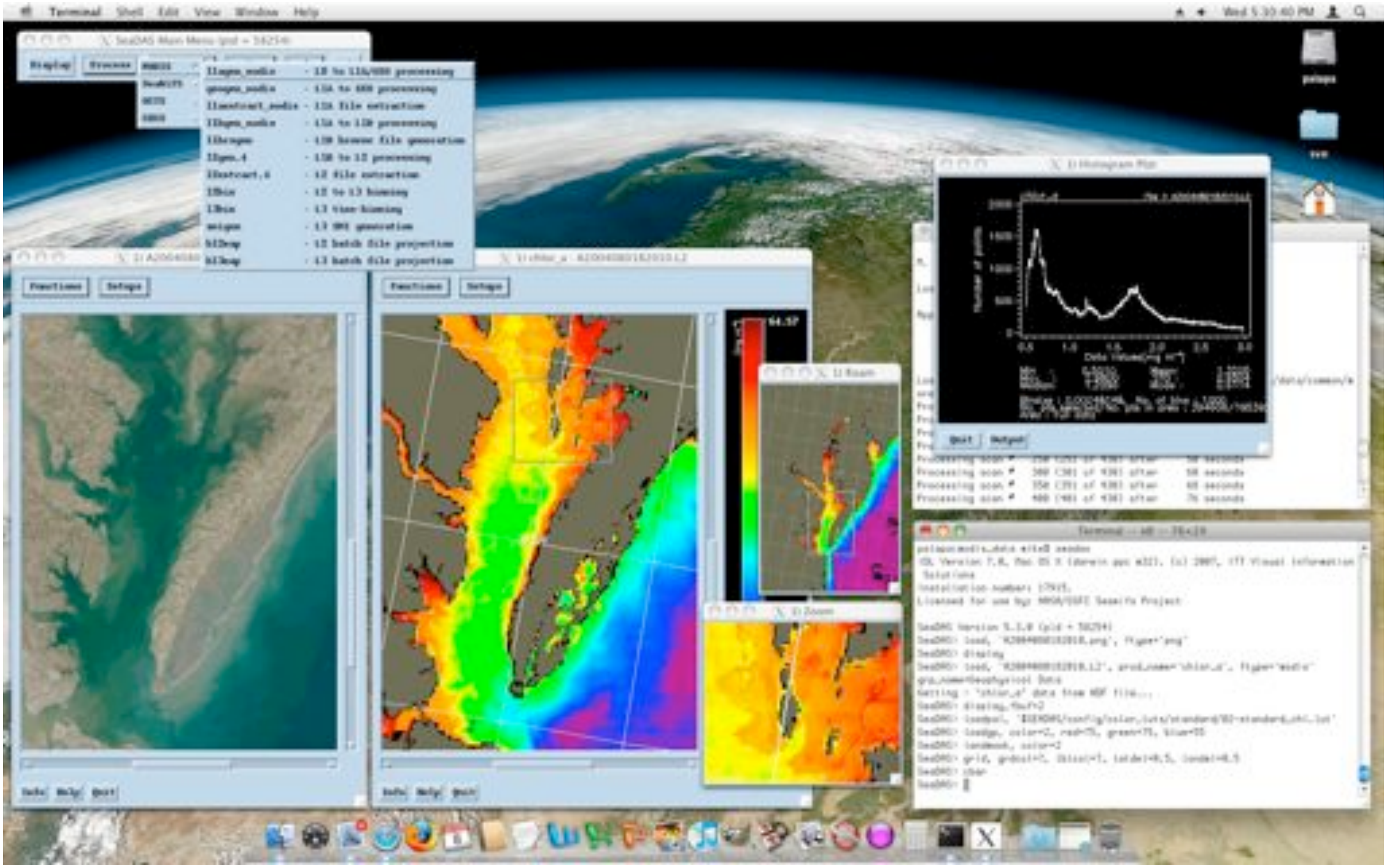
MODISA vs SeaWiFS Chl_a

at common in situ match-up locations



seawifs Range	aqua Range	N	Slope	Intercept	R Squared	Median Ratio	Abs % Difference
(-1.42248, 1.38101)	(-1.51267, 1.96563)	526	1.07836	0.0247077	0.92288022	1.0608265	13.805507

Reprocessing Algorithms in Latest SeaDAS



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

next steps: MODIST

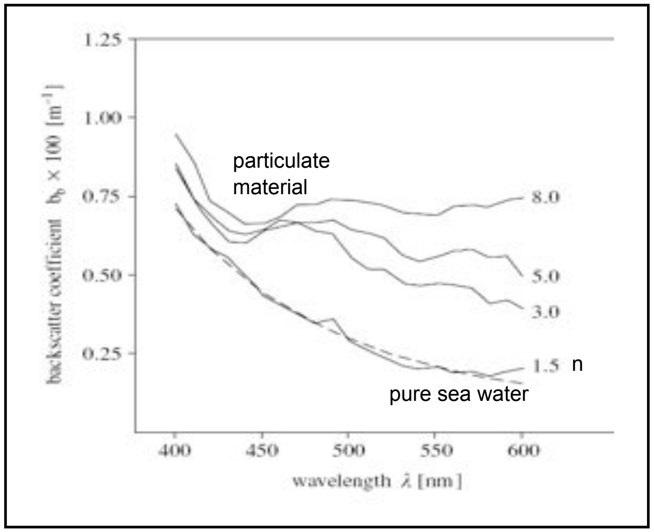
- Well documented issues with radiometric stability:
  - Franz, B.A., E.J. Kwiatkowska, G. Meister, and C. McClain (2008). Moderate Resolution Imaging Spectroradiometer on Terra: limitations for ocean color applications, J. Appl. Rem. Sens., 2, 023525.
- Vicarious on-orbit recharacterization of RVS and polarization:
  - Kwiatkowska, E.J., B.A. Franz, G. Meister, C. McClain, and X. Xiong (2008). Cross-calibration of ocean-color bands from Moderate Resolution Imaging Spectroradiometer on Terra platform, Appl. Opt., 47 (36).
- Analysis to be repeated and results fully implemented once SeaWiFS and MODISA reprocessing is completed.

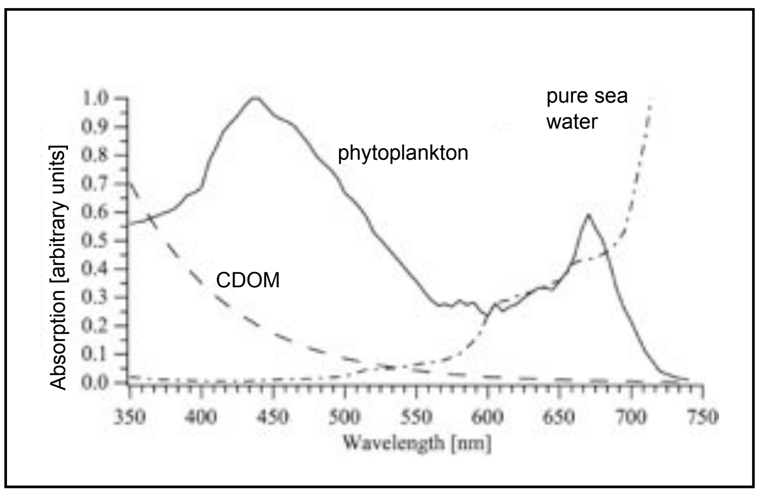
next steps: OCTS, CZCS

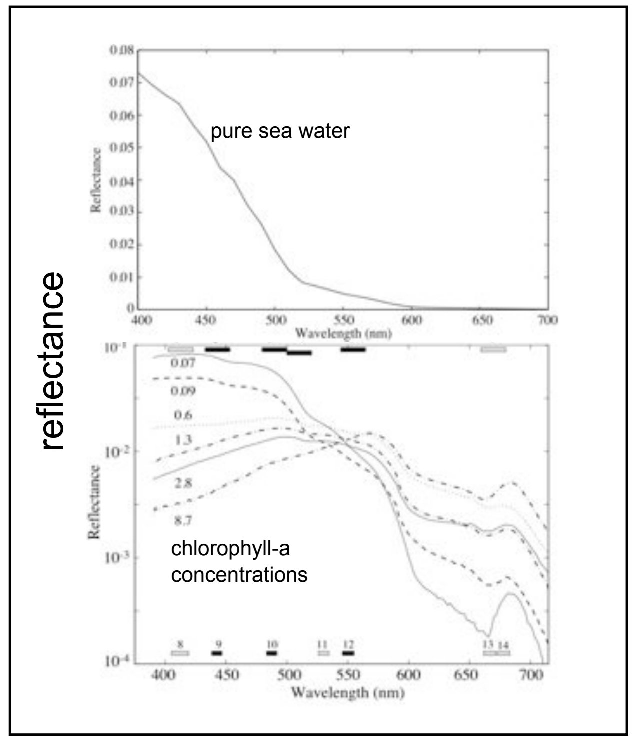
- Algorithms will be updated for consistency with SeaWiFS and MODIS, and missions will be reprocessed.

next steps: Inherent Optical Properties

$$R_{rs} \approx func\left(\frac{b_b}{a+b_b}\right)$$







next steps: Inherent Optical Properties

- OBPG hosted an international workshop in October 2008 (Barga, Italy), with excellent participation from the IOP modeling community.
- Existing algorithm approaches were reviewed, and a combined algorithm was defined as a way forward.
- Production software implementation is complete, and global mission testing and evaluation is now underway.
- Plan is to produce a second suite of IOP-based products for all sensors, to include total and component absorption and backscattering, and IOP-based derived products such as euphotic depth and spectral diffuse attenuation.
- See talk by Werdell in ocean breakout.

Summary

- AERONET-based aerosol models: improved agreement between satellite and in situ aerosol optical properties.
- Revised turbid-water atmospheric correction: improved agreement between satellite and in situ Chl_a in high-scattering waters.
- Updated SeaWiFS and MODISA calibrations: improved temporal stability in Rrs trends, MODISA fluorescence trend.
- Remaining issues with MODISA temporal drift in blue bands corrected through vicarious characterization of RVS shape changes.
- Consistency of algorithms and calibrations: much improved agreement between MODISA and SeaWIFS ocean color retrievals.
- Long-standing mission-to-mission differences in oligotrophic chlorophyll resolved: mean differences reduced from 15-20% to 1-2%.

http://oceancolor.gsfc.nasa.gov/REPROCESSING/R2009/


Thank You
http://oceancolor.gsfc.nasa.gov/REPROCESSING/R2009/