The Marine Optical BuoY (MOBY): the Primary Vicarious Calibration Reference Standard for Climate Quality Ocean Color Time Series

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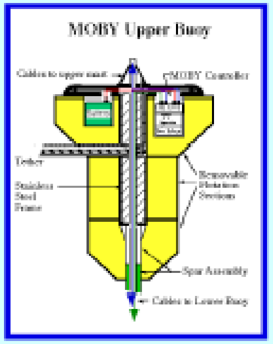
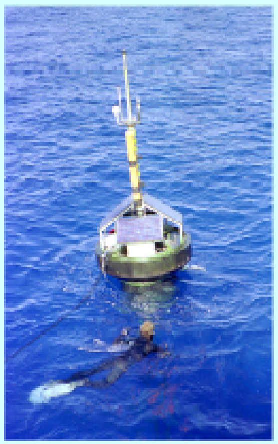
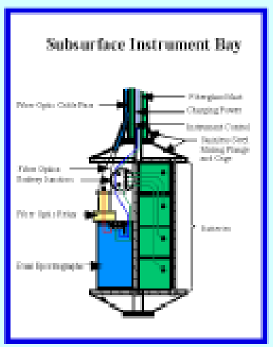
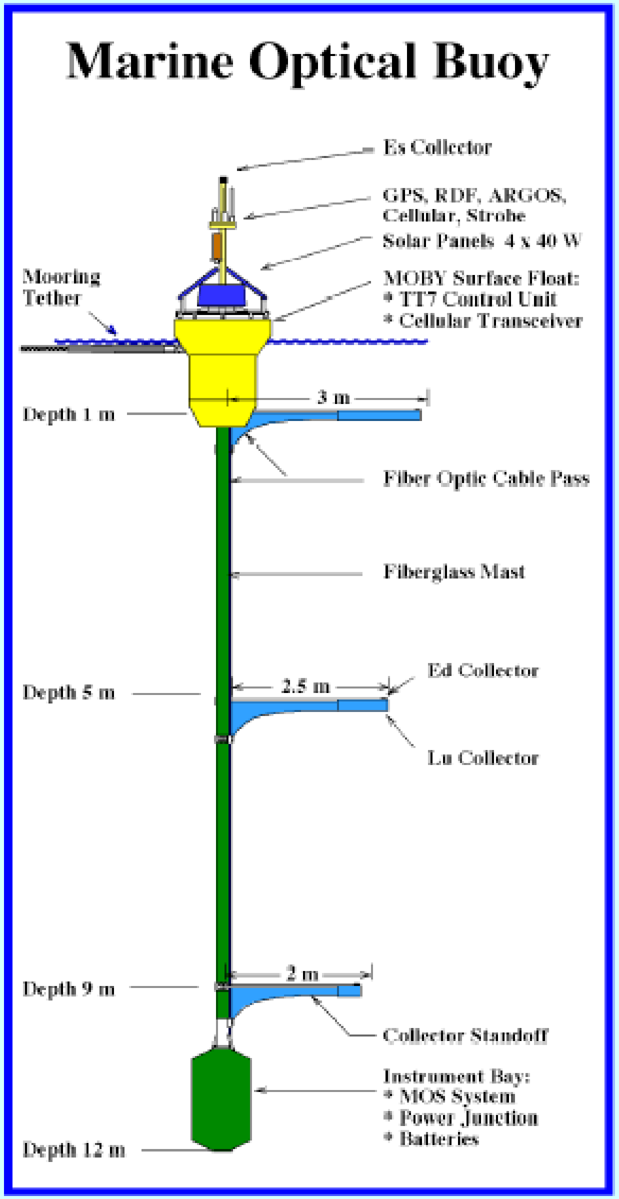
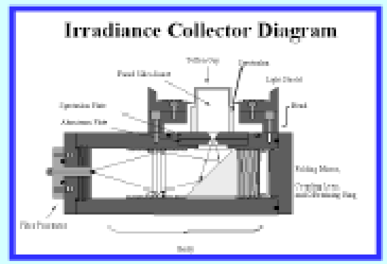
MOBY System



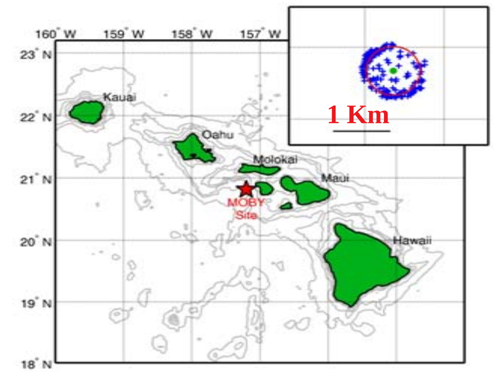




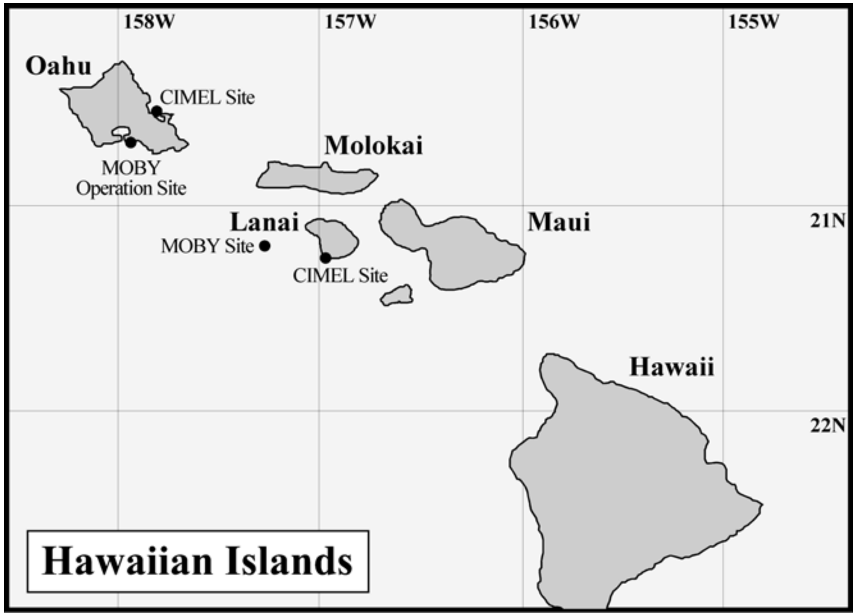


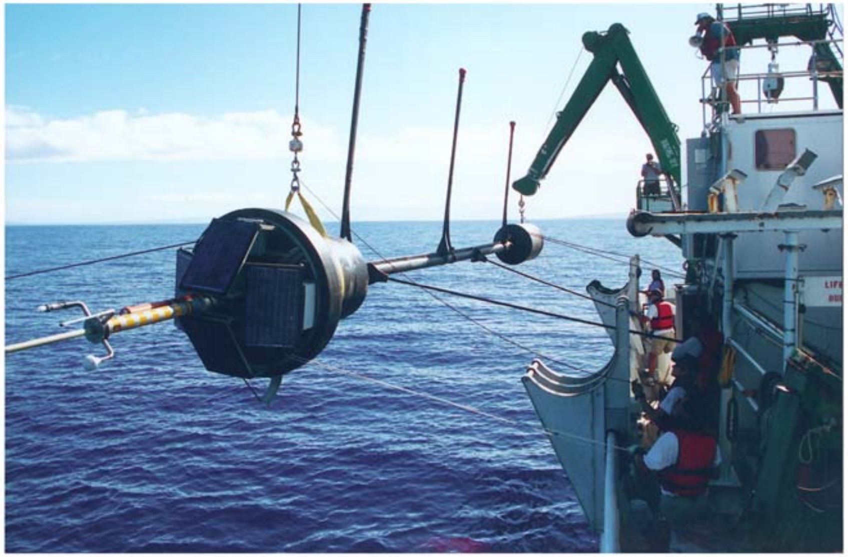


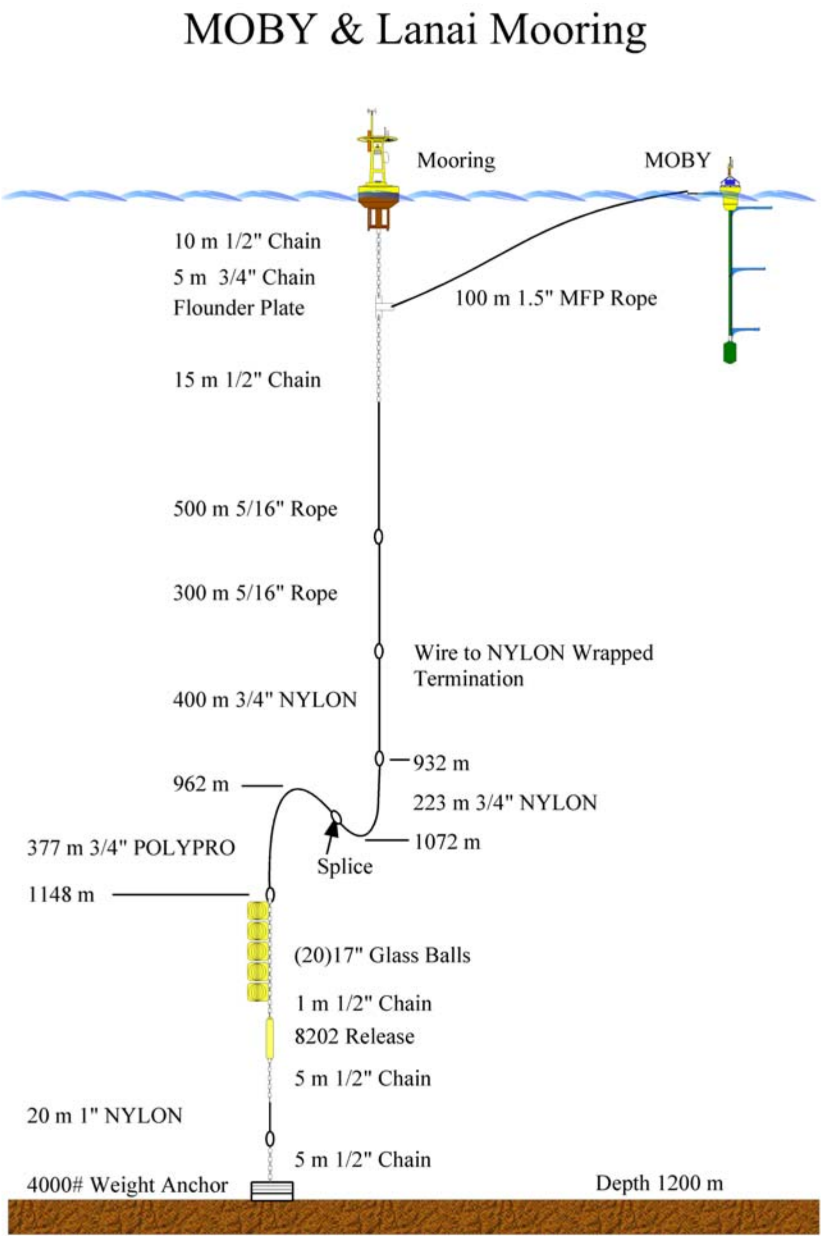
Watch Circle



MOBY Mooring Site







MOBY Operations Site - Univ. Hawaii

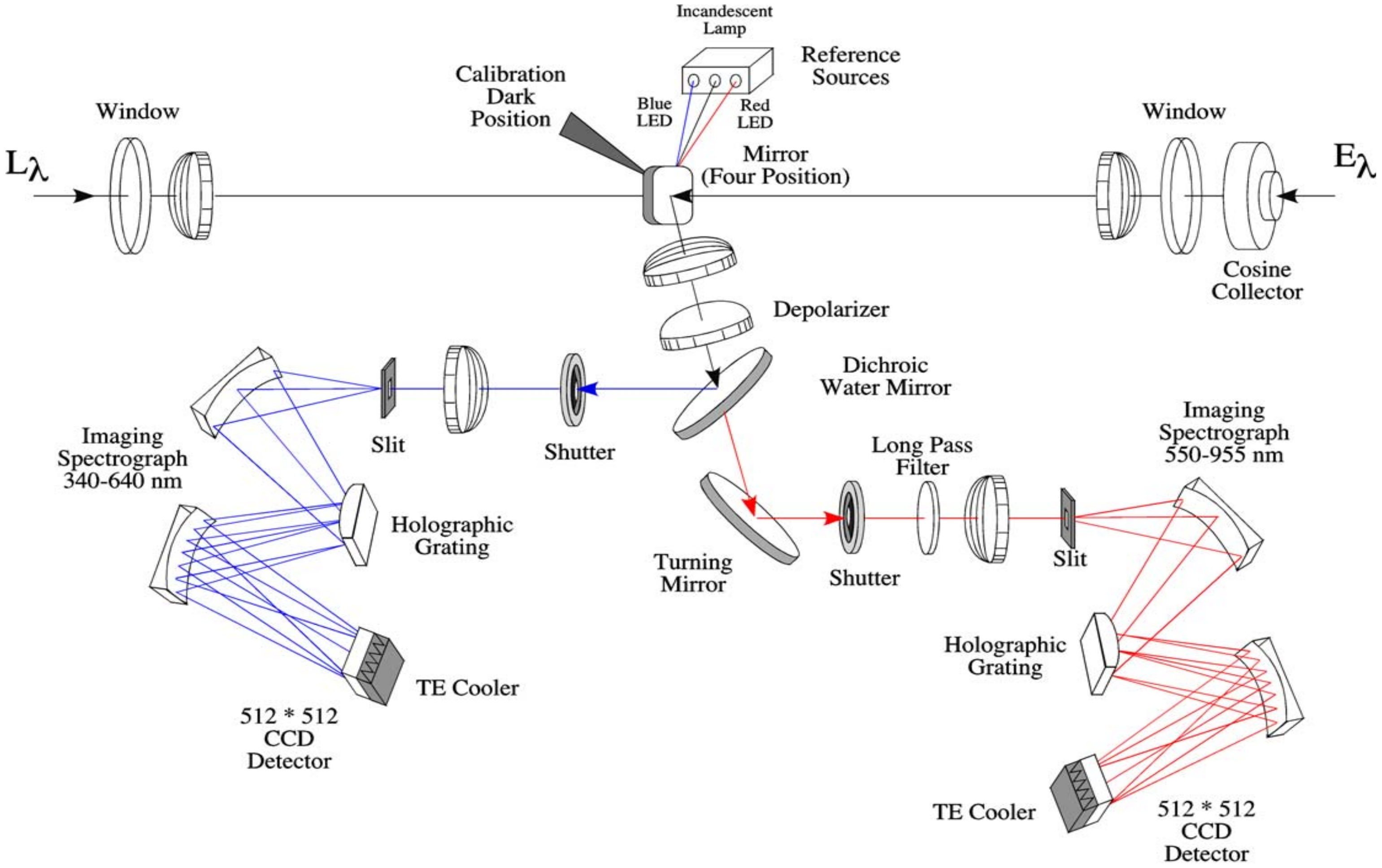
Two buoys actively used

- **1 in the water**
- **1 being refurbished and calibrated**

Deployment ~ 3 months

- **Monthly diver cals**

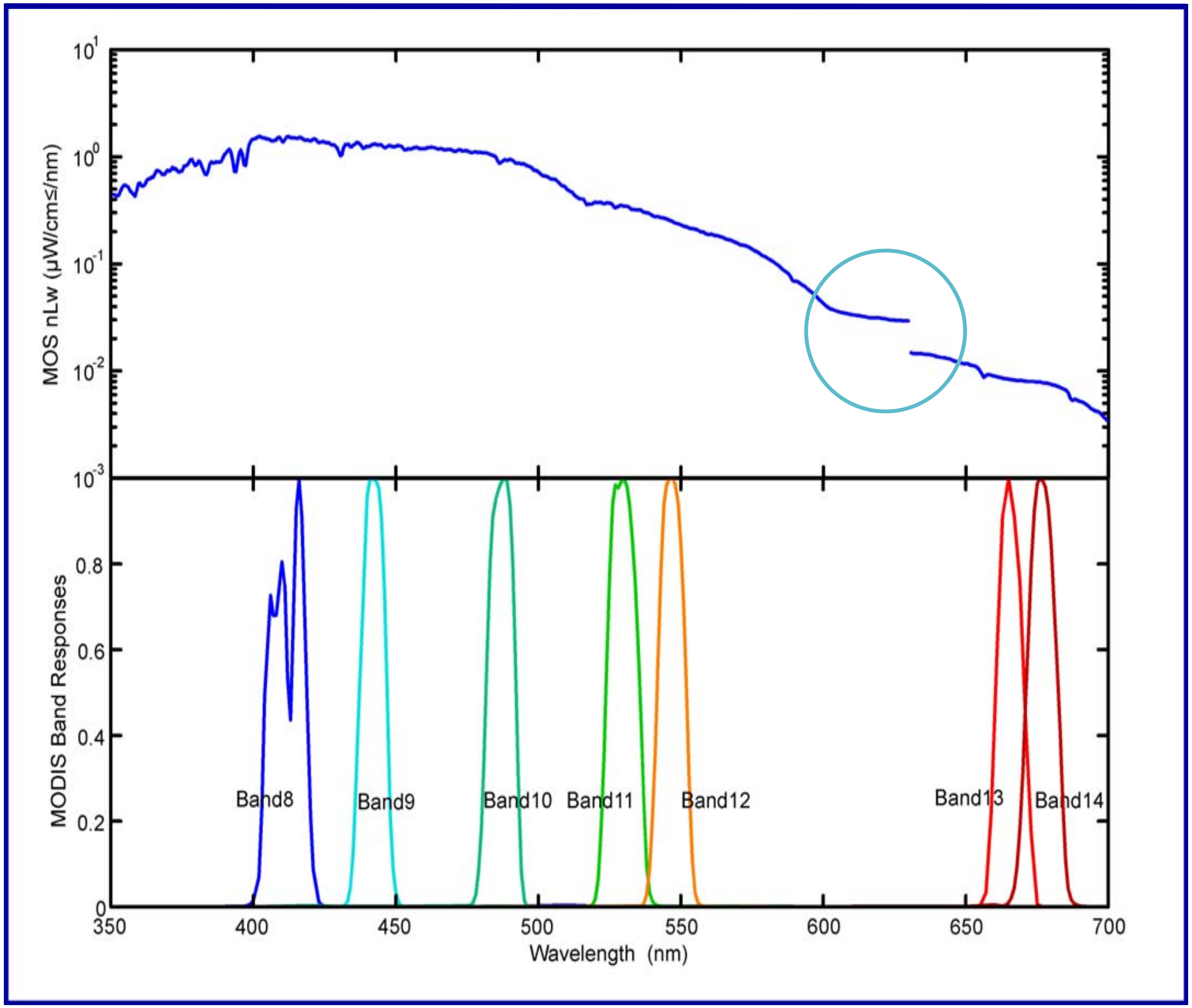
Marine Optical System



P-P spacing	**0.6 nm**	**0.8 nm**
Resolution	**0.5 nm**	**0.8 nm**
spectral coverage	**360 nm - 640 nm**	**560 nm – 940 nm**

Spectral Band Pass Matching

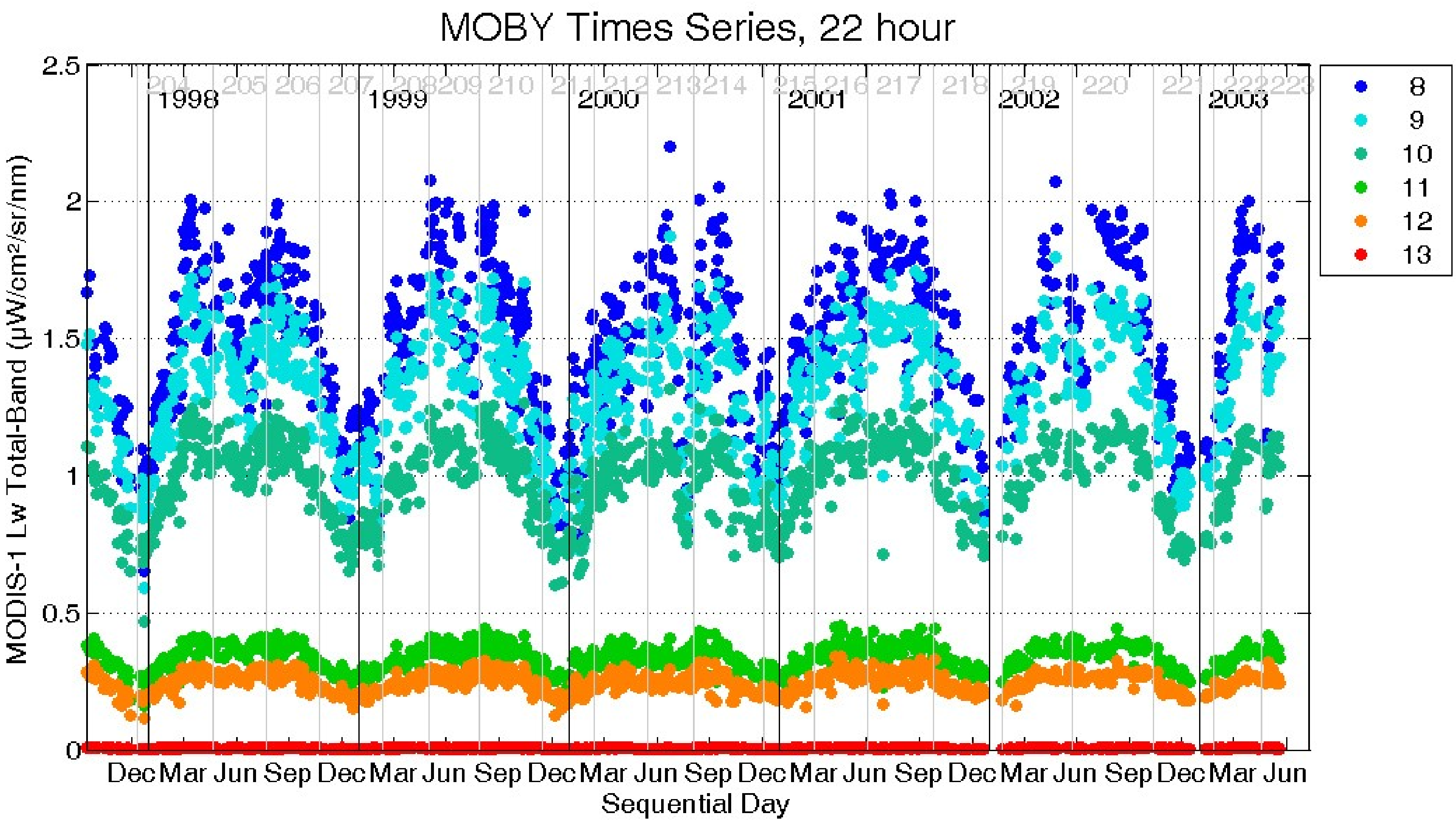
High Resolution Spectra Convolved with Sensor's Spectral Band Pass



Flexibility to be used to calibrate different satellite sensors – with differing sensor channels

Time Series of MODIS ocean color bands

Uncertainty ~ 5%



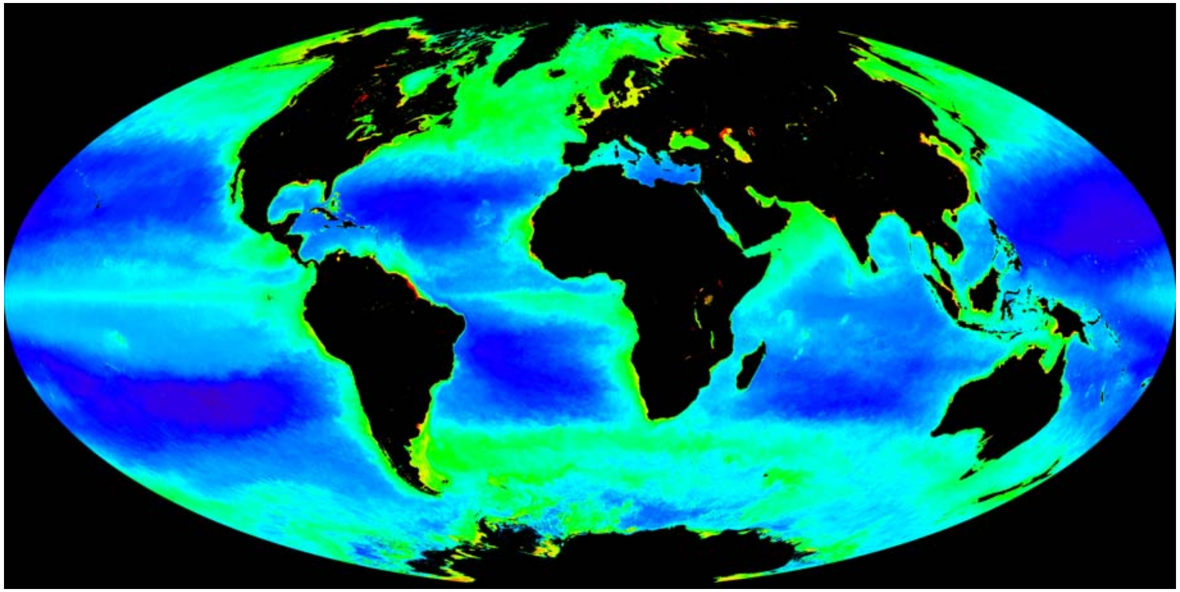
Ocean Color Sensors Supported by MOBY

- Japan - OCTS
- French - POLDER
- US - SeaWiFS
- US - MODIS (Terra and Aqua)
- US - MISR (Terra)
- Europe - MERIS
- Japan- GLI

Six Year + Time-Series 7/20/97 to Present

MODIS Chlorophyll

Yearly Avg 2001



✓ MOBY provides a common link between the present and the future
✓ Traceability to international radiometric standards (SI) critical

NOAA/MOBY Collaboration with NIST established with support from NASA (SeaWiFS)

- Establish rigorous measurement protocols ensuring direct traceability to primary national radiometric standards
- Establish radiometric uncertainty budget conforming with international recommendations
- NIST to work with MOBY team to reduce uncertainty components where feasible
  - Pre/Post Cal. System monitoring with NIST Cal. Radiometers
  - Annual On Site Calibration Systems Check by NIST

Radiometric calibration uncertainties of 4 % to 8 % (6 % > 400 nm)

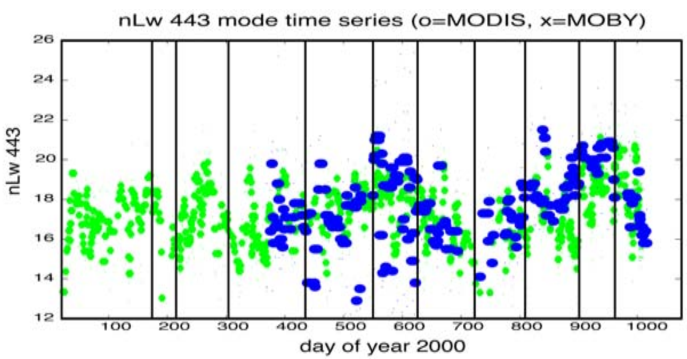
Ref & check Bob Barnes SPIE

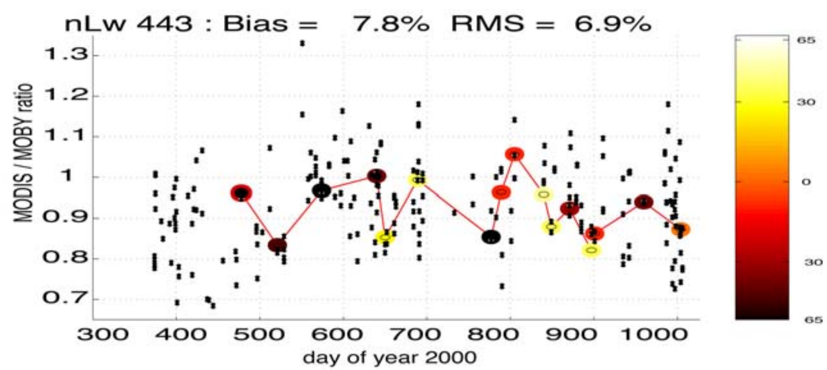
Terra-Aqua MODIS - MOBY Time Series
nL_w443 Modal & Match up

Modal Plots
of MODIS and MOBY L_w *vs* time
used to compute time corrections

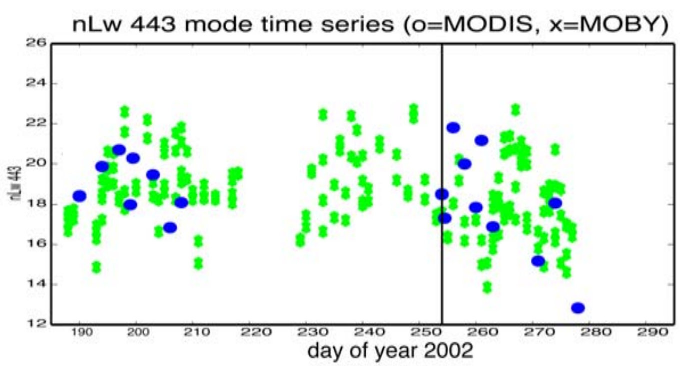
MODIS/MOBY point matchups,
used to compute bias corrections

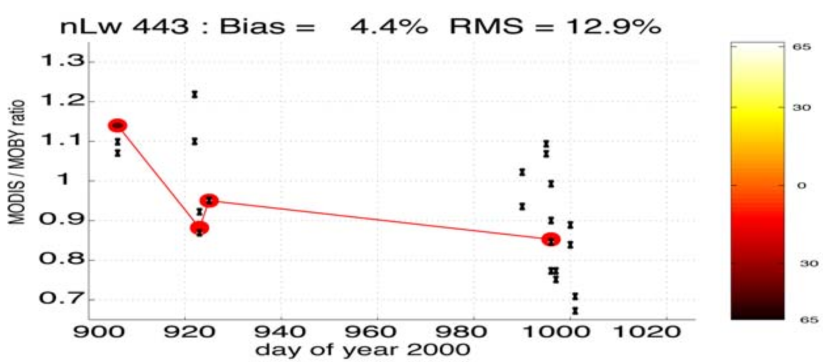
Terra





Aqua





Bob Evans, Univ. of Miami

Match up Statistics

MODIS - MOBY residuals by wavelength

Wave-length	Terra		Aqua	
	Bias	Std. Dev.	Bias	Std. Dev.
412	0.915	0.115	0.974	0.199
443	0.922	0.069	0.956	0.129
488	0.948	0.051	0.973	0.092
531	0.927	0.103	1.033	0.093
551	0.921	0.105	1.023	0.101

Final bias adjustment in progress for Version 4 L1b

SeaWiFS and Terra - MODIS

- **Comparison of SeaWiFS and Terra-MODIS water leaving radiances and analysis of Terra-MODIS and MOBY mooring in situ observations show differences in the retrieved water leaving radiances are less than 5% near the MOBY site.**
  - **Ocean color measurement systems and methodologies working well.**
  - **MOBY uncertainties may be impacting the combined uncertainty of the vicarious calibration; need to look at the MOBY uncertainty budget**
- **Comparison of SeaWiFS and Terra-MODIS show differences in the retrieved water leaving radiances in the southern hemisphere as large as 20 % to 30 %.**
  - **This difference in water leaving radiance translates to a 2-3% error in total top of the atmosphere radiance measured by the sensor. This discrepancy is by far the largest unresolved factor remaining in the MODIS calibration effort.**
  - The limited time and space distribution of in-situ matchups with MOBY used to evaluate the corrections and calibration of ocean color satellite sensors may not adequately capture seasonal and regional bias on a larger scales.

MOBY Uncertainties

- MOBY Calibration Workshop Nov 2003 to address uncertainties in measured water-leaving radiance
  - Radiometric components
    - Calibration sources
    - Transfer uncertainty; scale maintenance
    - MOBY radiometric stability during deployment
    - Systematic effects
      - Temperature
      - Stray light
  - Environmental components
    - e.g. instrument self-shading (Jim Mueller)

  - Finalizing the uncertainty budget, preparing for a full re-processing
    - Reprocessing Timeline: ~2-3 months

Match-up Statistics

- Match up statistics suggest MODIS instruments are working well
- While MODIS uncertainties are a significant part of the combined uncertainty, MOBY uncertainties starting to impact the combined uncertainty in MODIS vicarious calibration

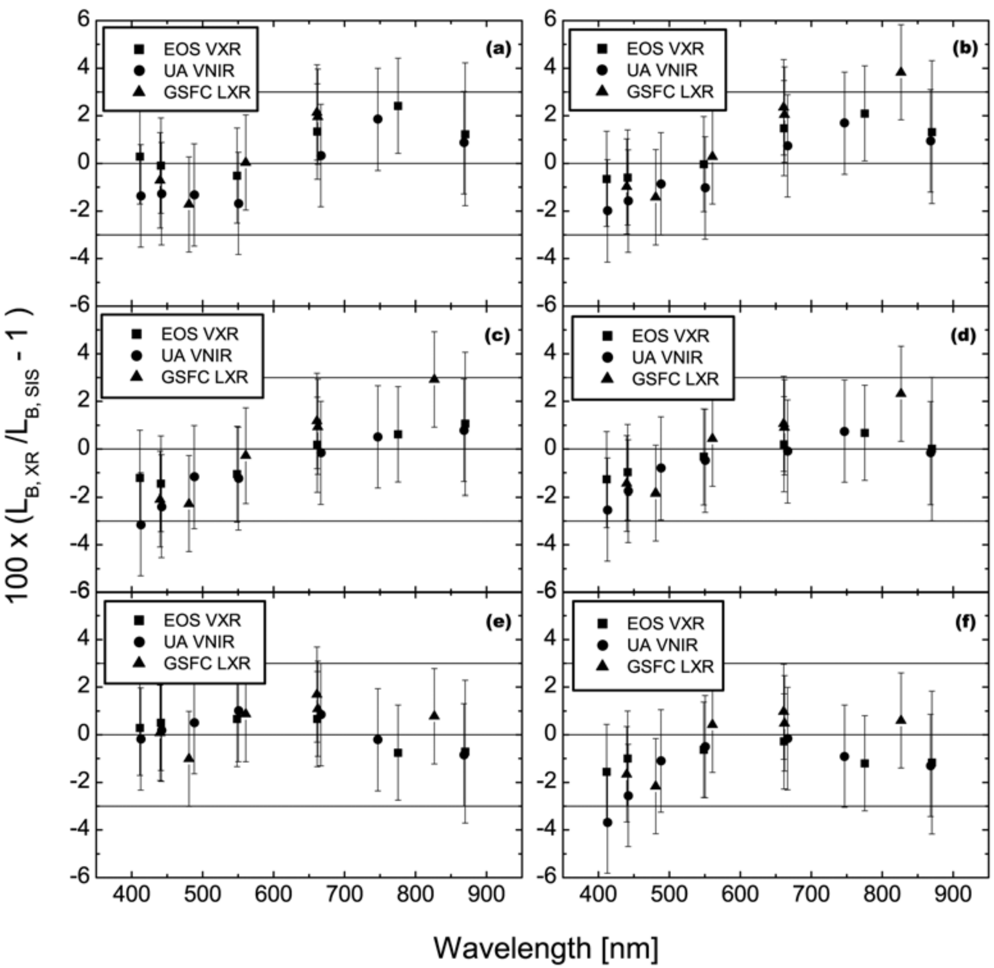
MOBY uncertainty goal: from 5 % to 3 %

How well can you do?

Results of measurements of Santa Barbara Remote Sensing SIS100 lamp-illuminated integrating sphere used for MODIS and Landsat ETM+ pre-launch calibrations)

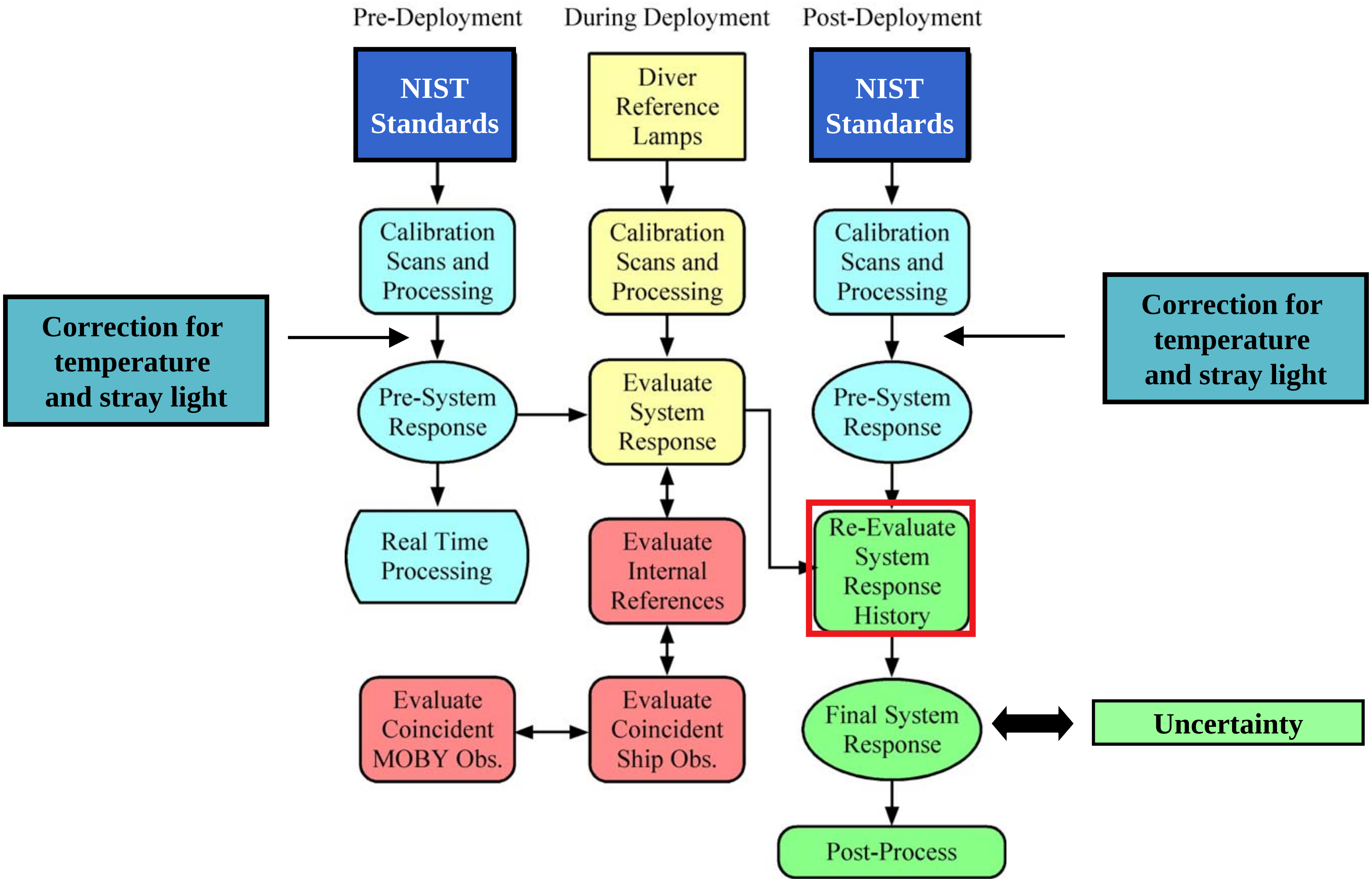
Transfer radiometers from NIST/EOS, NASA's GSFC, and the University of Arizona measured the sphere radiance under different illumination conditions and compared their results with the SBRS-determined radiance.

Best you can do, in a controlled laboratory setting, is 1 – 2 %.



Reference: SBRS98 paper

MOBY Radiometric Calibration Flow Diagram



MOBY Calibration Sources & Uncertainties

Re-calibrated every 6 months or 50 H of use

- Calibrated first with original lamps (0.5 % to 1 % agreement)

- Re-lamped and calibrated a second time

Monitored during operation using NIST calibrated filter radiometers called Standard Lamp Monitors (SLMs)

Yearly NIST visits with transfer radiometers and sources to validate the MOBY radiance scales

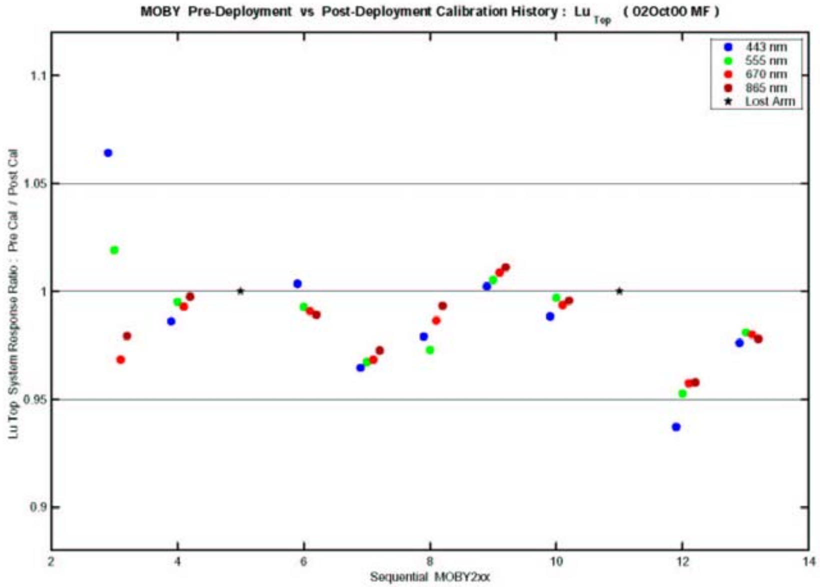
NIST-traceable calibration: 3-5 % uncertainties

NIST calibration: < 0.5 % uncertainties

Source of Uncertainty	Relative Expanded Uncertainties ($k = 2$) [%]								
	300 nm	325 nm	400 nm	500 nm	600 nm	700 nm	800 nm	900 nm	1000 nm
1. Blackbody quality (A)	0.12	0.10	0.07	0.03	0.01	0.00	0.01	0.03	0.04
2. Calibration of the reference radiance temperature lamp relative to the 1990 NIST Radiance Temperature Scale (B)	0.33	0.32	0.27	0.22	0.18	0.15	0.12	0.11	0.10
3. Temperature determination of blackbody and transfer of blackbody spectral radiance to test source (A)	6.35	2.57	0.70	0.45	0.66	1.40	2.13	3.34	2.06
4. Wavelength measurement (B)	0.12	0.12	0.10	0.07	0.06	0.05	0.04	0.04	0.04
5. 1990 NIST Radiance Temperature Scale (1990 NIST) (B)	0.58	0.55	0.46	0.37	0.30	0.27	0.24	0.20	0.19
Overall uncertainty of the test with respect to SI units	**6.39**	**2.65**	**0.89**	**0.63**	**0.75**	**1.43**	**2.15**	**3.35**	**2.07**

Note: The Type A or Type B evaluation of uncertainty is indicated in parentheses.

Pre to Post deployment calibration ratios



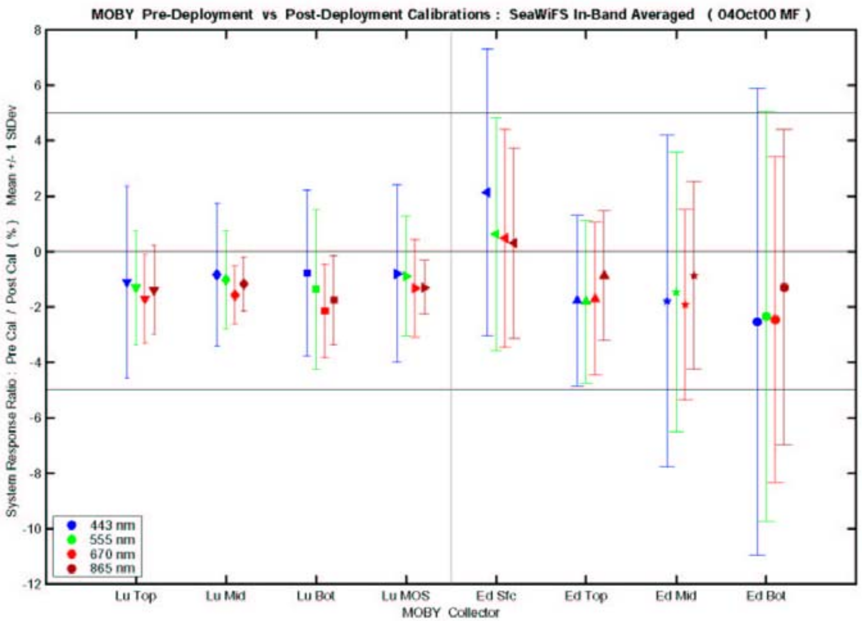
Responsivity and uncertainty?

Take the mean value of the two calibrations

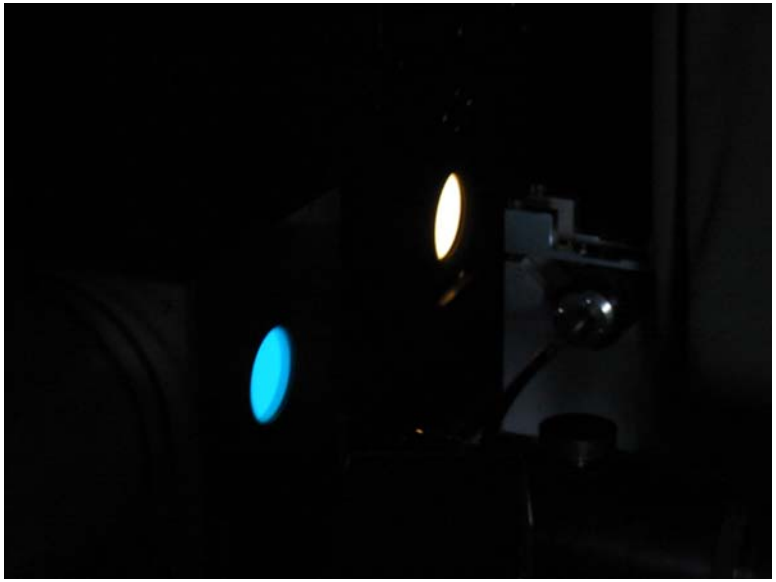
Assume a rectangular probability distribution with limits

Uncertainty 1/sqrt(12)* limits

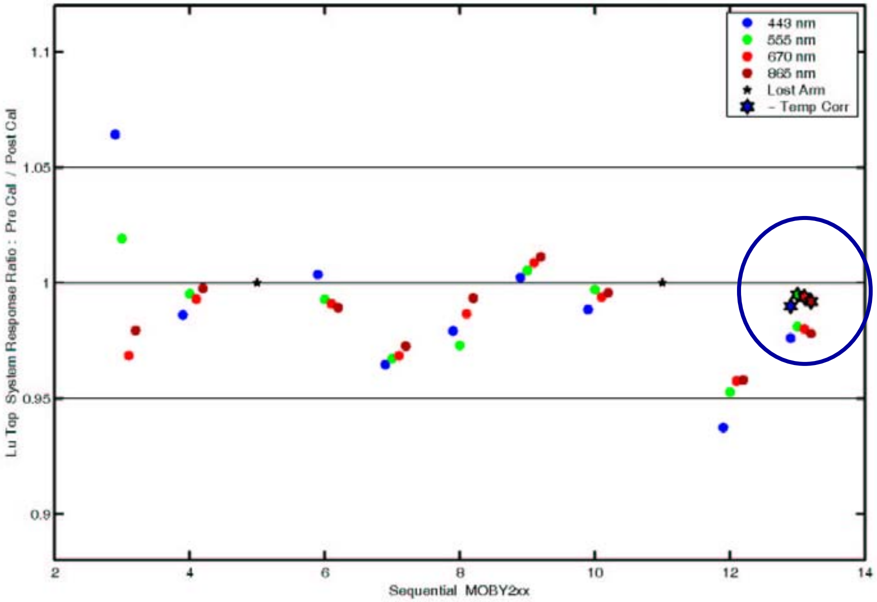
>> Limits 2 %, Unc ~0.5 %



Temperature

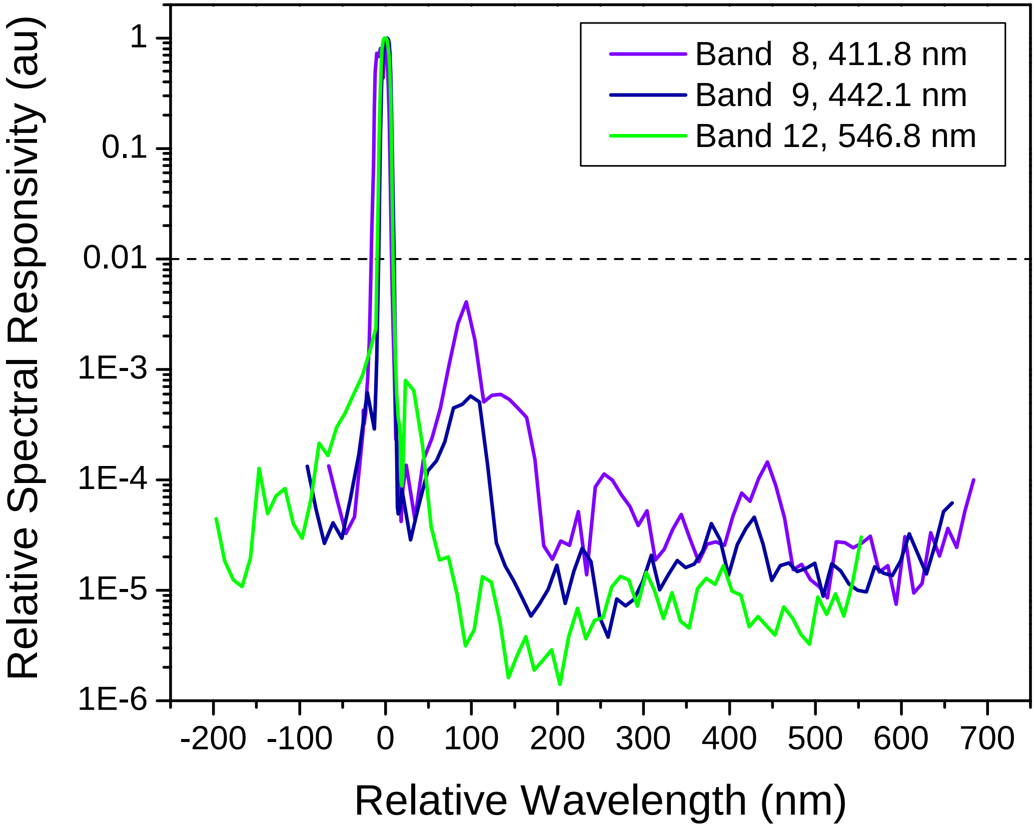


Applying a temperature correction to pre- and post-deployment calibrations



Impact of Stray Light or Spectral out-of-band

Spectral out-of-band of representative MODIS bands

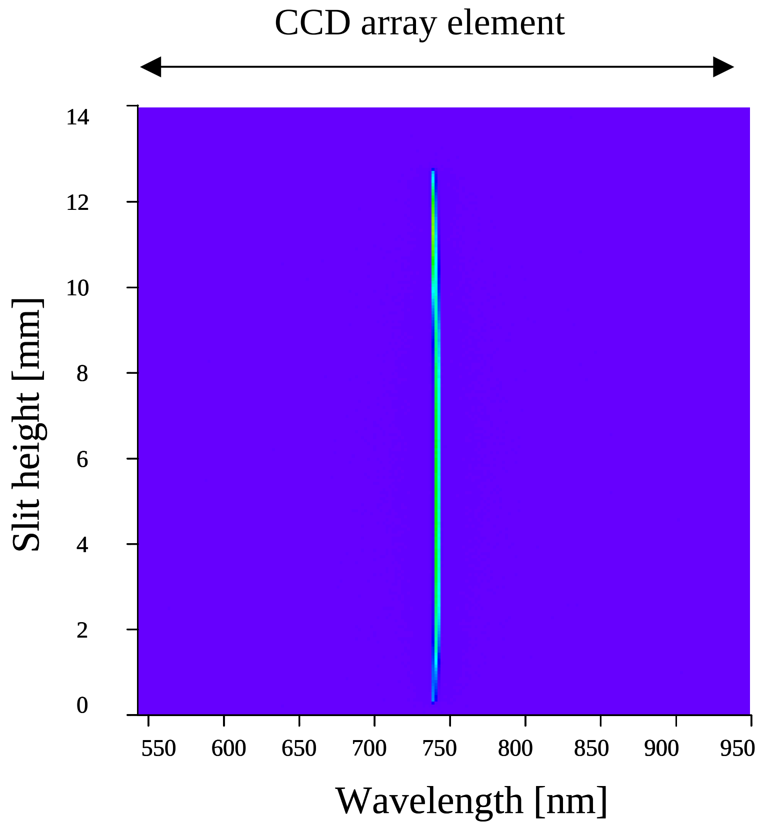


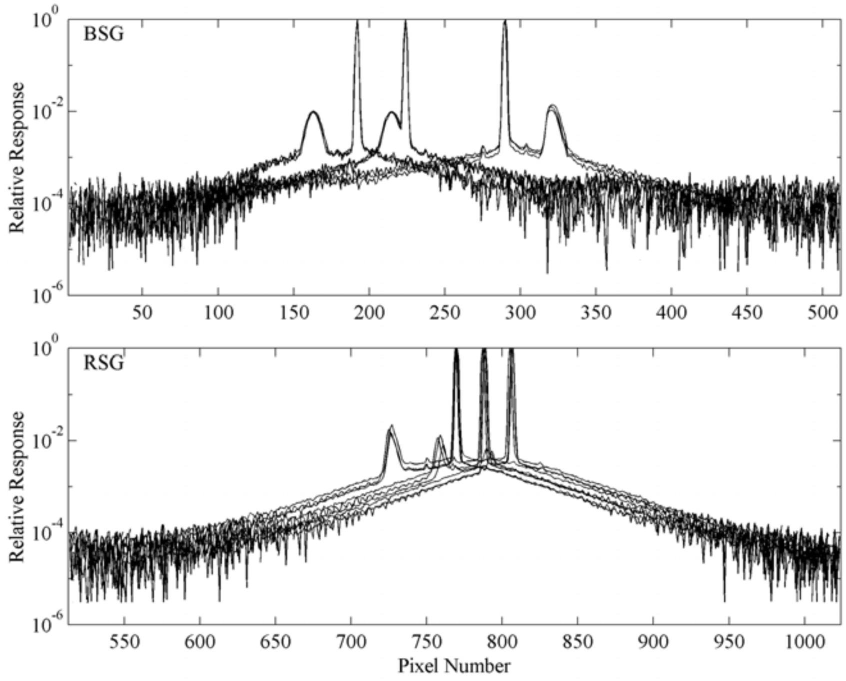
Every instrument measures unwanted radiation

What is its magnitude?

Does it impact the measurement requirements?

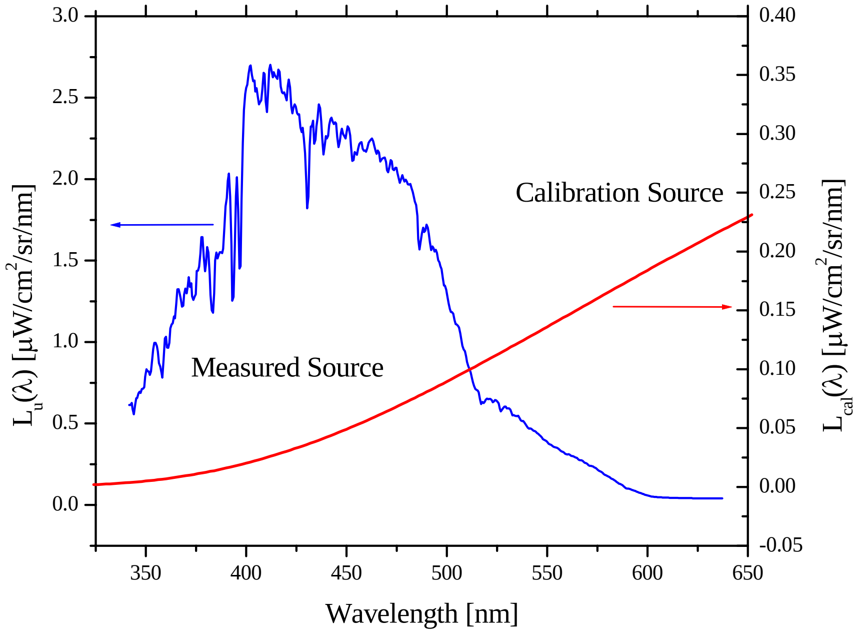
Stray light in MOBY





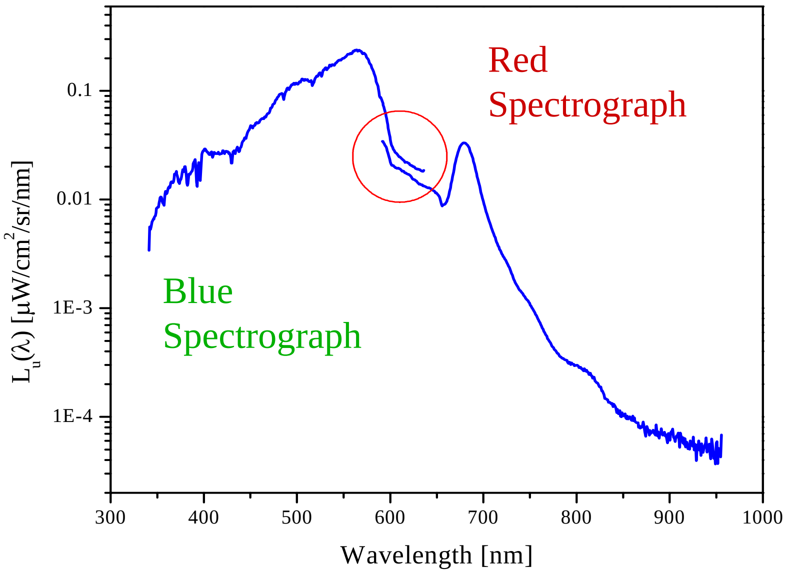
Stray light and MOBY

Source spectral power distributions



MOBY measurements did not agree in the spectrograph overlap region

Because of stray Light?



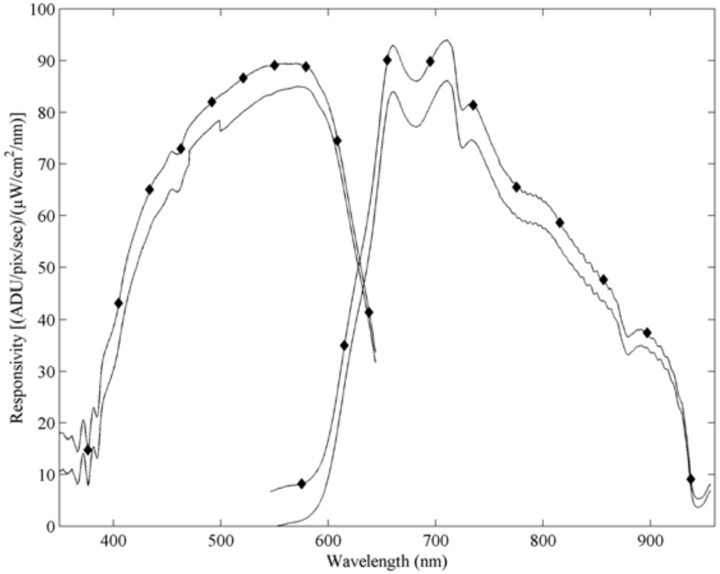
Stray light characterization and correction of MOBY

Stray light characterization of MOBY (MOVIE)

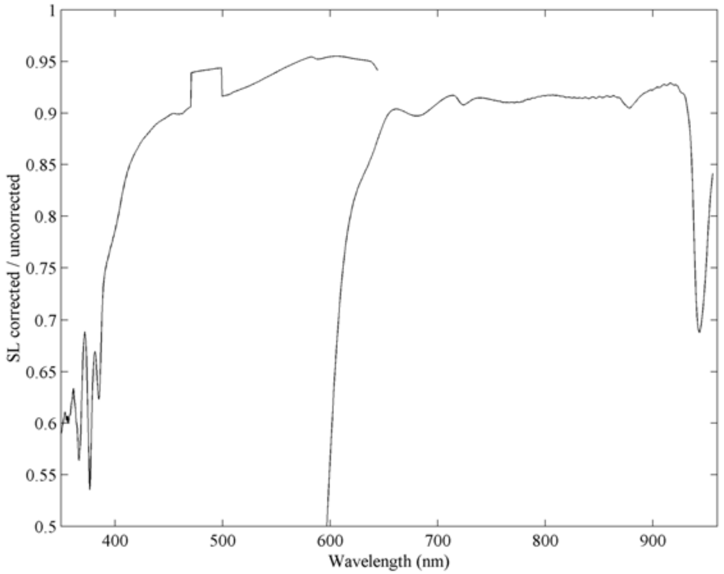
Using these characterization data sets, a method was developed to correct each element in the array for stray light.

MOBY stray light correction

Responsivity



Stray light correction factor

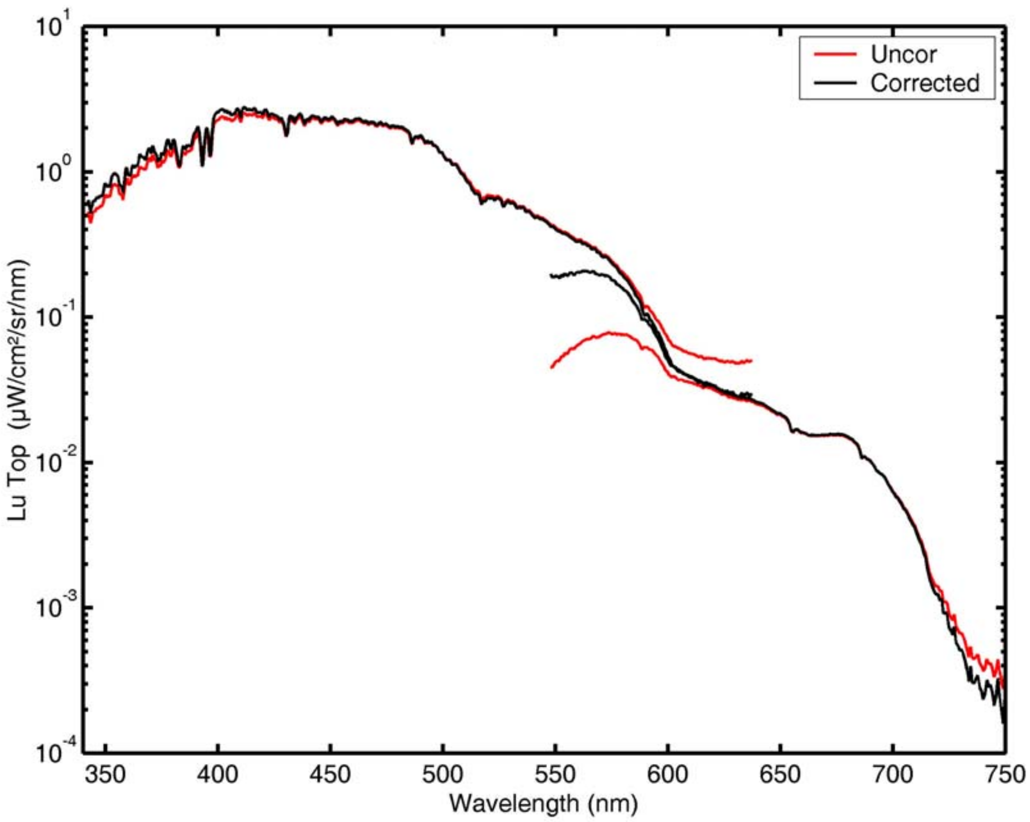


–Validation checks using lasers and colored source

– Monte Carlo uncertainty analysis

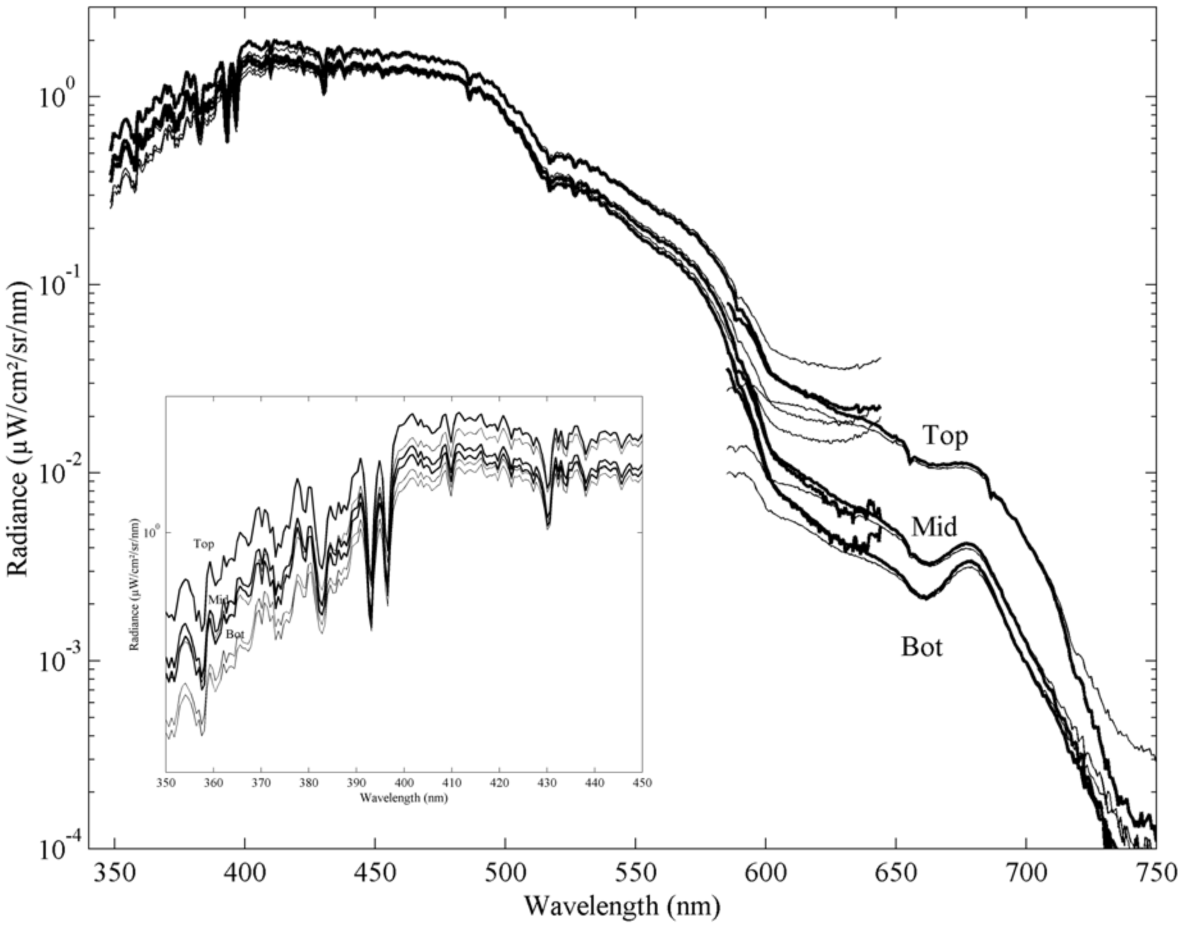
Measured upwelling radiance from top MOBY arm

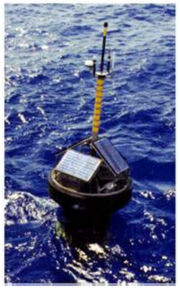
Uncorrected and corrected for stray light



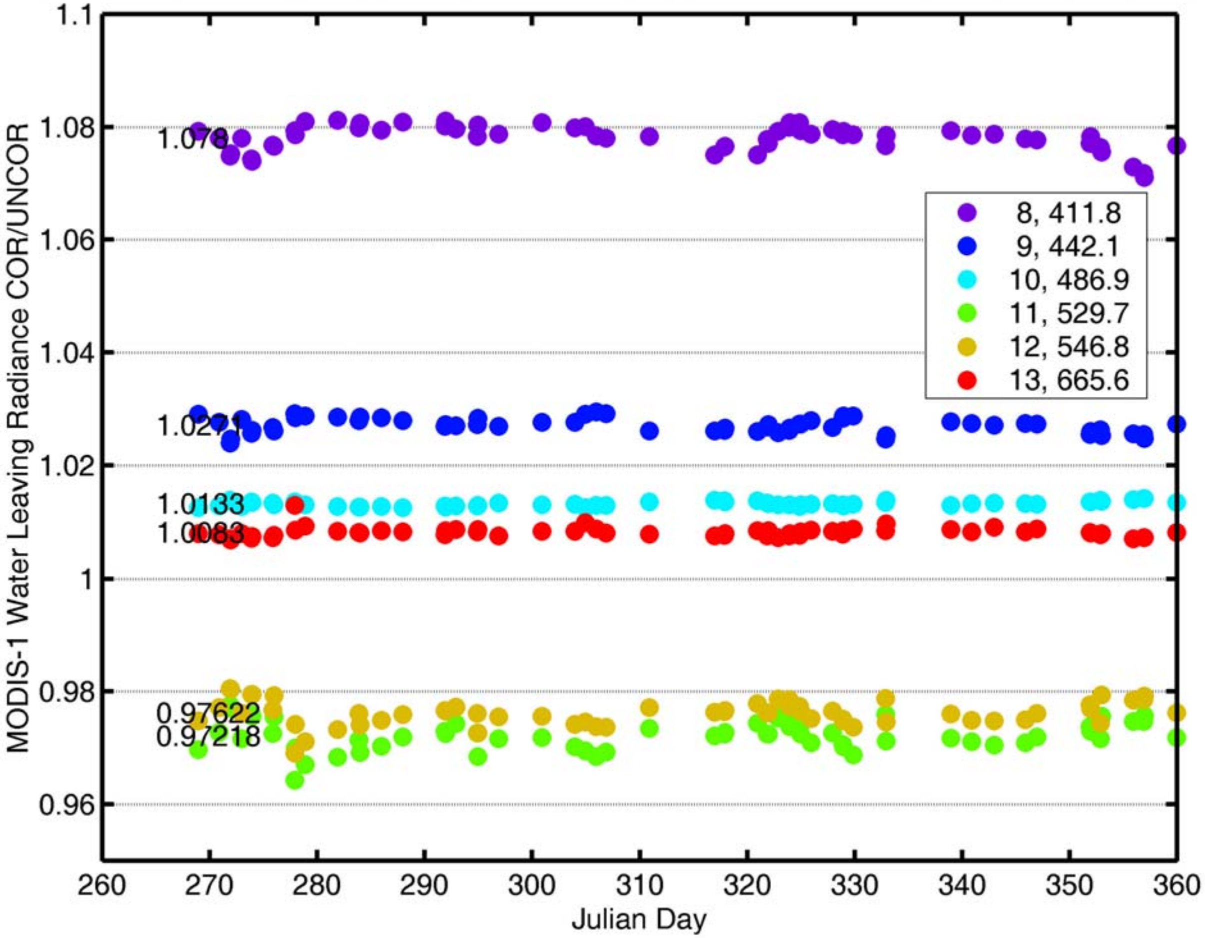
✓ **Better agreement in the overlap region**
✓ **More UV**

Good agreement for different MOBY arms





Stray Light Correction to MOBY L_w's



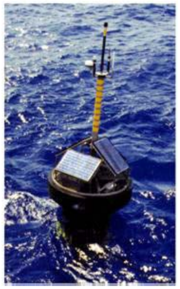
7.8 %

2.7 %

1.3 %

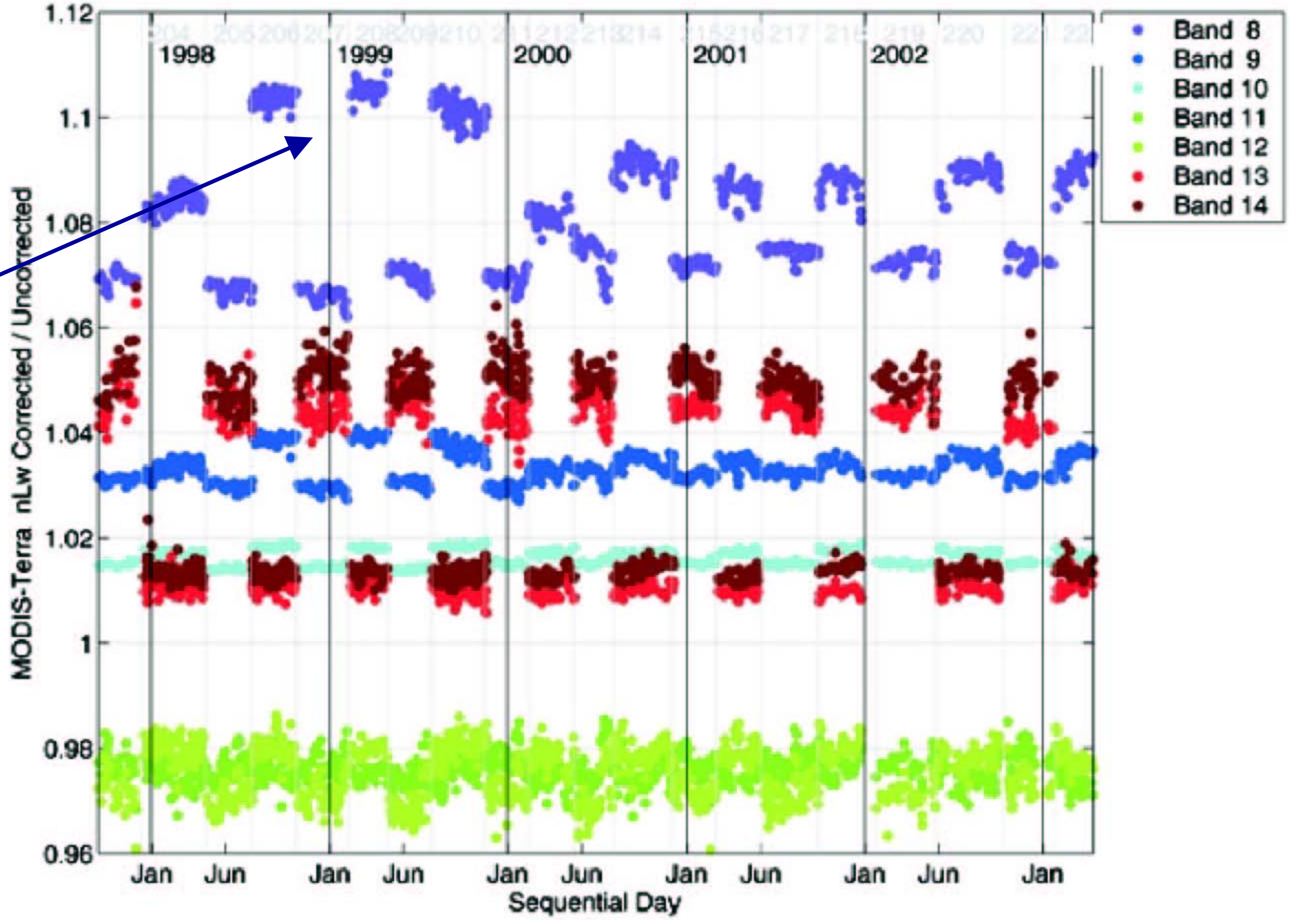
0.8 %

-2.5 %

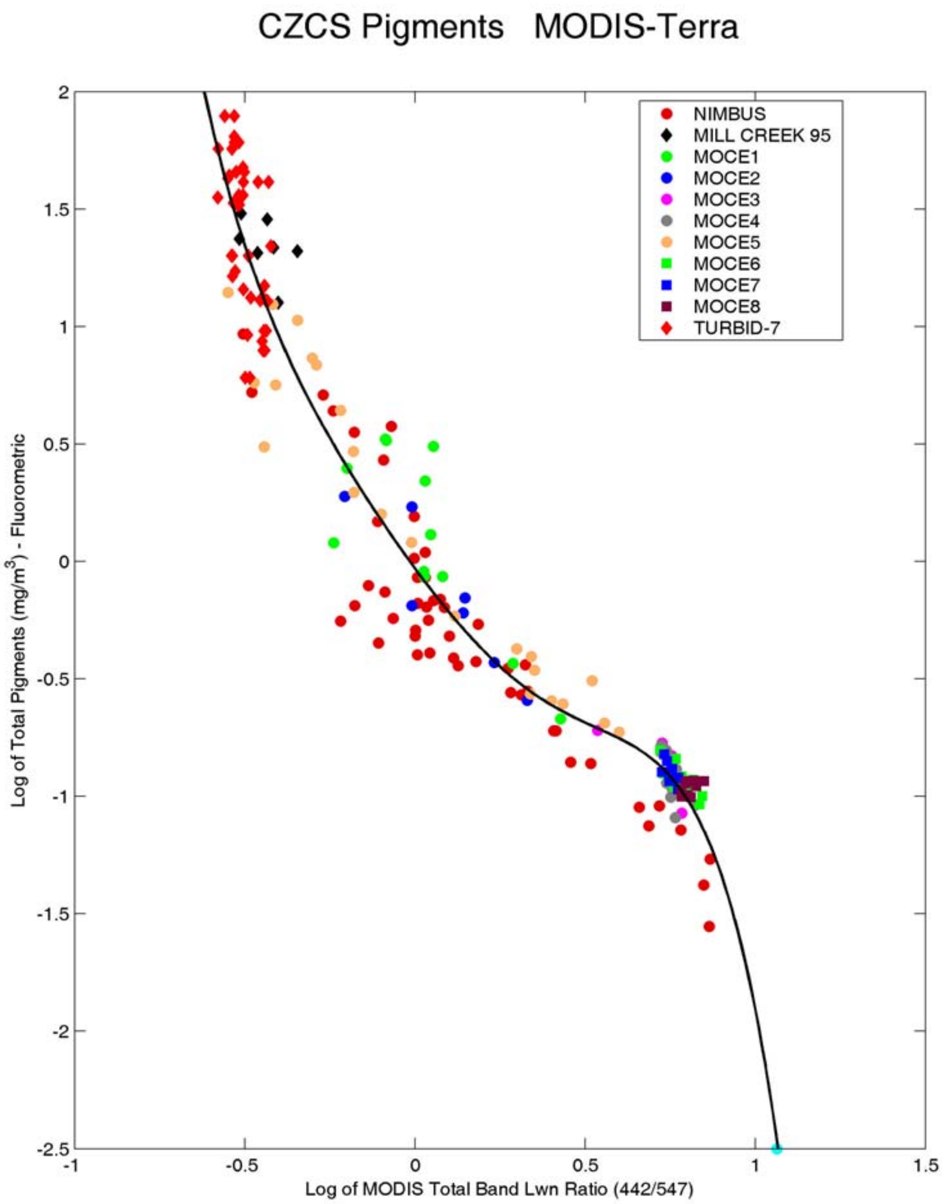


Stray Light Correction to MOBY L_w's

Different Fiber



Effect on Ocean Color Data Products



MOBY

$L^C(442)=L^C(442) + \delta L^C(442)$ **(2.5 %)**

$L^C(547)=L^C(547) - \delta L^C(547)$ **(2.5 %)**

MODIS Responsivity

$R=S/L$

$R_{442}=S^C_{442}/(L^C(442) + \delta L^C(442))$ $R^{SL} < R$

$R_{547}=S^C_{547}/(L^C(547) - \delta L^C(547))$ $R^{SL} > R$

MODIS measured L_w

$L=S/R$

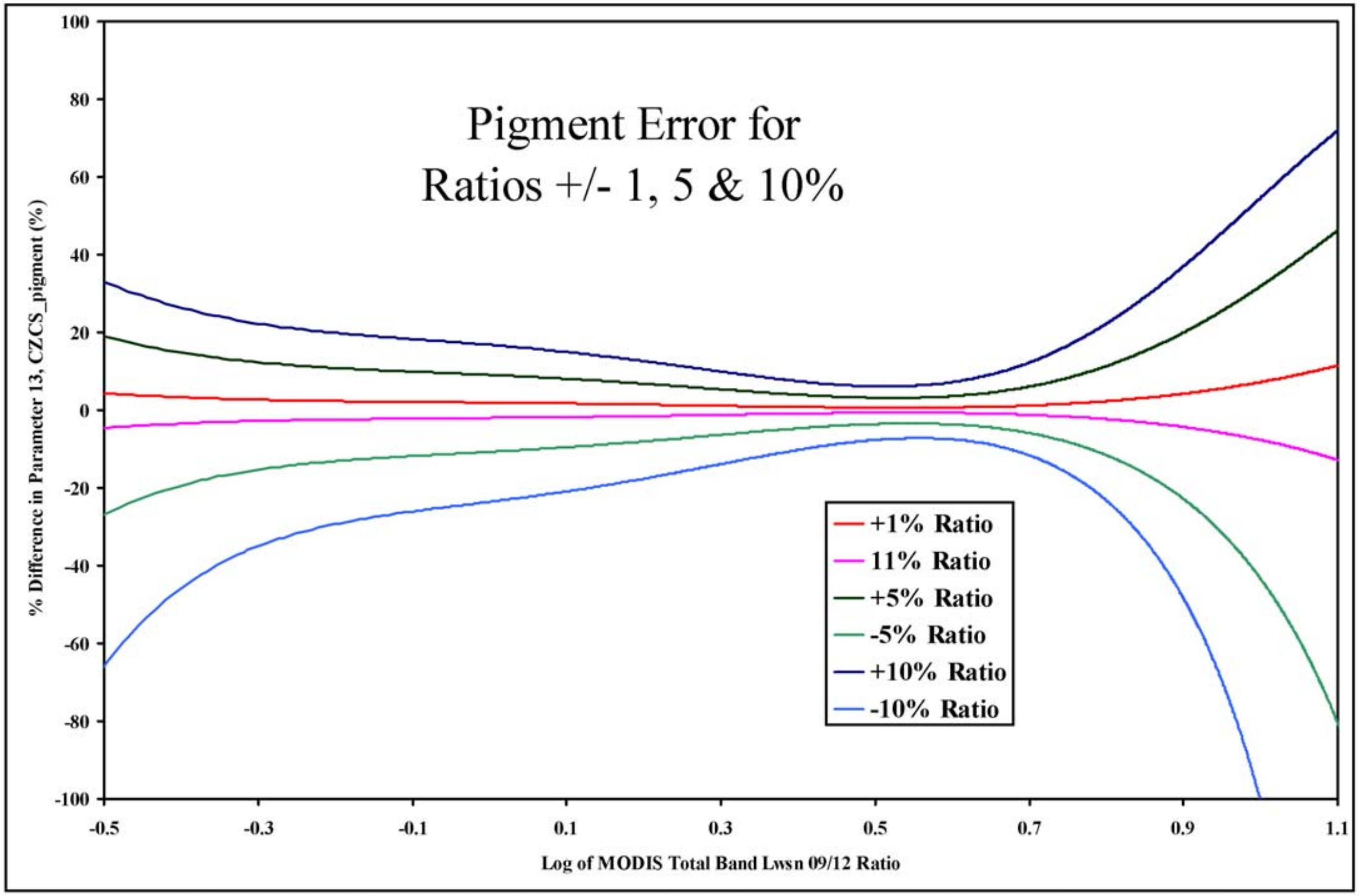
L_{442}: responsivity lower, so for the same signal, the measured radiance is higher.

L_{547}: responsivity higher, so for the same signal, the measured radiance is lower.

L_{wn} ratio (442/547) increases by ~5 %

Note: Constant change in the calibration

CZCS - Empirical Pigment Product



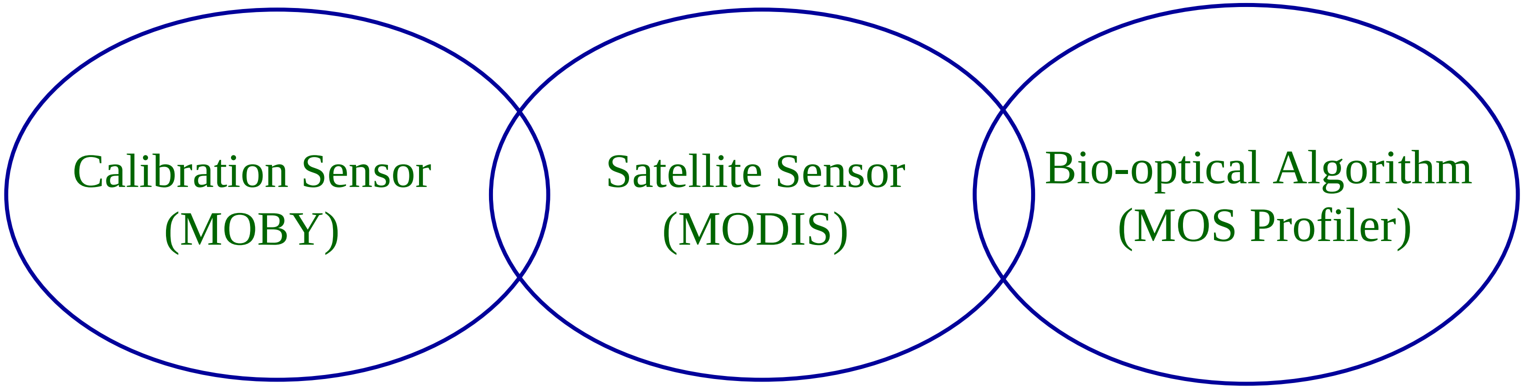
Clarify slide: as the ratio increases, the measured pigment product decreases – from slope of bio-algorithm, previous slide

Stray light/spectral out-of-band & ocean color data products

There are a number of sensors involved in the derivation of remotely sensed ocean color data products

Data Product

Chlorophyll-a



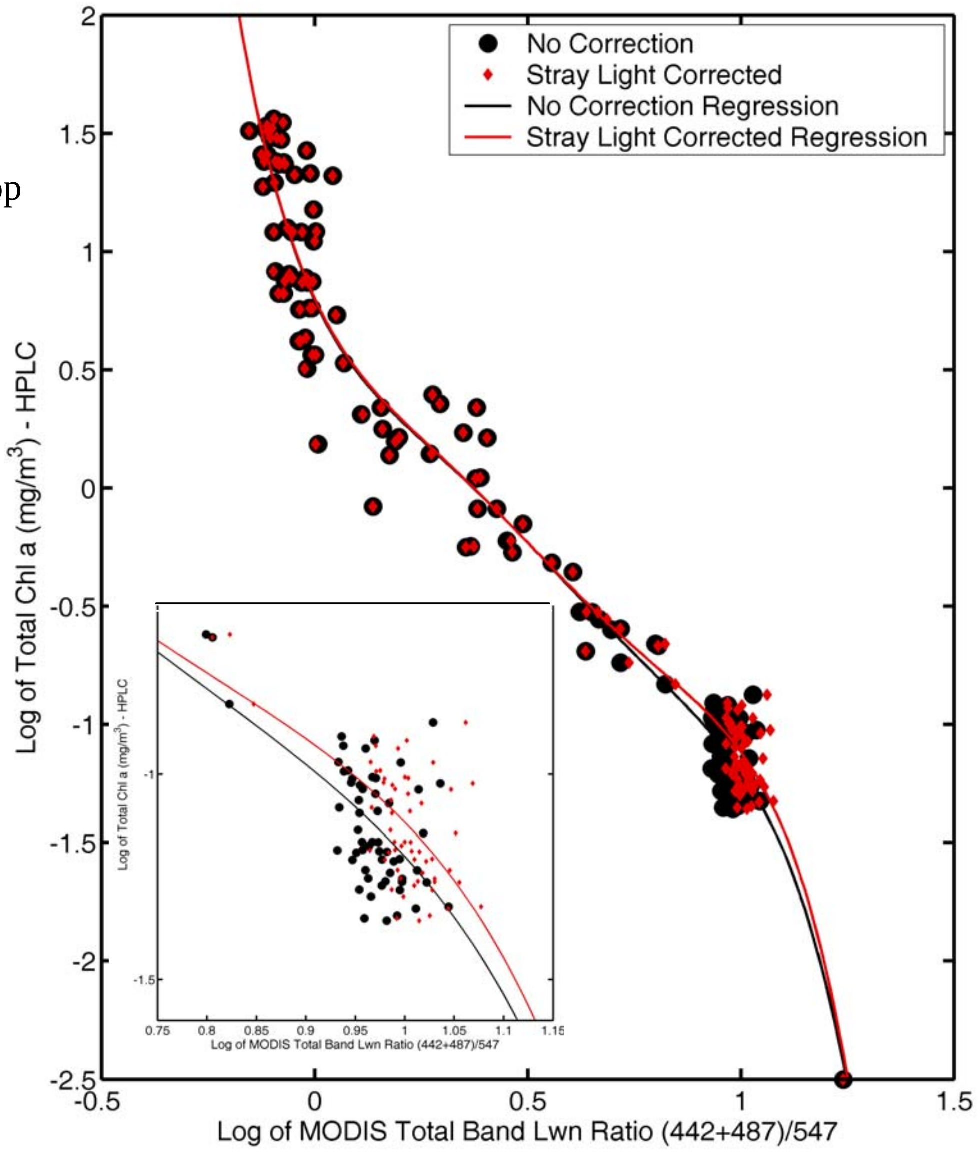
They are linked in the sense that errors in any one of the three components propagates through to errors in the desired data product.

Stray light/spectral OOB should be considered and evaluated for each sensor suite.

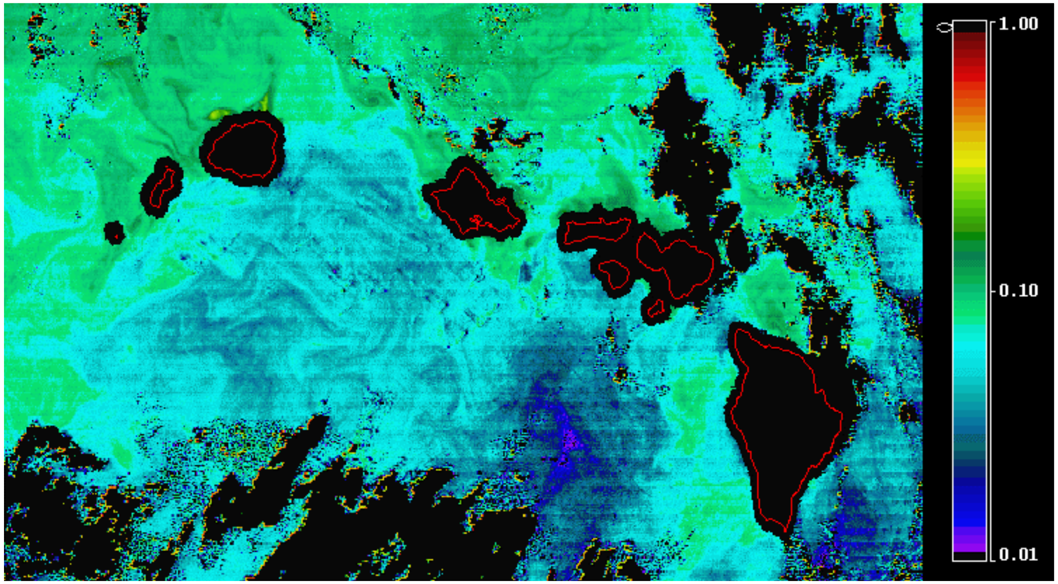
Stray Light and bio-optical algorithms

Deployments of the MOS Profiler, which is a profiling version of MOBY, are used in conjunction with analytical sampling to develop bio-optical algorithms for MODIS.

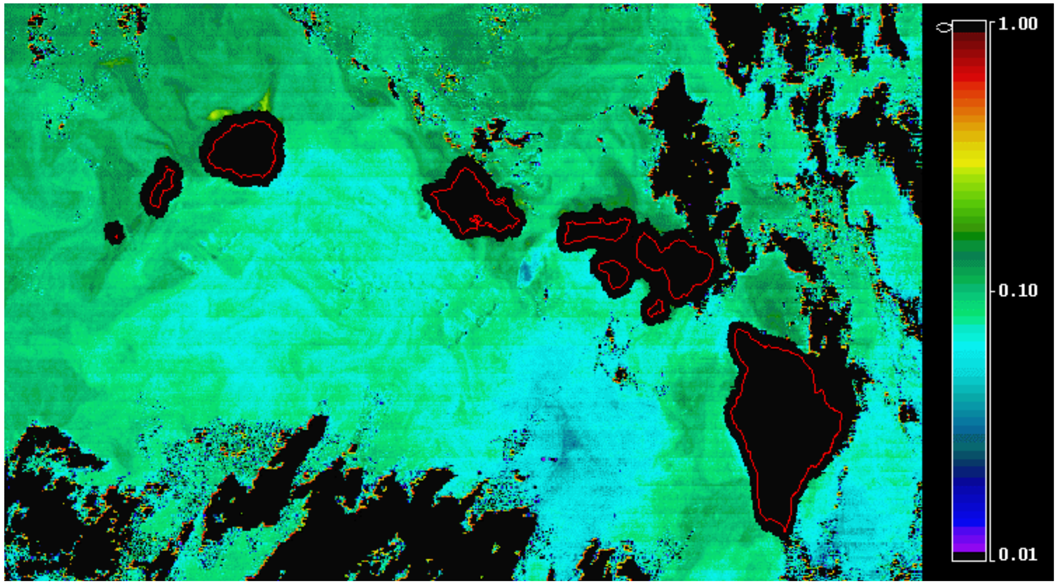
Need to also consider effects of stray light in the MOS Profiler



Application to a MODIS Image



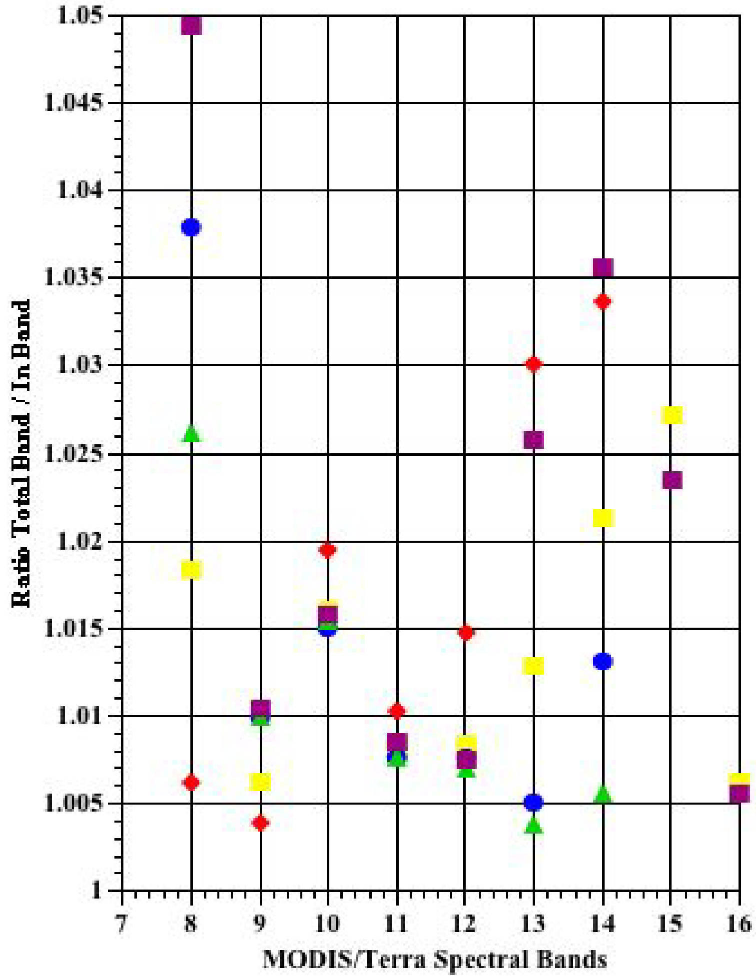
Using bio-optical algorithm developed with radiometric measurements **uncorrected** **for stray light**

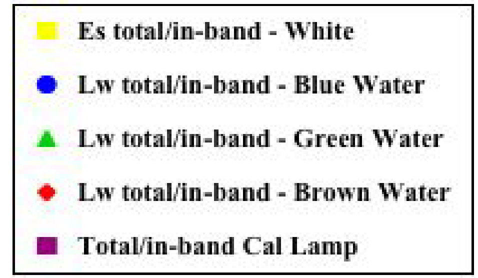


Using bio-optical algorithm developed with radiometric measurements **corrected** **for stray light**

Sources of systematic error at the satellite level

Spectral OOB a problem for MODIS?





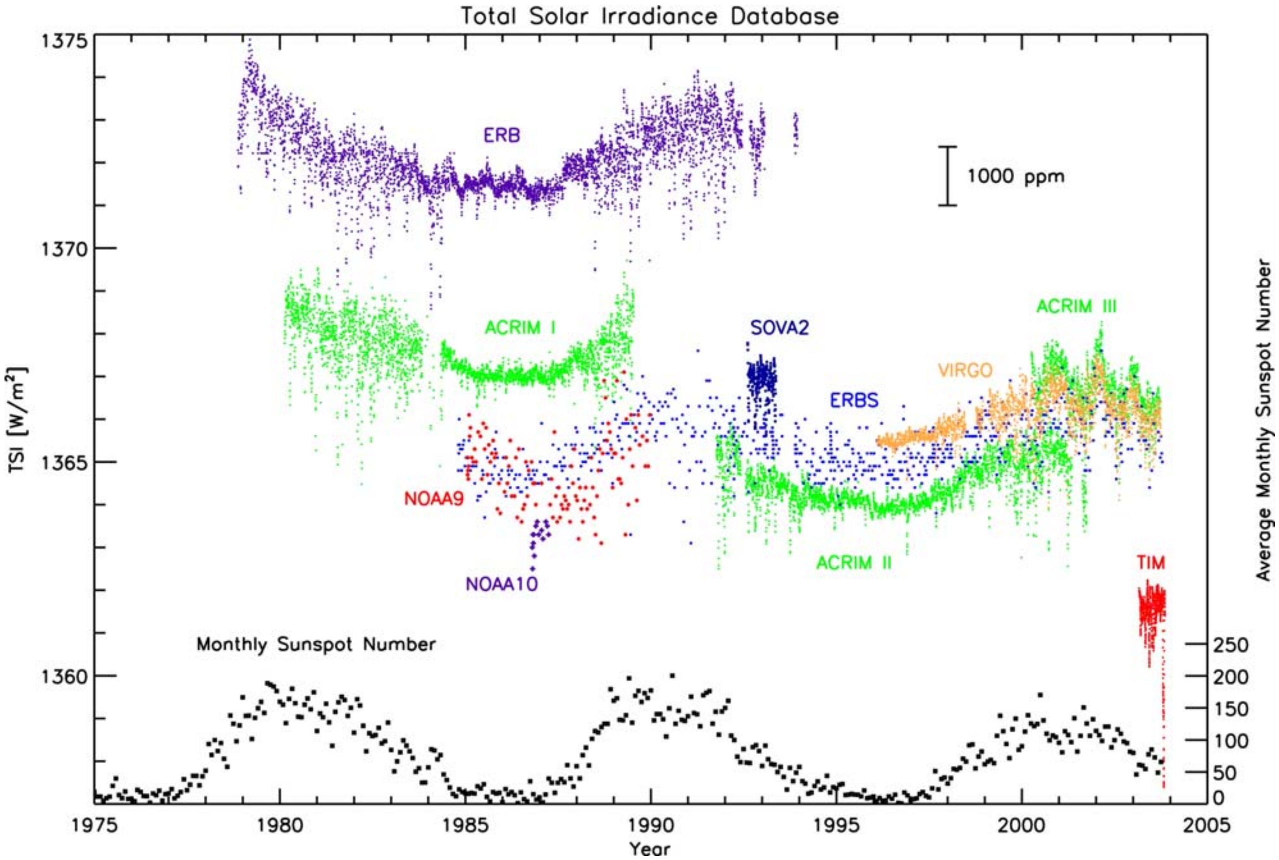
Band	Wavelength nm
8	411.8
9	442.1
10	486.9
11	529.7
12	546.8
13	665.6
14	676.7
15	746.4
16	866.2

Ken Voss to discuss in greater detail

MOBY Summary

- High resolution instrument with wide spectral coverage
- Traceability to primary national and international radiometric standards and the SI
  - Great deal of effort to understand measurement uncertainty and potential sources of error
- Link between past/present and future ocean color missions
  - Complementary strategies: e.g. Lunar Photometry
    - Lunar photometry
      - Excellent trending results for stability and degradation
      - Comparisons between satellite sensors
    - Ground-based vicarious calibration offers advantages
      - Like-to-like radiometric calibration principle
        - » Atmosphere
        - » Size of source
    - Comparison of differing calibration strategies and methodologies can be helpful in uncovering unforseen sources of bias in measurement

Total Irradiance Monitor (TIM) on the Solar Radiation and Climate Experiment (SORCE)

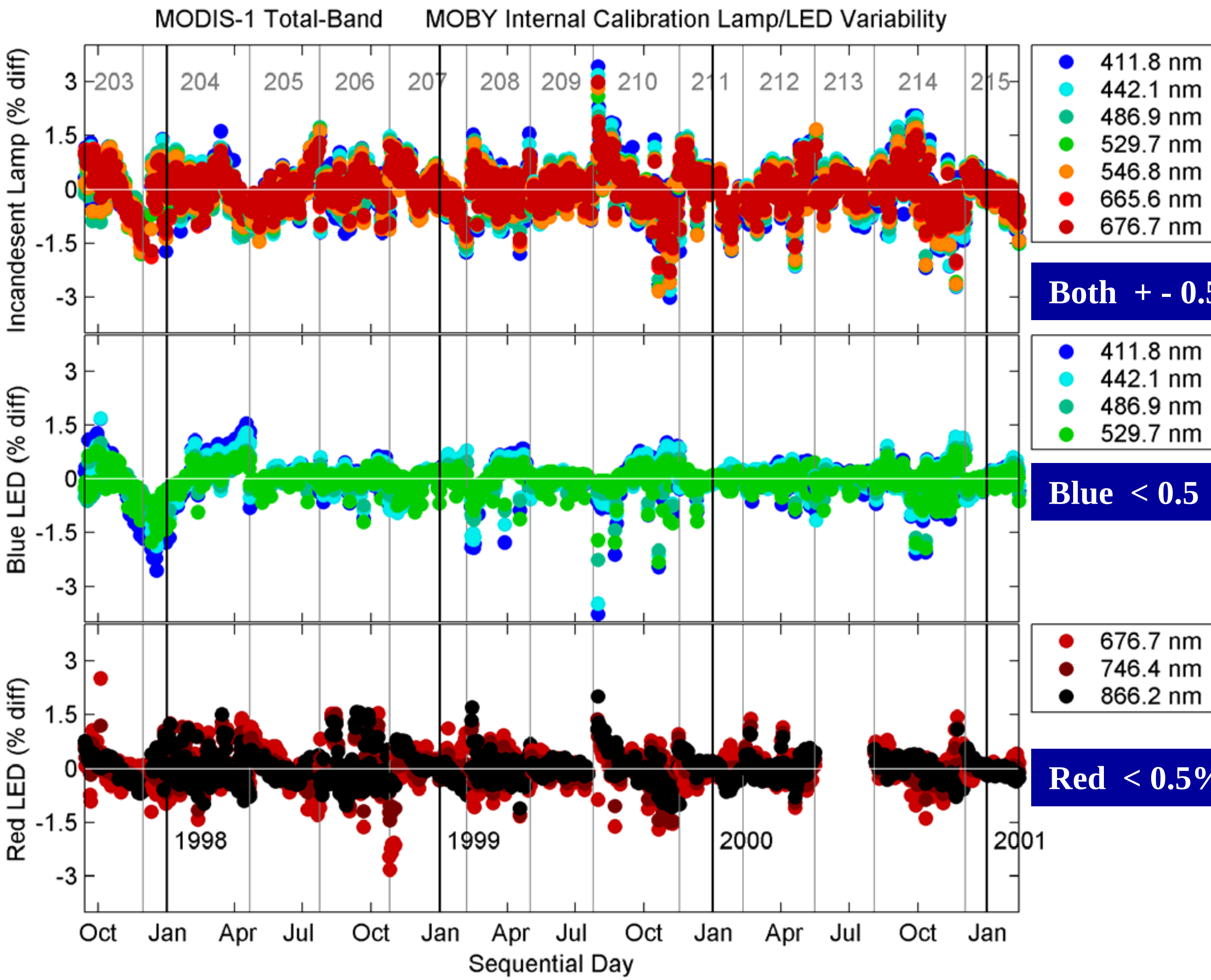


http://spot.colorado/edu/~koppg/TSI or contact Greg Kopp 303 735 0934

The variability at the end is from sun spots and flares.

Backup Material

Internal Reference Lamps - Stability QC

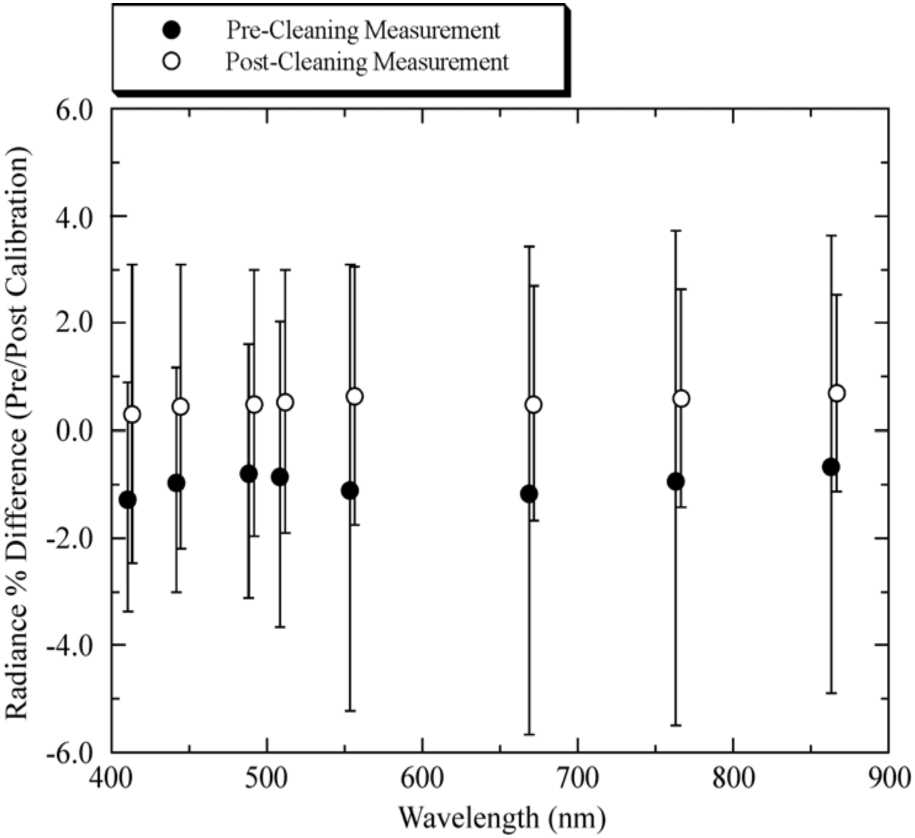


Both + - 0.5%

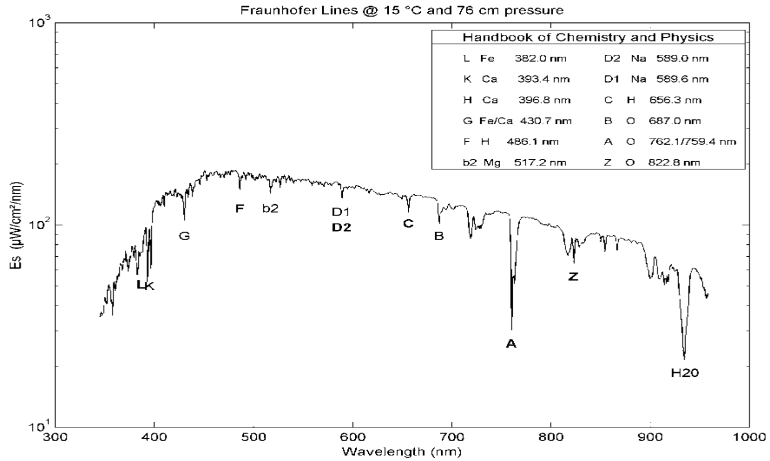
Blue < 0.5 %

Red < 0.5%

Diver Reference Lamp Calibrations



Wavelength Calibration QC-Solar



Blue Spectrograph
2.5 years
Approx. +/- 0.6 nm

Red Spectrograph
2.5 years
Approx. +/- 1 nm