Stray Light, Ocean Color and Chlorophyll-a

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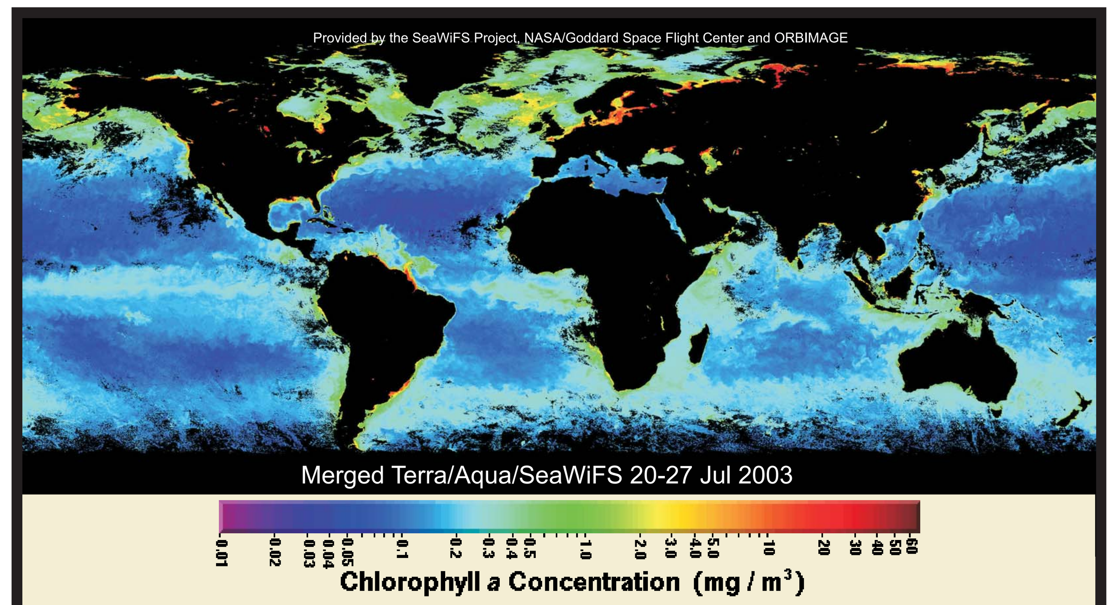
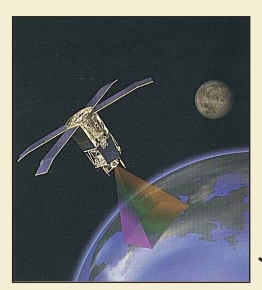
The Goal: Estimate Global Pigment Concentration



Ocean color instruments measure the water-leaving radiance in selected wavelength bands to determine important bio-physical and bio-chemical data products. Globally derived ocean color-based data products provide climate quality data to be used in coupled biochemical and bio-physical models for regional and global process research. Because the duration and magnitude of phytoplankton primary productivity impacts carbon flux, carbon export and air-sea carbon flux, knowing the magnitude and distributions of phytoplankton biomass is crucial to understanding carbon budgets. Phytoplankton chlorophyll a (Chl a) is a key parameter used in global primary productivity models.

Relating Satellite Radiance to Pigment Concentration



Ocean Color Satellite

- Pre-launch characterization and calibration
- Vicarious calibration on-orbit
- Proper correction of atmospheric effects
- Development of bio-optical algorithms to relate a radiometric measurement to chlorophyll concentration

Atmosphere

Instruments used to develop Bio-optical Algorithms

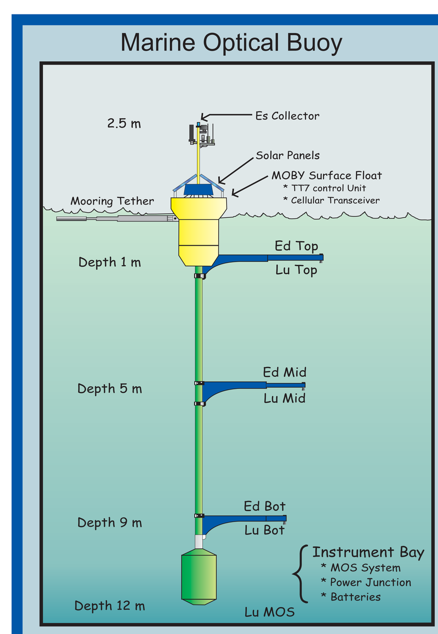
Data Products Chlorophyll a

Measurement errors by instruments in any one of the components will adversely affect the validity of the final data product.

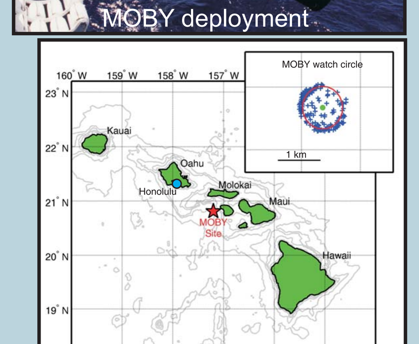
Marine Optical Buoy

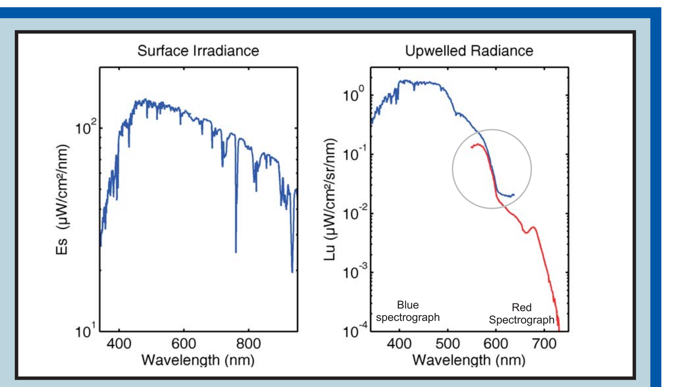
Measurements by MOBY are used in the vicarious calibration of ocean color satellite instruments such as SeaWiFS and MODIS.

MOBY- the Primary Vicarious Calibration Instrument



MOBY deployment





MOBY measures the surface irradiance, Es, and up-welling spectral radiance, Lu.

MOBY measurements did not agree in the spectrograph overlap region

Circled Region: Lu derived using the two spectrographs in MOBY disagreed in their region of overlap;

Magnitude of discrepancy is depth-dependent

Two CCD spectrographs cover the spectrum from ~ 350 nm to 950 nm. A dichroic mirror splits the spectrum into blue and red components

Blue spectrograph: 350 nm – 640 nm
Red spectrograph: 550 nm – 940 nm

Time series of band-averaged Lwn since 1996

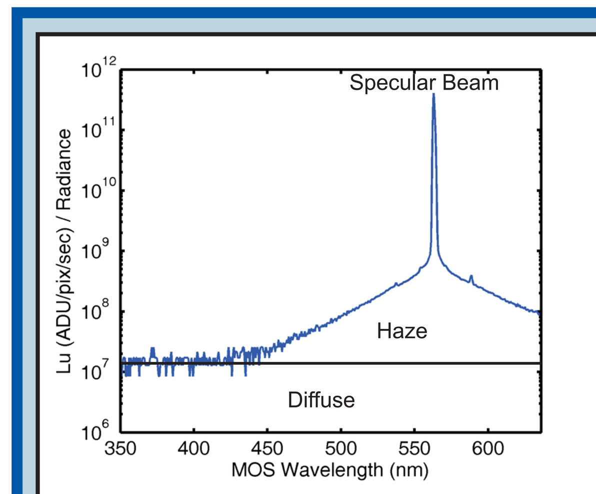
Uncertainties

Science requirements: 5 % nLw
MOBY is currently 4 % to 8 %;

Radiometric sources

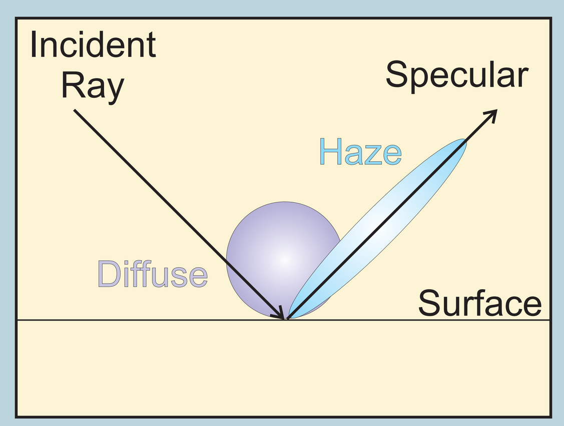
E and L sources NIST-traceable
Lamps recalibrated every 50 h
Lamps verified during use with SLMs
(NIST-designed radiometers)

Stray Light and MOBY

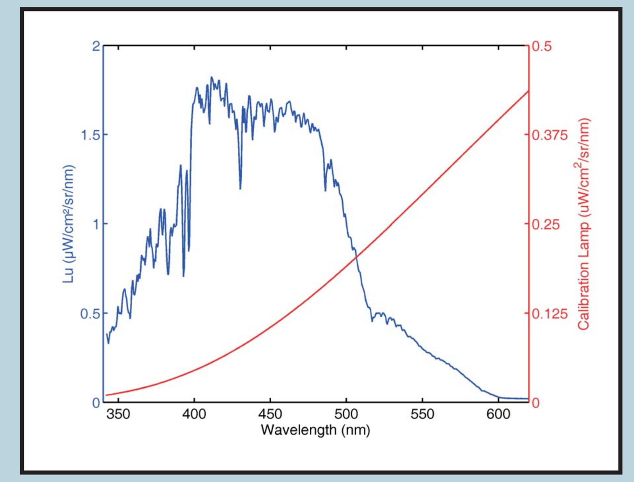


For a monochromatic excitation source(wavelength tunable lasers), an image of the entrance slit is formed on the detector array.

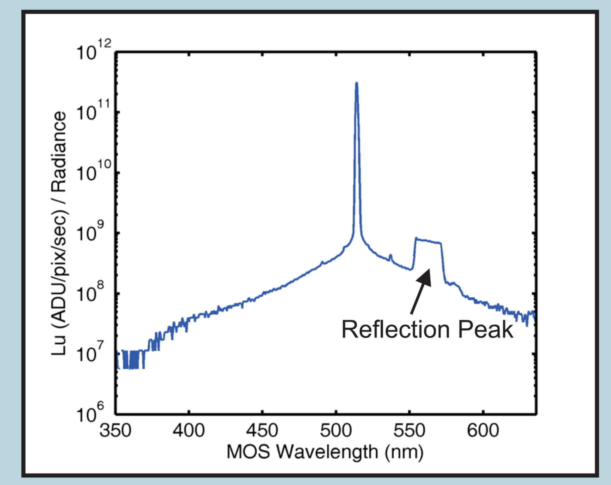
Stray light is light scattered off optical surfaces in the spectrograph that hits the CCD array in spectral regions other than the region where the image of the entrance slit is formed.



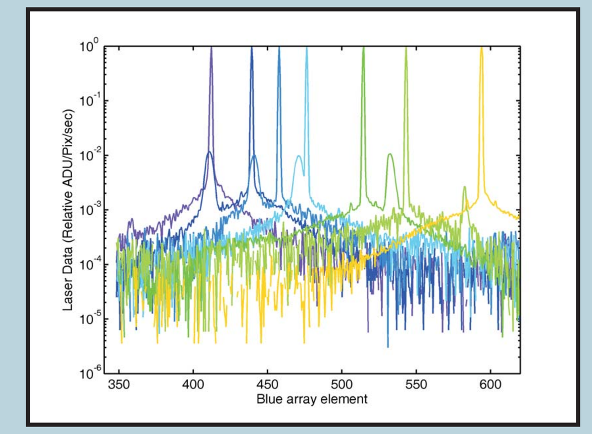
Haze and diffuse reflection components contribute to stray light in the instrument.



Stray light is a common issue for single grating spectrographs used to measure sources with different spectral shapes



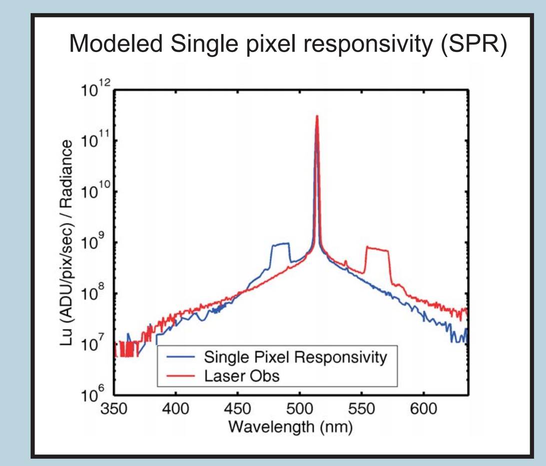
The stray light correction model is complicated by presence of 2nd order 'reflection peaks'



Modeling the stray light requires spatial laser profiles across the CCD array

From these measurements we are able to develop a correction algorithm for MOBY when measuring broad-band sources (calibration and in-water radiance)

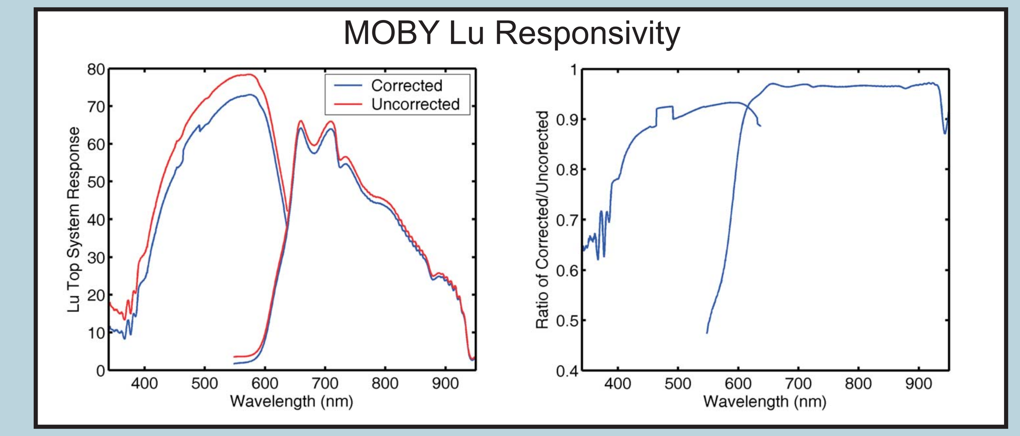
Modeled Single pixel responsivity (SPR)



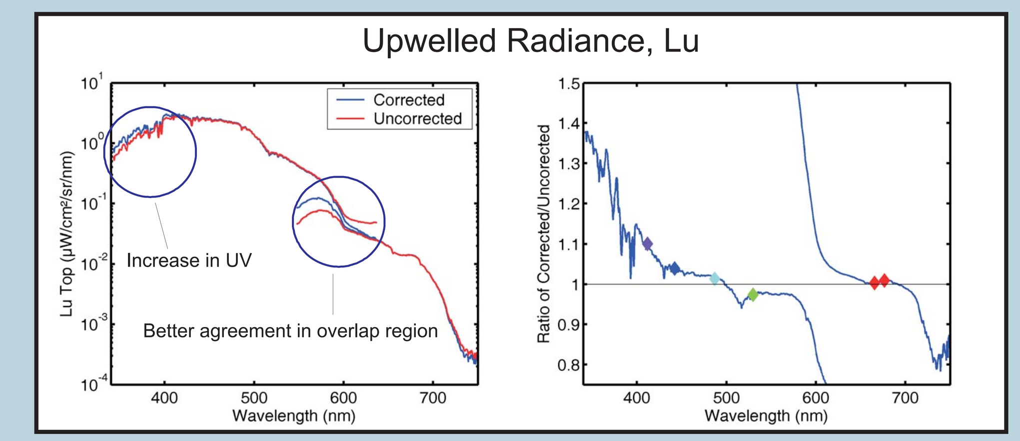
Notice the SPR and Laser Obs reflection peaks are on opposite sides of the specular peak. The SPR reflection peak is also narrower.

Stray light corrected system response and In-water data

MOBY Lu Responsivity



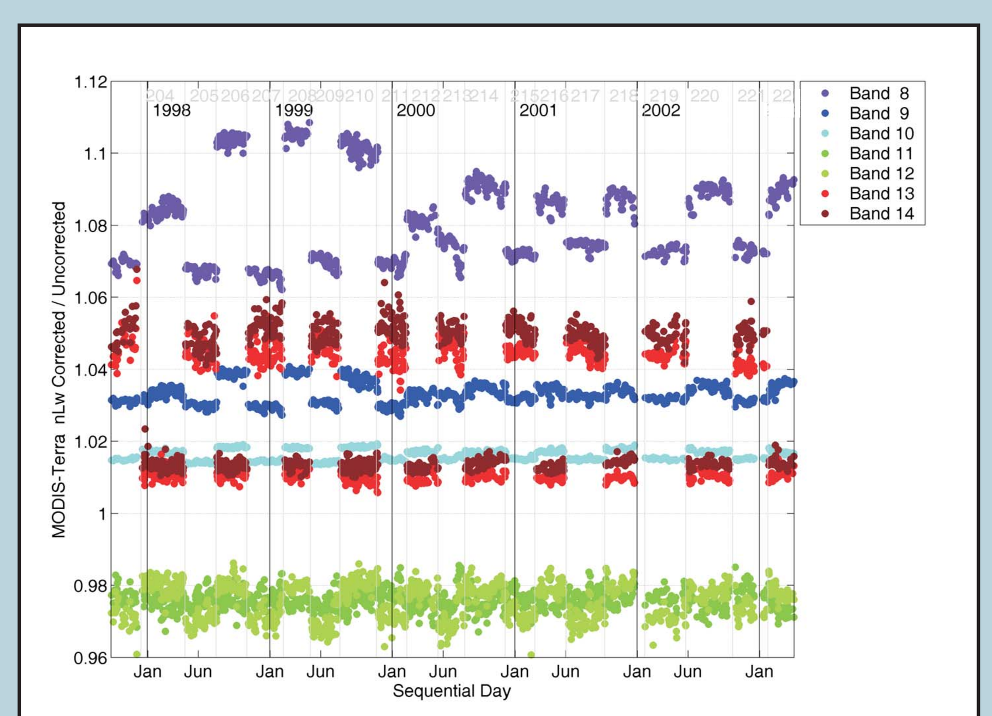
Upwelled Radiance, Lu



The system response can be stray light corrected because we know the output and spectral distribution of the lamp. Once the system response has been determined by an iterative stray light correction process involving the lamp spectra, measured lamp spectra and SPR, then in-water data are stray light corrected iteratively from the measured in-water spectrum, the stray light corrected system response and SPR. The iterations stop when the change between iterations is less than a set tolerance.

Impacts of Stray Light Correction on Satellite Calibrations

MODIS Band Correction Factors



All MOBY deployments were stray light corrected and the band correction factors calculated by ratioing the corrected to the uncorrected data. The above graphs shows the band correction factors for MODIS bands.

Two different MOS instruments are used in MOBY one for the even deployments and a second for the odd deployments. A stray light correction model was developed for each MOBY/MOS (even and odd deployments). The results give slightly different band correction factors for each MOS instrument.

MOBY is used to set the calibration coefficients for ocean color satellites

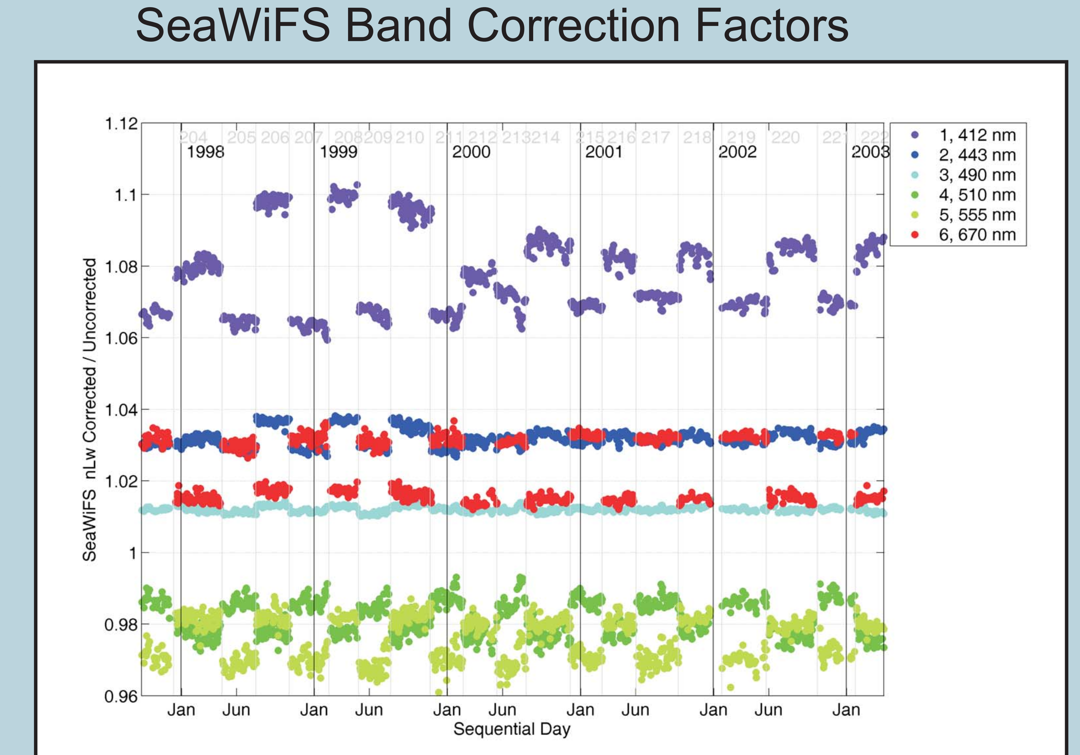
Any changes in MOBY-derived water-leaving radiances (Lw's) are directly reflected in calibration coefficients for these satellite channels.

Band ratios are used to determine chlorophyll concentrations.

Deployment Correction Factors for MODIS-Terra Bands

MOBY Deploy	Band 8 411.8	Band 9 442.1	Band 10 486.9	Band 11 529.7	Band 12 546.8	Band 13 665.6	Band 14 676.7
203	1.069	1.031	1.015	0.977	0.972	1.047	1.051
204	1.084	1.034	1.017	0.975	0.980	1.011	1.014
205	1.067	1.030	1.014	0.977	0.971	1.045	1.047
206	1.104	1.039	1.018	0.975	0.980	1.011	1.013
207	1.066	1.029	1.014	0.977	0.971	1.045	1.052
208	1.105	1.039	1.018	0.975	0.980	1.011	1.014
209	1.070	1.031	1.014	0.975	0.969	1.046	1.050
210	1.102	1.038	1.018	0.976	0.980	1.010	1.013
211	1.069	1.030	1.015	0.977	0.971	1.043	1.052
212	1.081	1.033	1.017	0.975	0.979	1.009	1.013
213	1.074	1.032	1.015	0.976	0.970	1.046	1.050
214	1.091	1.035	1.017	0.974	0.979	1.010	1.014
215	1.072	1.032	1.015	0.977	0.971	1.045	1.052
216	1.086	1.034	1.017	0.975	0.979	1.010	1.013
217	1.074	1.032	1.015	0.977	0.971	1.045	1.049
218	1.087	1.034	1.018	0.977	0.981	1.010	1.015
219	1.073	1.032	1.015	0.977	0.971	1.044	1.049
220	1.089	1.035	1.017	0.975	0.979	1.010	1.014
221	1.073	1.031	1.015	0.979	0.973	1.041	1.050
222	1.089	1.035	1.017	0.974	0.978	1.011	1.014

SeaWiFS Band Correction Factors



The stray light correction parameters for MOBY were derived from laser measurements of a subset of the deployments (218 and 219). The "even" or "odd" stray light correction algorithm was applied to all deployments using the system responses from the radiometric calibrations prior to the deployment. This procedure is valid because the internal optics in MOS were never changed or realigned. For a few deployments of the even buoy (206, 208 and 210), different optical fibers were used and this makes a difference to the bluest wavelength satellite correction factors.

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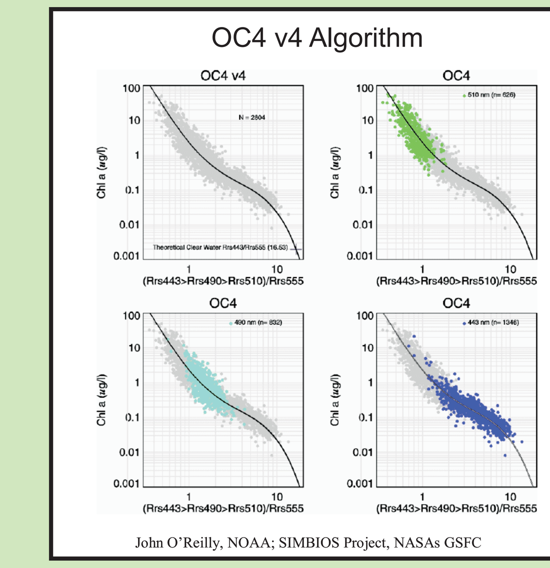
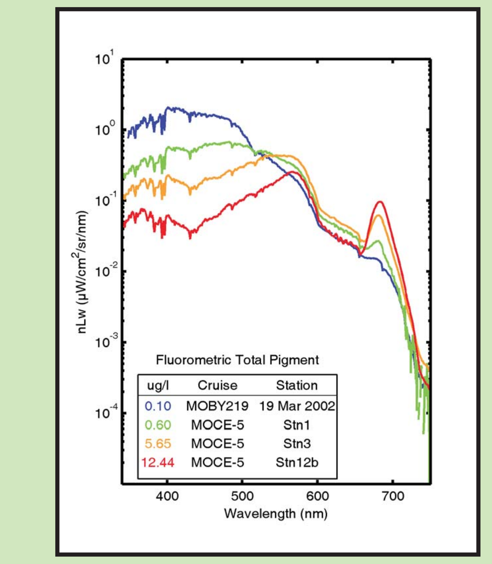
Technical Support: William Broenkow[1], Y.S. Kim[2] and Keith Lykke[2]

NASA's Bio-optical Algorithms and Band Ratioing

OC4 v4 Algorithm

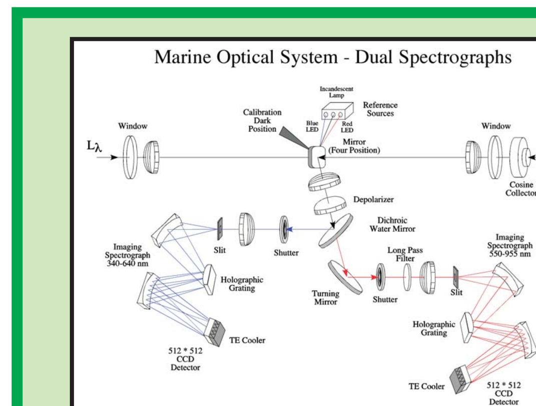


John O'Reilly, NOAA; SIMBIOS Project, NASAs GSFC

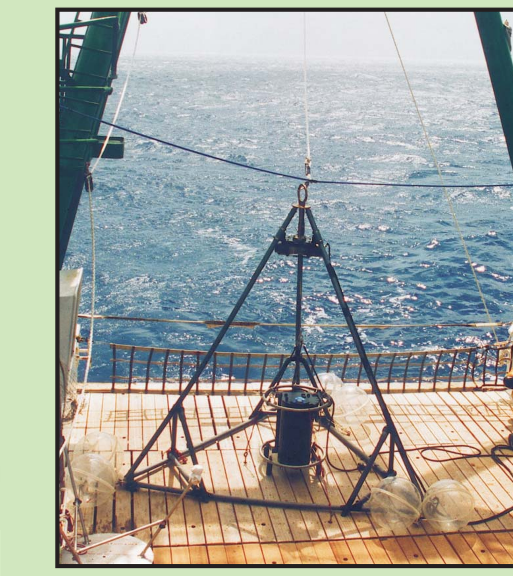


Once the Satellite data are correctly calibrated and the atmospheric contamination is removed, the data are converted into pigment concentrations using band ratioing. Measurements of in-situ pigment concentrations and in-water radiance are used to produce a bio-optical algorithm which convert the satellite measured water leaving radiance into pigment concentrations. The four scatter graphs above show the relationship between observed pigments and in-water radiometric data from the world ocean, the solid line gives the SeaWiFS empirical algorithm. MODIS uses a similar scheme to relate a number of different satellite band ratios to various bio-optical products.

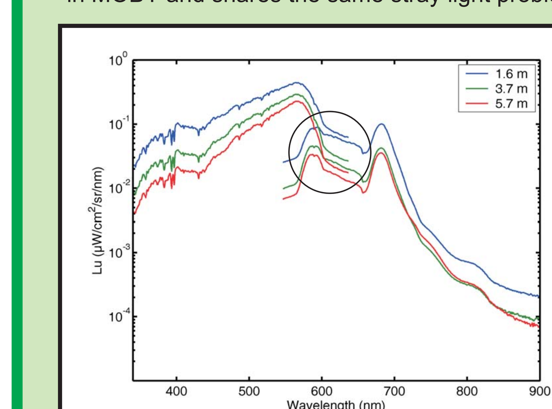
Instrument used to Develop the Bio-optical Algorithms



The Marine Optical System (MOS) is a sophisticated, general-purpose, high spectral resolution radiometer. The same radiometer is used in MOBY and shares the same stray light problem.



Ship deployed MOS profiler

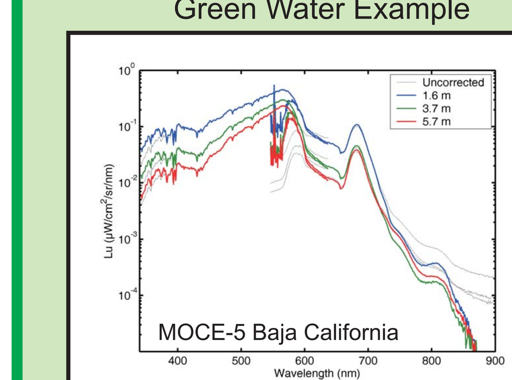


Circled Region: Lu derived using the two spectrographs in MOS, as in MOBY, disagree in their region of overlap.

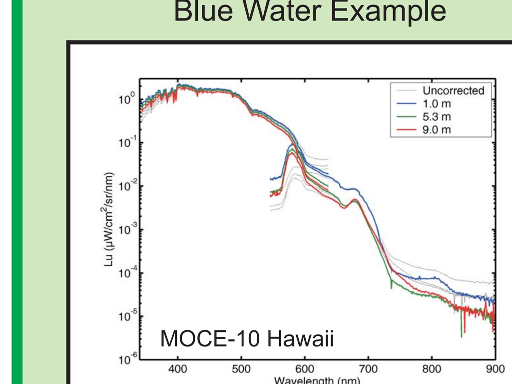
The primary difference between MOBY and the MOS profiler is that MOS is ship deployable and therefore portable. This allows characterization of many different water types and locations.

Impacts of Stray Light Correction on Bio-optical Algorithms

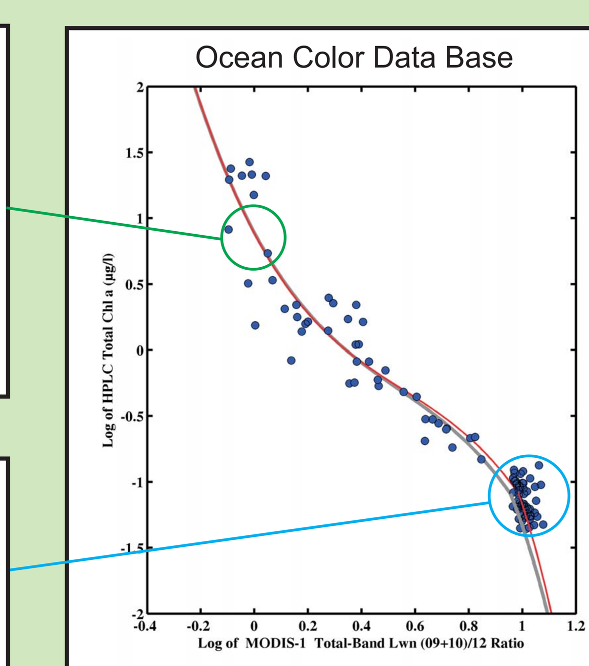
Green Water Example



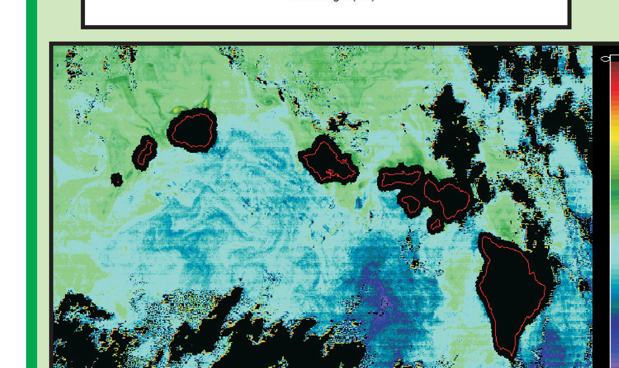
Blue Water Example



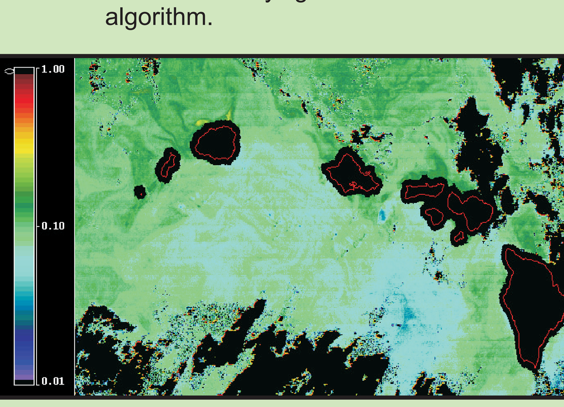
Ocean Color Data Base



The gray line shows the non-stray light corrected satellite algorithm; the red line shows the stray light corrected algorithm.



Before stray light correction



After stray light correction