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"Ocean Color Vicarious Calibration, the role of surface measurements"

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MOBY TEAM (Carol Johnson, NIST, and Mark Yarbrough and many at Moss Landing Marine lab)

4/10/13, NOAA.

1) The problem

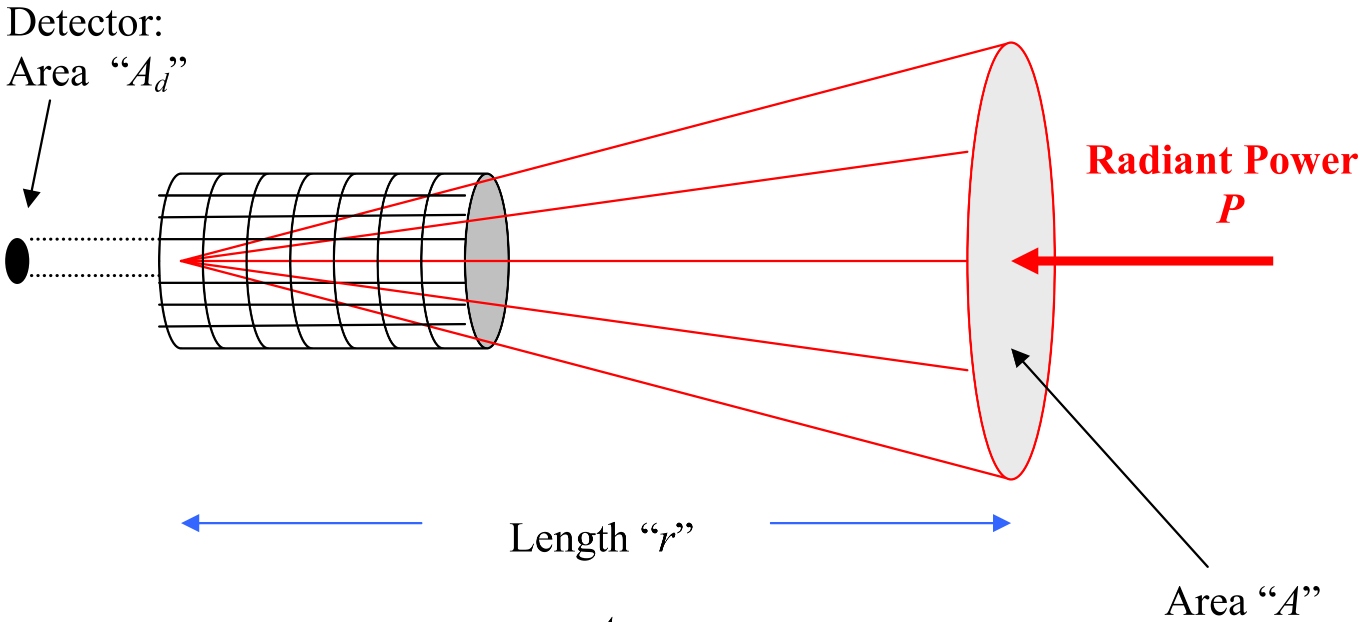
2) Definition of terms

3) Overview of the in-water approach

4) The current MOBY system and how it is used

5) The Refresh MOBY system, and at least one advantage of the new system

Radiance (L)
Reflectance (ρ)

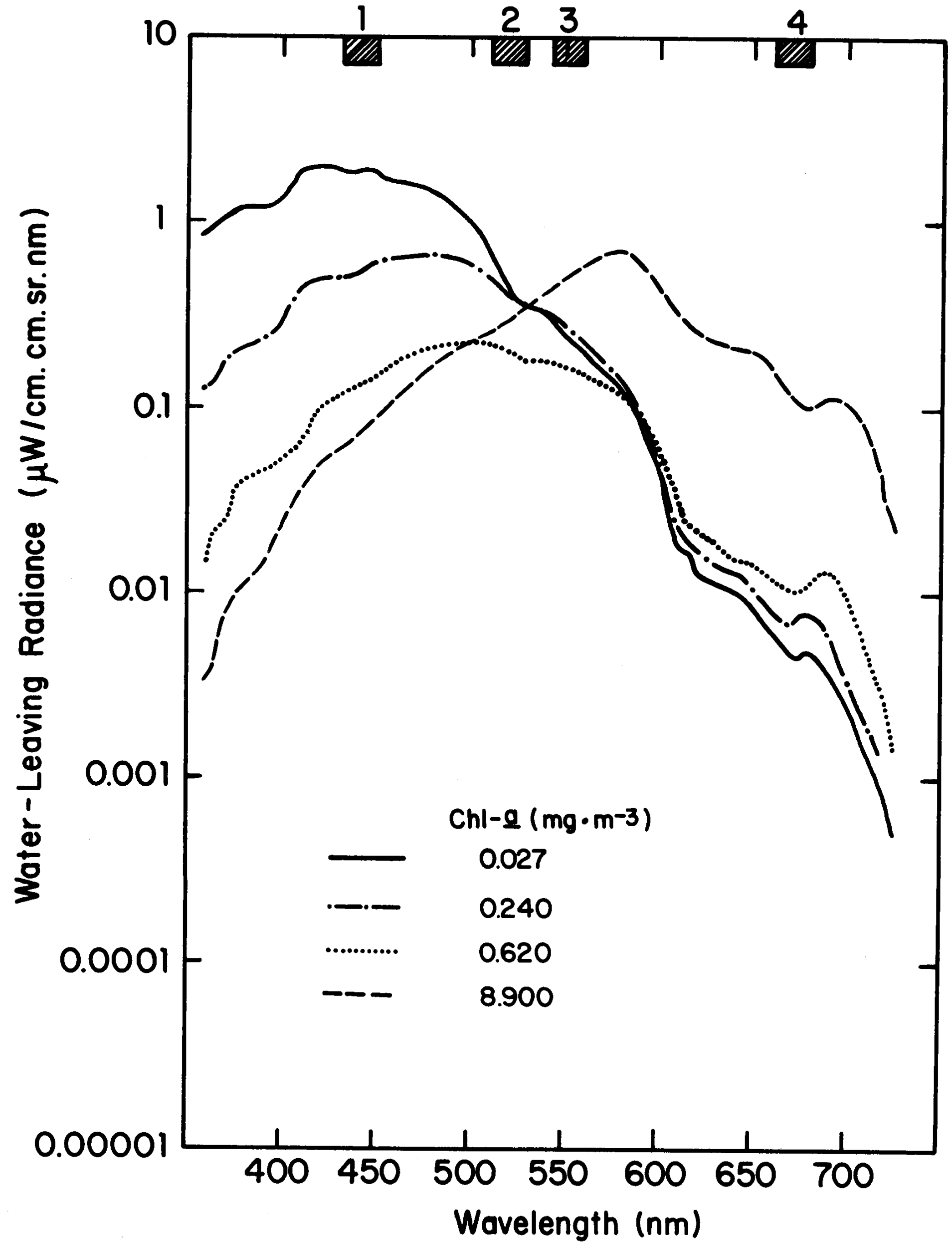


$$\Omega = \frac{A}{r^2}$$

$$\boxed{L = \frac{P}{A_d \Omega}}$$

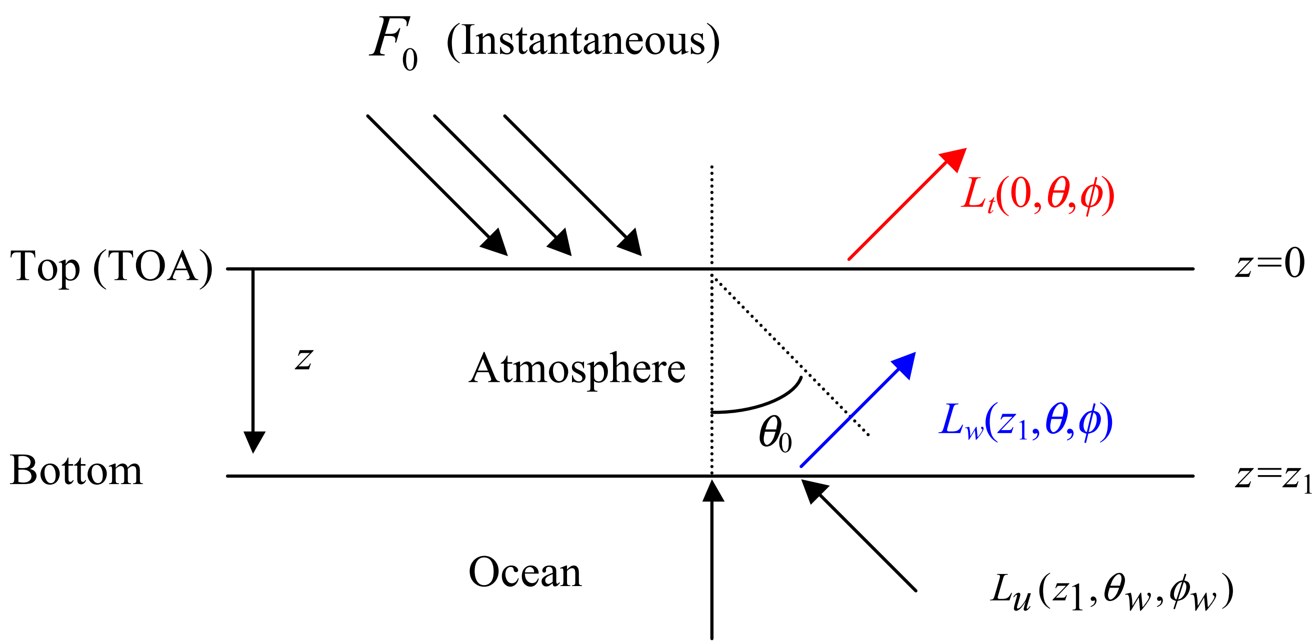
$$\boxed{\rho = \frac{\pi L}{F_0 \cos\theta_0}}$$

Since Clarke, Ewing and Lorenzen's aircraft measurements (Science, 1970) the relationship between surface Chl and the spectra of the water leaving the ocean has been known. This leads to the possibility of measuring Chl from space.



From Gordon et al.1985, in **Satellite Oceanic Remote Sensing**

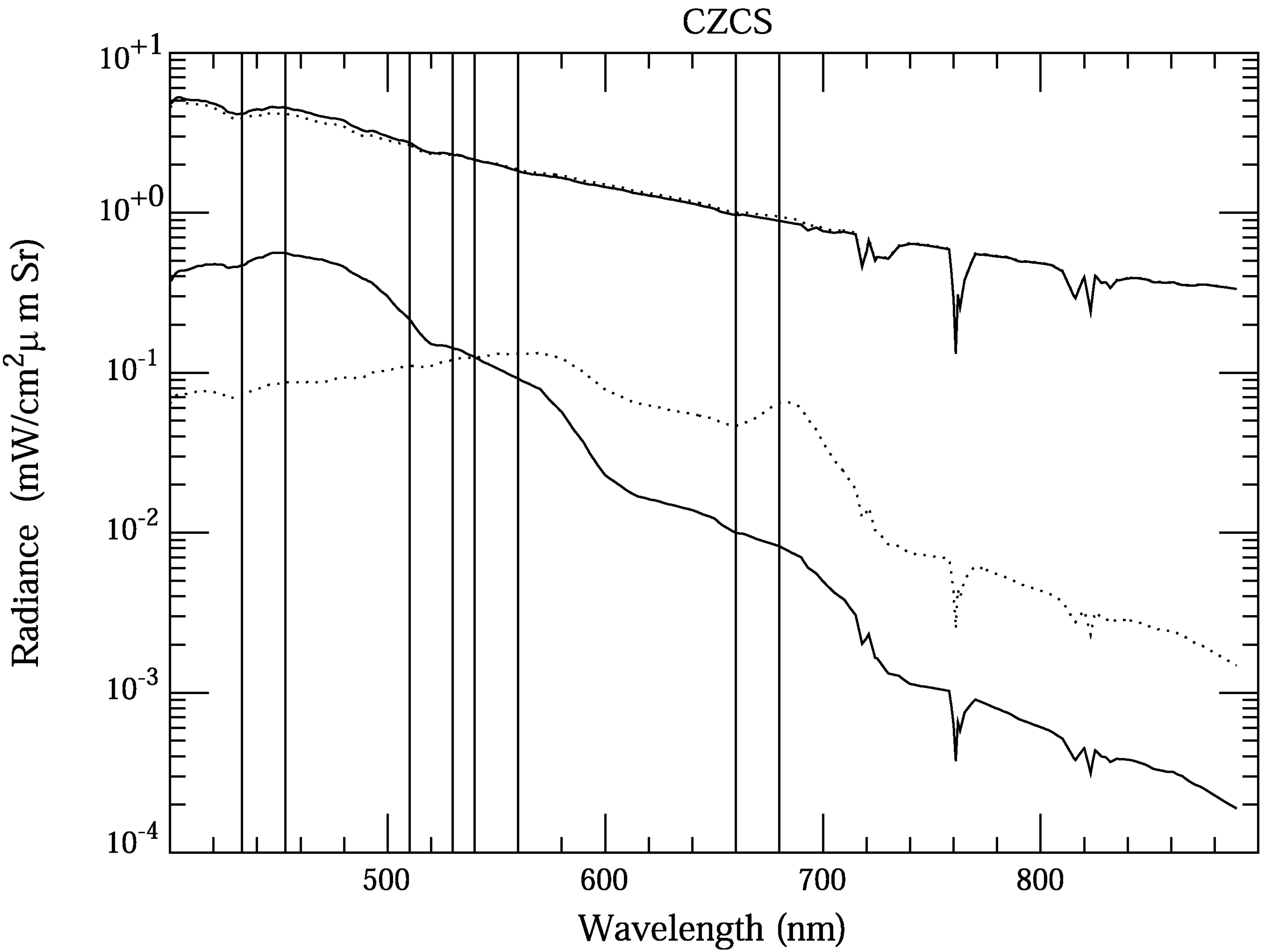
The Remote Sensing Problem



The goal is given L_t find L_w

$$L_t = L_r + L_a + L_{ra} + t_v L_w$$

$$L_w=(1-\rho)L_u/n^2$$



CZCS
10^{+1}
10^{+0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Radiance (mW/cm^{2}μ m Sr)
500
600
700
800
Wavelength (nm)

The originally announced goal for ocean color sensors:

The uncertainty in the (normalized) water-leaving radiance retrieved from the sensor in oligotrophic waters at 443 nm should not exceed 5%, and uncertainty in Chlorophyll should be < 30%.

For such waters, $[\rho_w(443)]_N$ is approximately 0.04, meaning that the maximum error allowed is 0.002. The atmospheric correction algorithm was specifically designed to meet this goal.

If we take the error in atmospheric correction to typically be of the order of 0.001, then meeting this goal would require the sensor have a calibration uncertainty no more than about 0.001/0.20 or ~ 0.5% at 443 nm. This is difficult to meet even prelaunch!

In-orbit calibration (vicarious) to adjust the pre-launch calibration.

Two methods

1) Radiometric Vicarious Calibration

$$L_t(\lambda) = L_r(\lambda) + L_A(\lambda) + t_v(\lambda)t_s(\lambda)[L_w(\lambda)]_N$$

Compute using atmospheric pressure

Estimate using sun photometer and sky radiance

Determine using in-situ measurements

Estimate L_t and adjust calibration to force agreement with the estimated value. Calibration accuracy is limited by the accuracy of the surface measurements.

2) System Vicarious Calibration

"System" means the sensor *and* the atmospheric correction algorithm.

Determine using in-situ measurements

$$L_t(\lambda) = L_r(\lambda) + L_A(\lambda) + t_v(\lambda)t_s(\lambda)[L_w(\lambda)]_N$$

1) Assume calibration in longest NIR band is correct (no error).

2) Adjust calibration in second longest NIR band so that the spectral variation of L_A is consistent with the aerosol type typical at the calibration site.

3) Apply atmospheric correction algorithm to L_t and adjust the calibration to force agreement with the measured values of $[L_w(\lambda)]_N$. (Note: ancillary data, etc., measured at cal. site.)

NEED ONLY ACCURATE $L_w(\lambda)$

Obtain a factor, g, which adjusts original cal number (L_t (true) = gL_t(old cal))*

System calibration has several advantages:

1) The residual calibration errors will all be of the same sign. Good for ratio algorithms.

2) The residual calibration errors will decrease from the NIR to the blue. Blue channels most important for OC.

3) The NIR error can be reduced/quantified by radiometric vicarious calibration. Reducing this error will concomitantly reduce the residual error in all shorter wave bands.

4) Pragmatically, the sensor is being forced to do the job for which it was designed.

Requirements for primary ocean color site:

1) Able to reliably observe from space: cloud free as much as possible

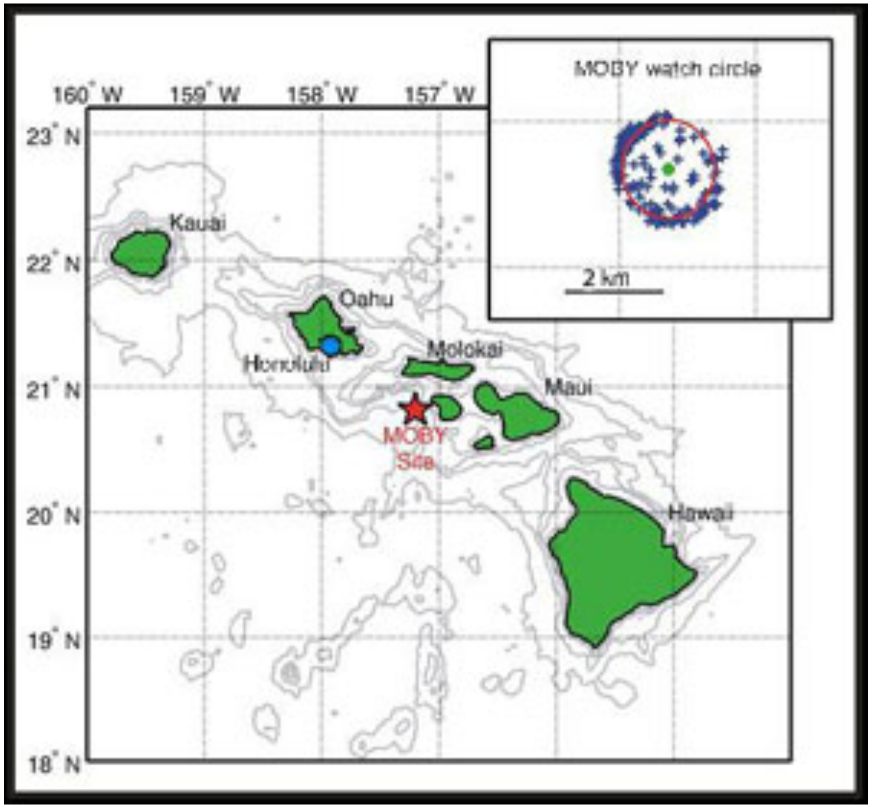
2) clear, clean atmosphere so that the demands on the atmospheric correction are limited

3) stable homogeneous water properties: must be able to extend point measurement of optical properties to that of the 1km pixel (or more) measured by the satellite sensor

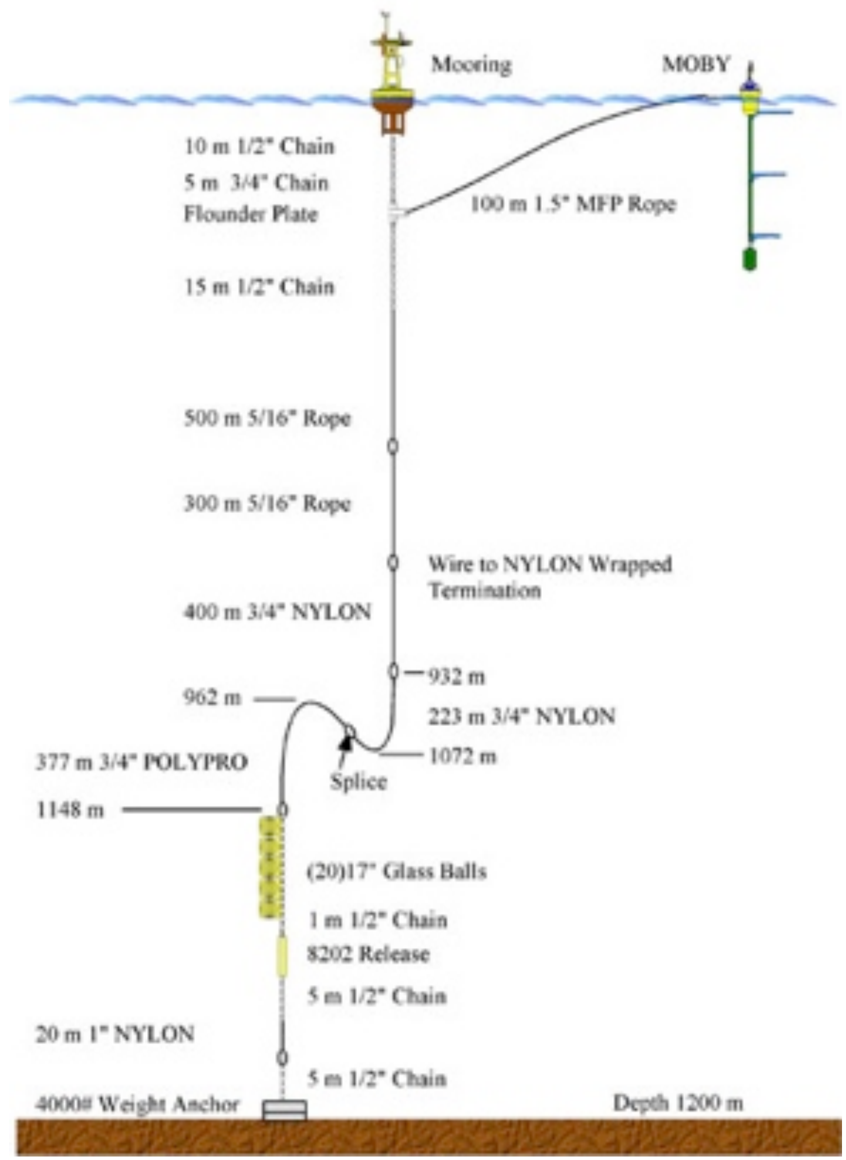
4) far enough from shore to avoid near-field optical influences

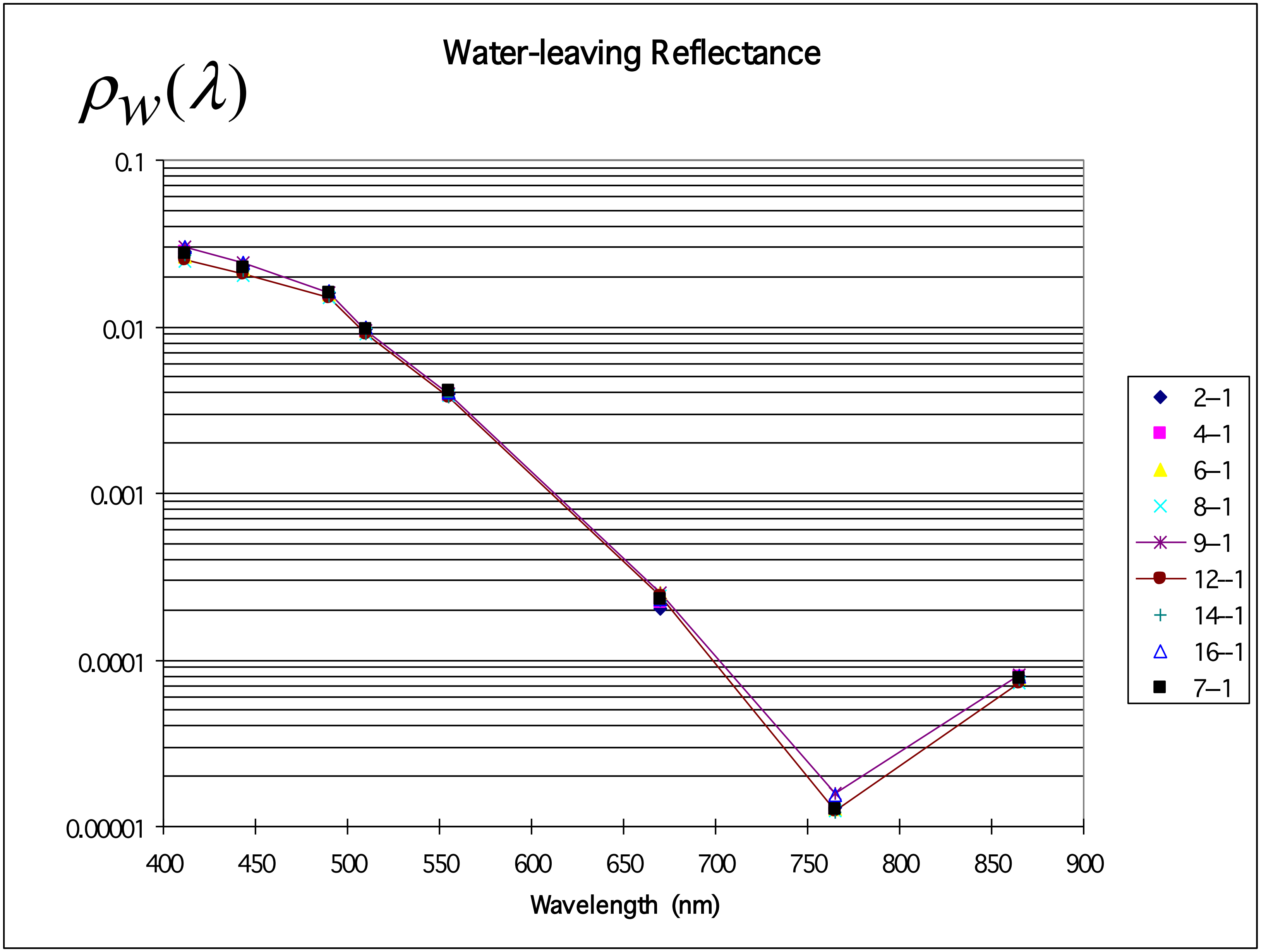
5) deep water so that shallow water influence is gone

Dennis Clark (NOAA/NESDIS) chose the site shown below off of Lanai, Hawaii.

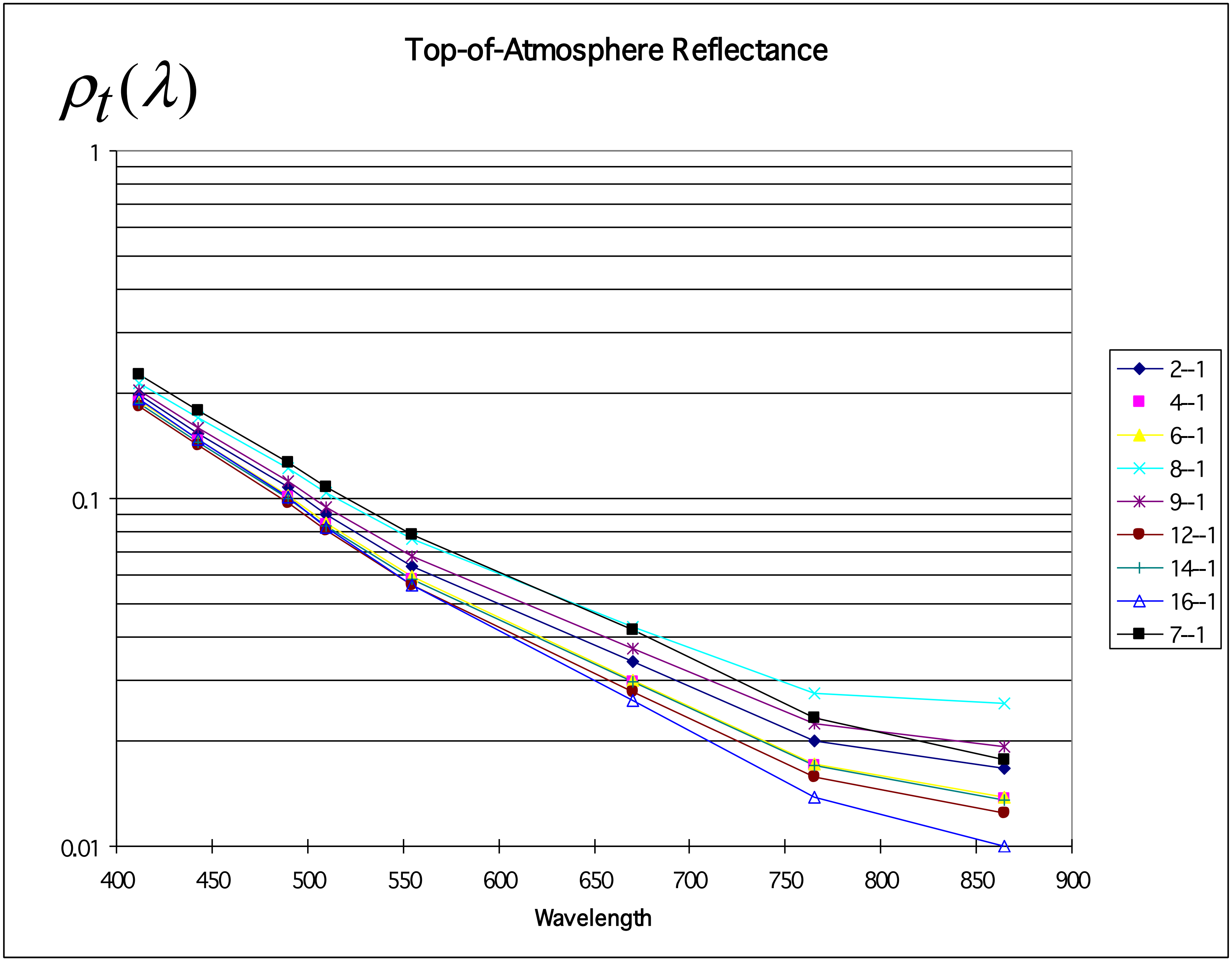


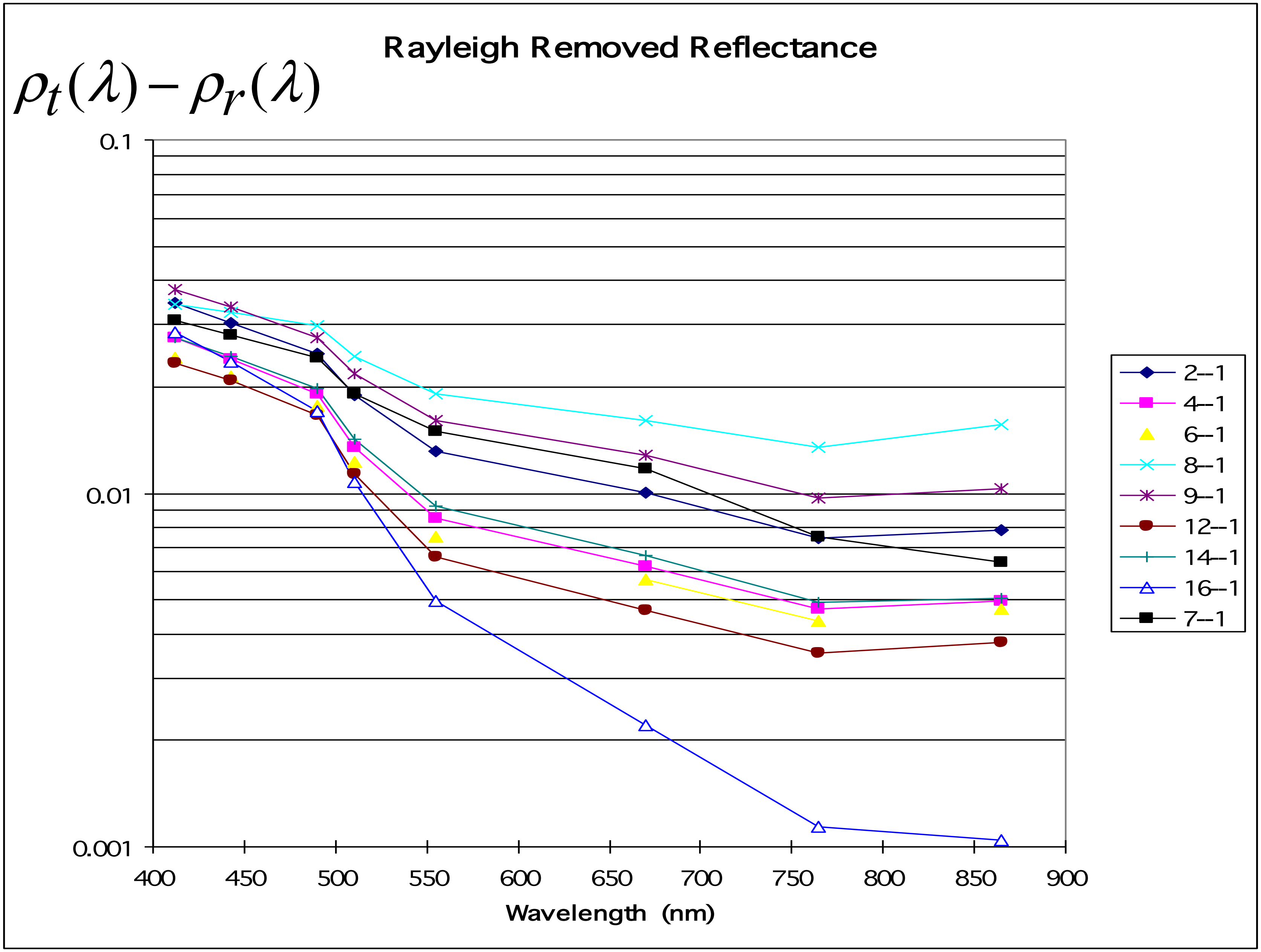
MOBY & Lanai Mooring

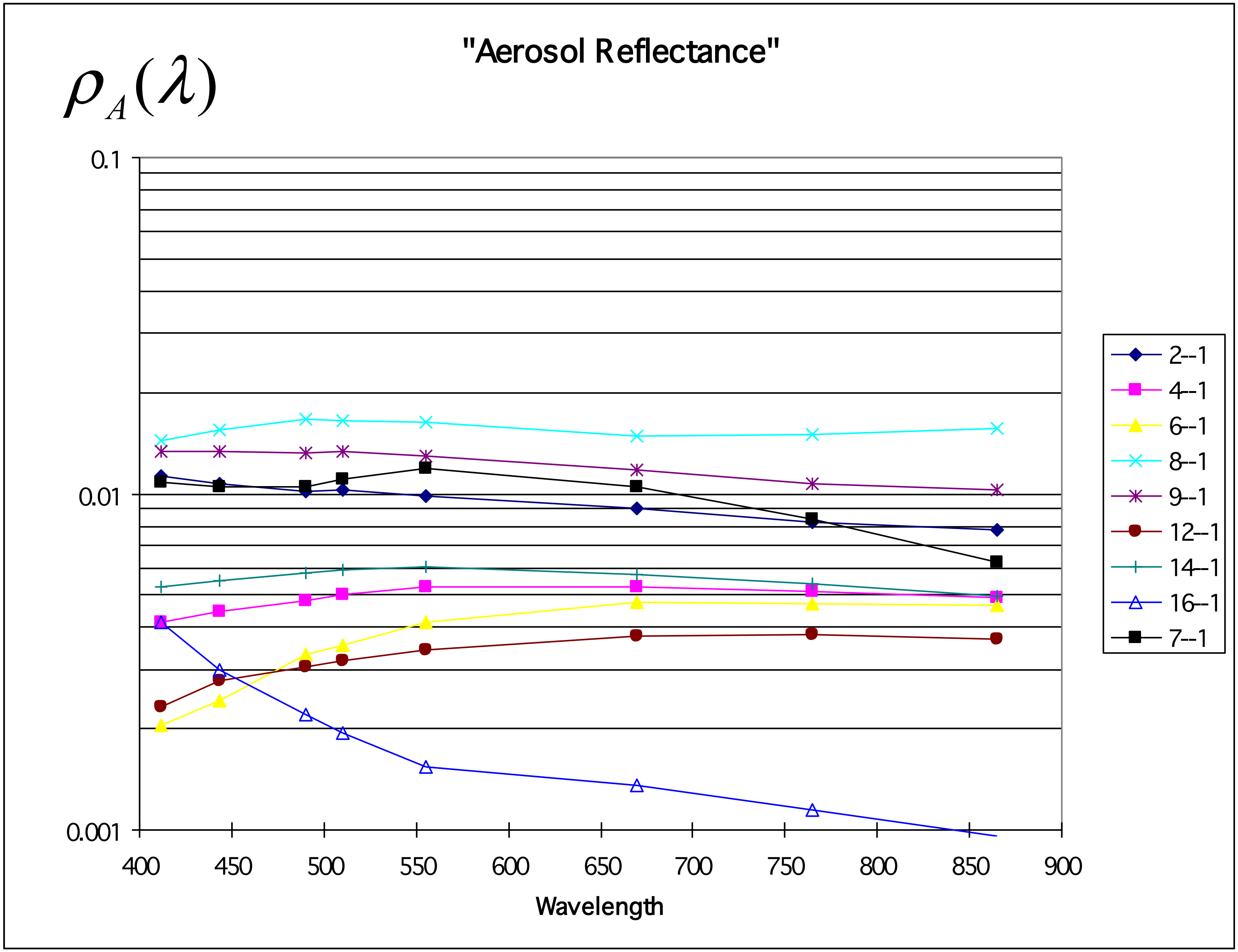




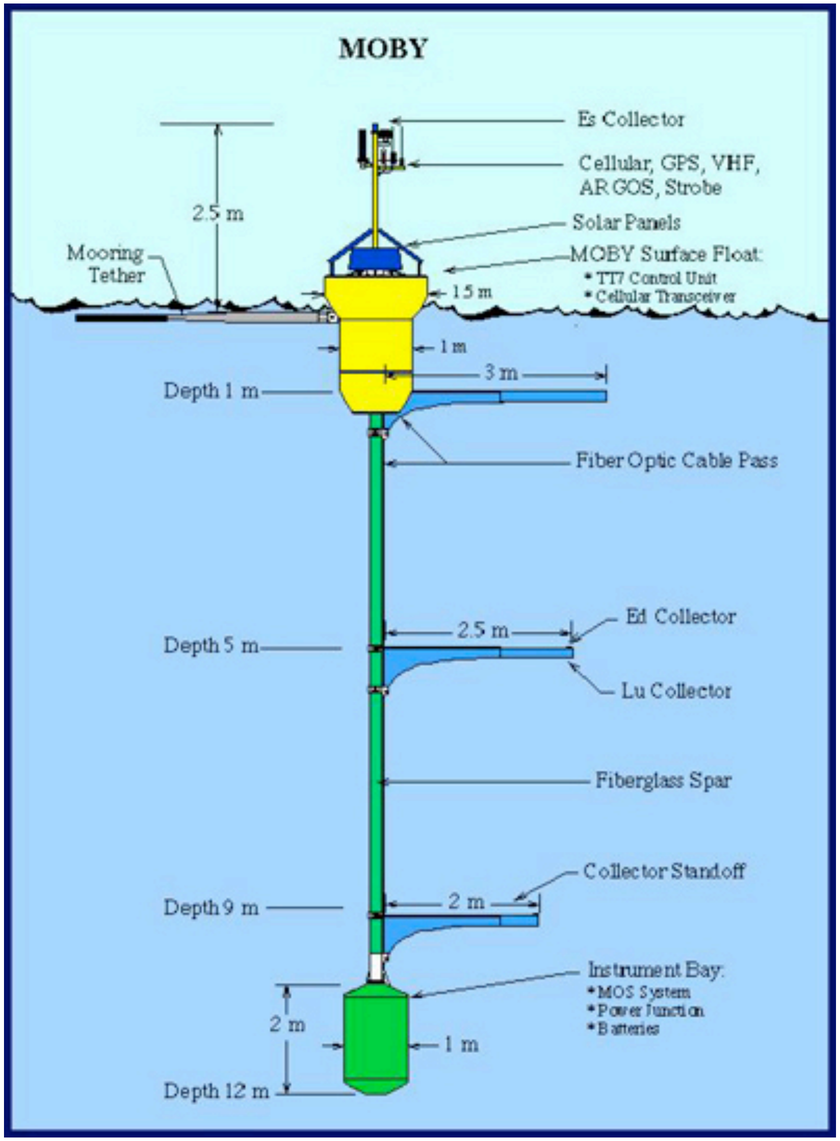
Water-leaving Reflectance
$\rho_w(\lambda)$
0.1
0.01
0.001
0.0001
0.00001
400
450
500
550
600
650
700
750
800
850
900
Wavelength (nm)
2–1
4–1
6–1
8–1
9–1
12–1
14–1
16–1
7–1

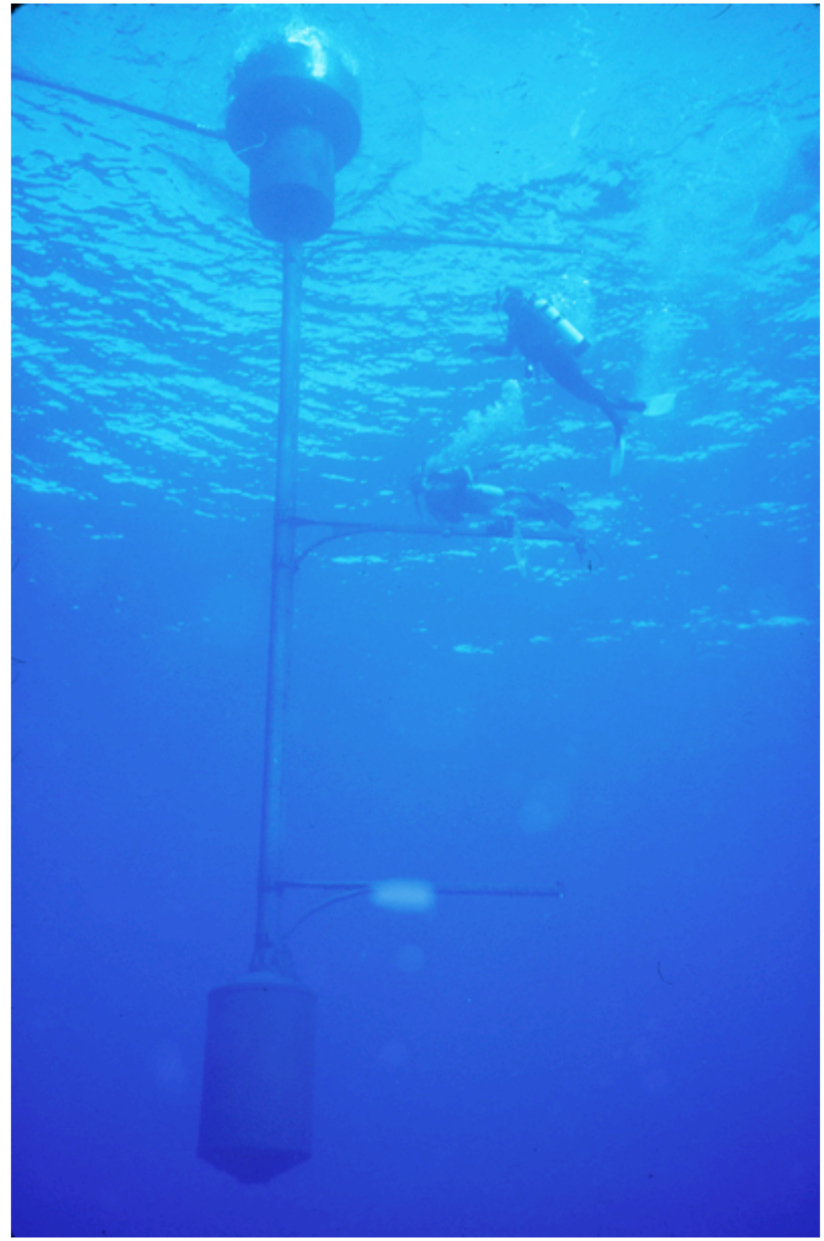

Top-of-Atmosphere Reflectance
$\rho_t(\lambda)$
1
0.1
0.01
400
450
500
550
600
650
700
750
800
850
900
Wavelength
2--1
4--1
6--1
8--1
9--1
12--1
14--1
16--1
7--1


Rayleigh Removed Reflectance
$\rho_t(\lambda) - \rho_r(\lambda)$
0.1
0.01
0.001
400
450
500
550
600
650
700
750
800
850
900
Wavelength (nm)
2--1
4--1
6--1
8--1
9--1
12--1
14--1
16--1
7--1

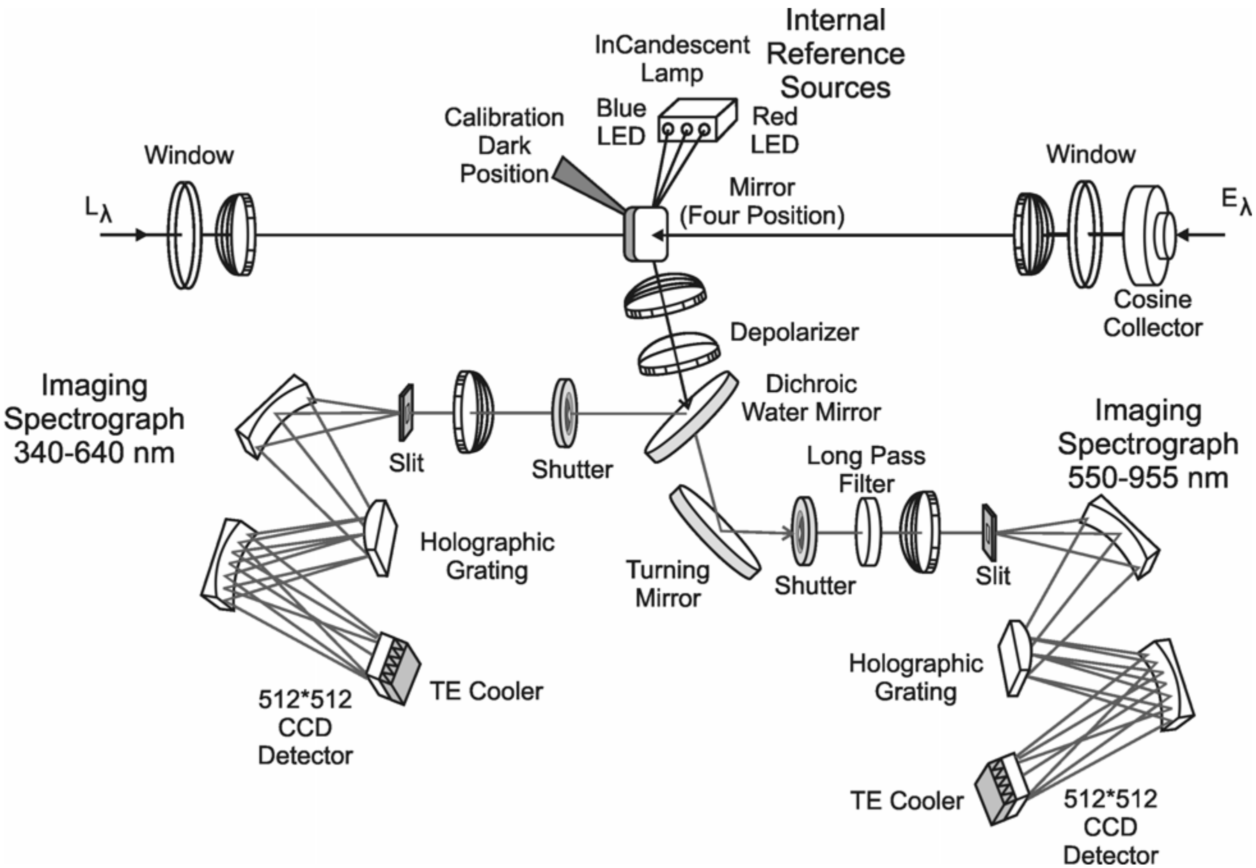


"Aerosol Reflectance"
$\rho_A(\lambda)$
0.1
0.01
0.001
400
450
500
550
600
650
700
750
800
850
900
Wavelength
2--1
4--1
6--1
8--1
9--1
12--1
14--1
16--1
7--1


MOBY
Es Collector
Cellular, GPS, VHF, ARGOS, Strobe
2.5 m
Solar Panels
Mooring Tether
MOBY Surface Float:
* TT7 Control Unit
* Cellular Transceiver
1.5 m
1 m
3 m
Depth 1 m
Fiber Optic Cable Pass
Depth 5 m
2.5 m
Ed Collector
Lu Collector
Fiberglass Spar
Collector Standoff
Depth 9 m
2 m
Instrument Bay:
*MOS System
*Power Junction
*Batteries
2 m
1 m
Depth 12 m



Schematic of Current MOBY



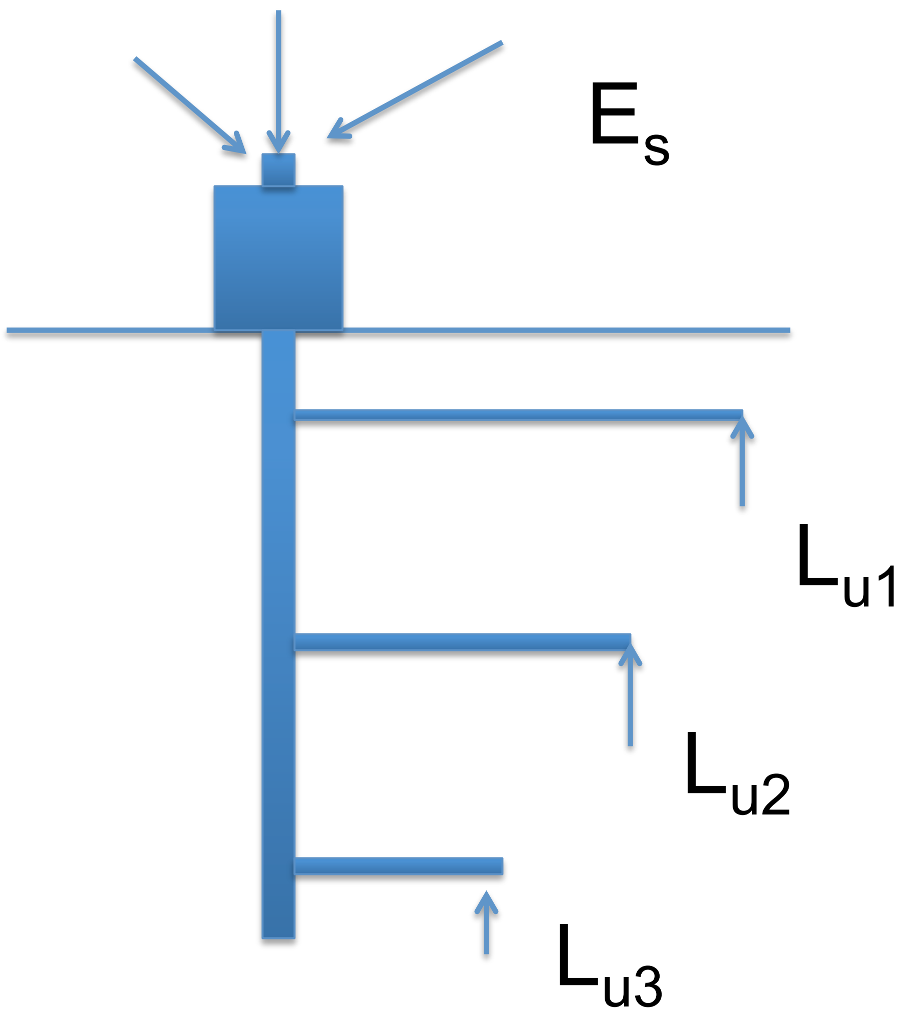
Hyperspectral,0.57 nm spacing in blue spectral region, 0.91 nm FWHM
0.81 nm and 1.2 nm FWHM in red.

Hyperspectral, with this much resolution, allows the same system (one site) to be used for multiple satellite sensor systems, including out-of-band response, to tie these systems together.

This system has been extensively characterized

- Stray light characteristics on SIRCUS repeatedly measured, with corrections added to data
- Pre-post radiometric response with direct traceability to NIST scales
- Additional monitoring of calibration sources with custom instruments
- Diver calibrations/cleaning monthly
- Daily on board sources monitored
- Site has been extensively characterized

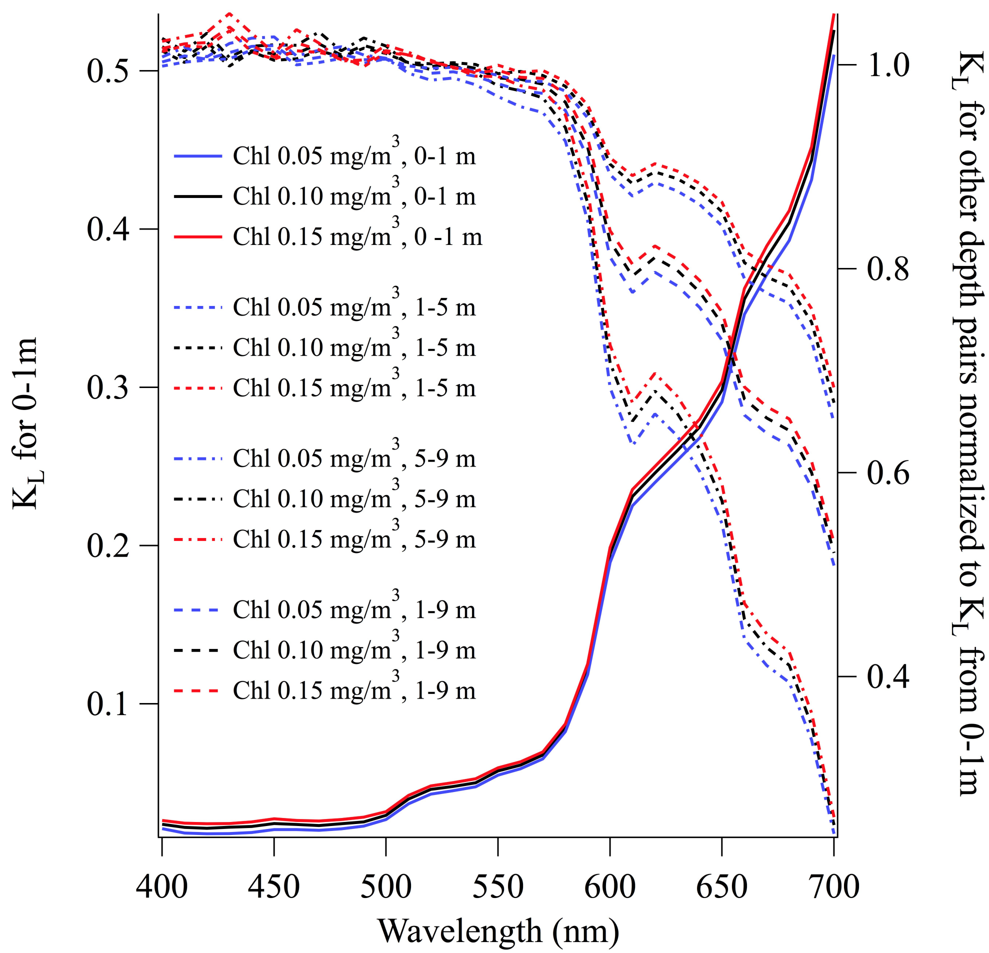
MOBY Measurements, three times/day

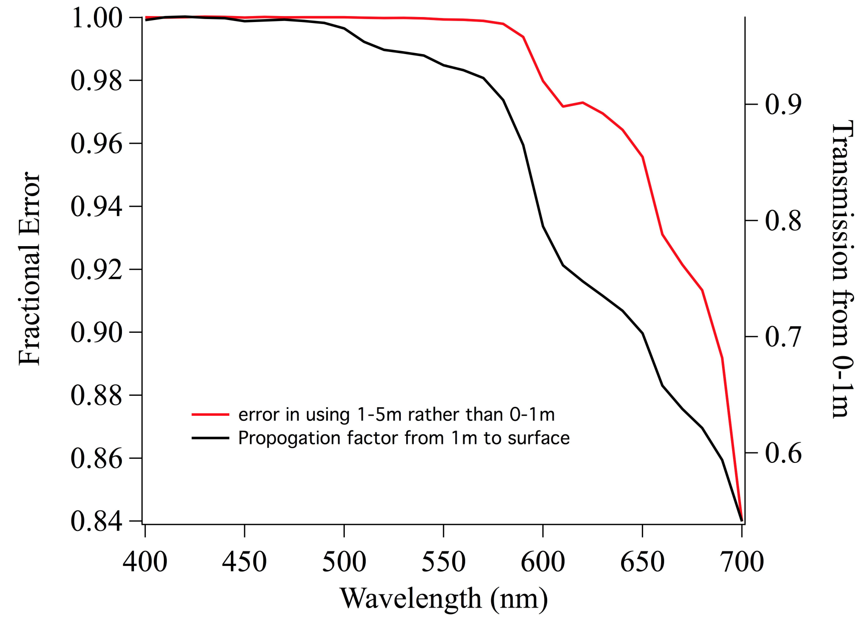


Need to take one of the Lu's and propagate it from the measurement depth to the surface, and then through the surface.

Use pairs of Lu to get radiance attenuation coefficient.

KL (0-1m) from a model





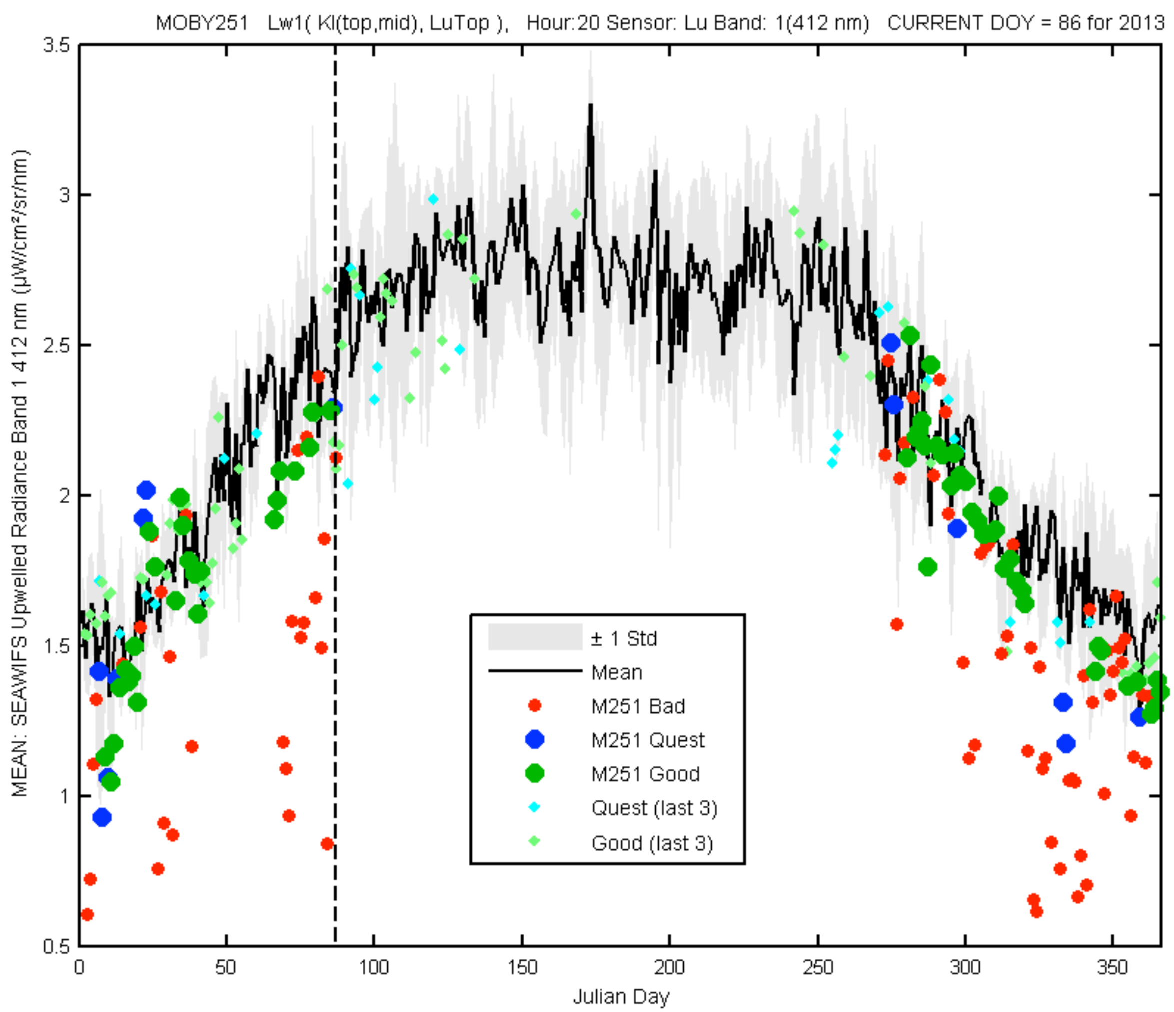
Derivation of water leaving radiance

$$K\left(z_{ij},\lambda\right)=\frac{1}{z_j-z_i}\ln\left(\frac{L_u(z_i,\lambda)E_s(t_j,\lambda)}{Lu(z_j,\lambda)E_s(t_i,\lambda)}\right), z_j > z_i, i = 1,2,3, j = 2,3$$

$$L_{w}(\lambda)=\frac{1-\rho}{n^2}L_u\left(z_i,\lambda\right)e^{K_L(z_{ij},\lambda)z_i}$$

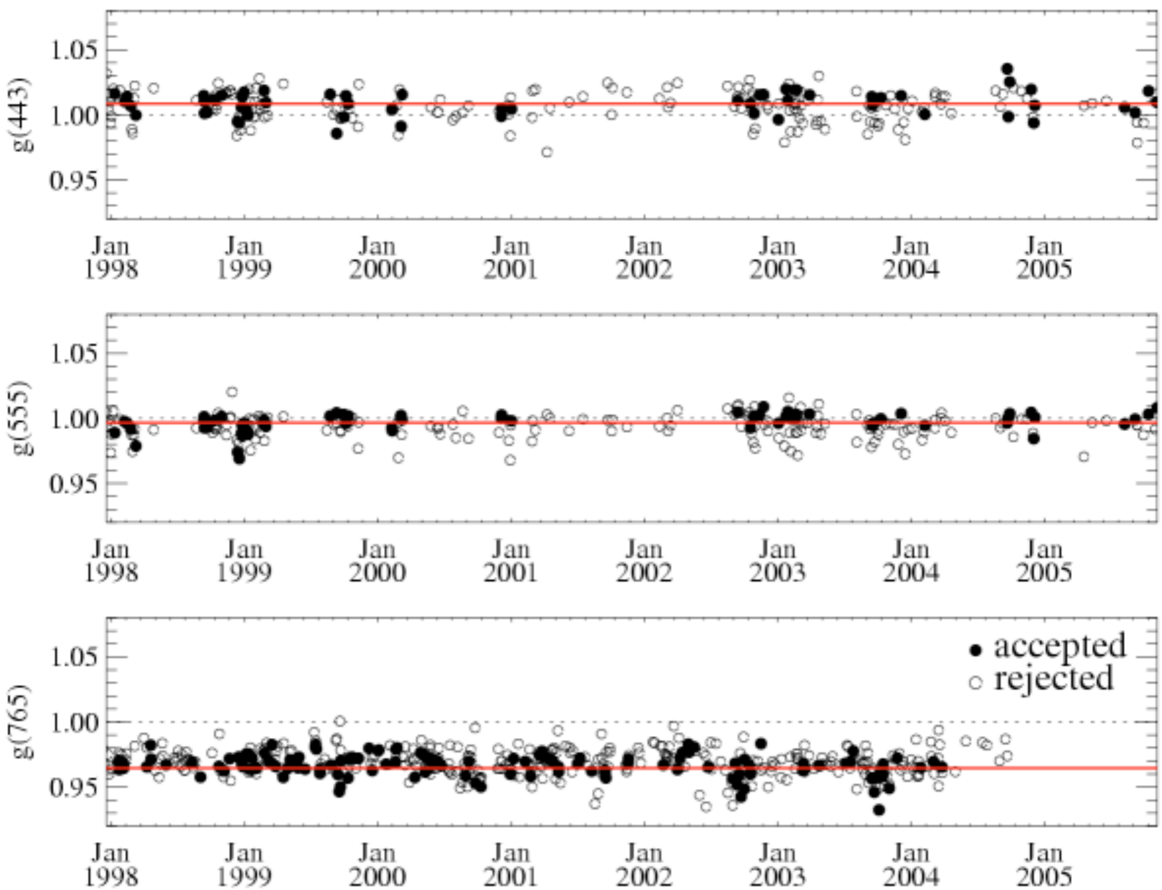
Typically propagate upwelling radiance from 1m arm to surface (via K), then through the surface (via (1-ρ) and n^2)

Obtain a time series of Lw, individual measurements used in VC



Each good measurement if a corresponding satellite measurement is found, can be be used to generate a gain factor to adjust the calibration of the satellite sensor

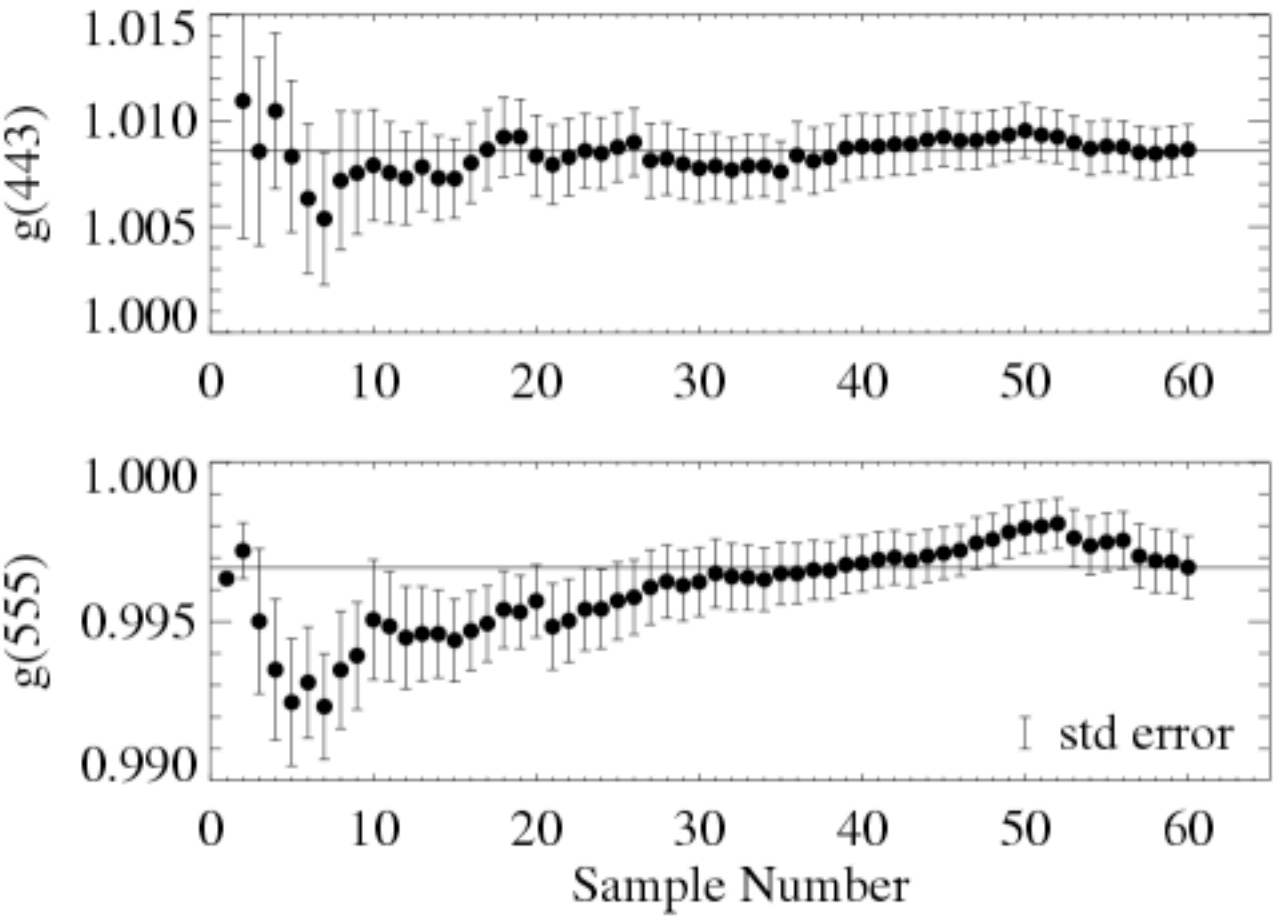
Example of gain calibration (SeaWiFS, OBPG, NASA/GSFC)



Note, this is with SeaWIFS which had very good stability characteristics and had frequent lunar looks to keep temporal stability in check.

Werdell et al., 2006, Ocean Optics XVIII, http://oceancolor.gsfc.nasa.gov/cgi/obpgpubs.cgi

Because of measurement uncertainties and variabilities, one measurement is not sufficient.



Once again, this is with SeaWIFS which had very good stability characteristics and had frequent lunar looks to keep temporal stability in check.

Werdell et al., 2006, Ocean Optics XVIII,
http://oceancolor.gsfc.nasa.gov/cgi/obpgpubs.cgi

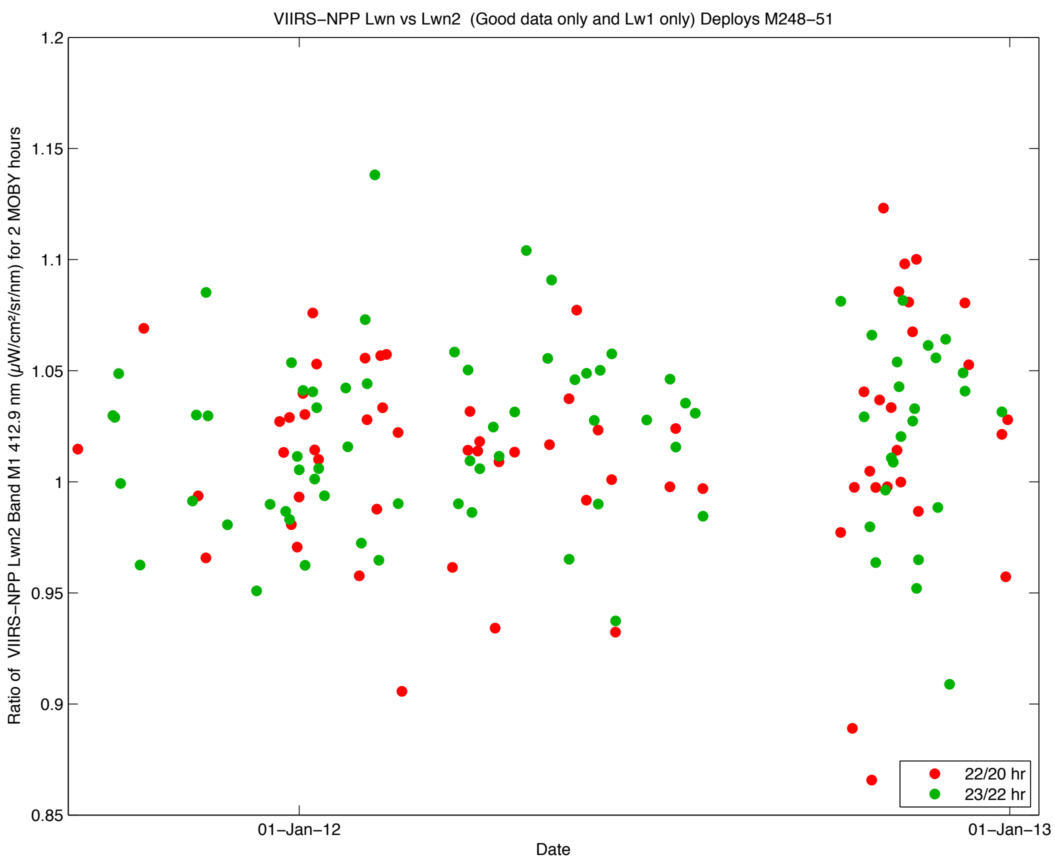
Typical conditions on Satellite matchups

- Suitable homogeneity in 5 x 5 pixel box around measurement site
- Measurement within 3 hrs of satellite view
- Sensor view zenith <60 degrees
- Solar zenith angle <75 degrees

(Bailey and Werdell, 2006, RSE)

From Menghua Wang (NOAA) so far there have been about 83 matchups of best quality MOBY data for VIIRS

- Typically 5% variation or so, independent of time.

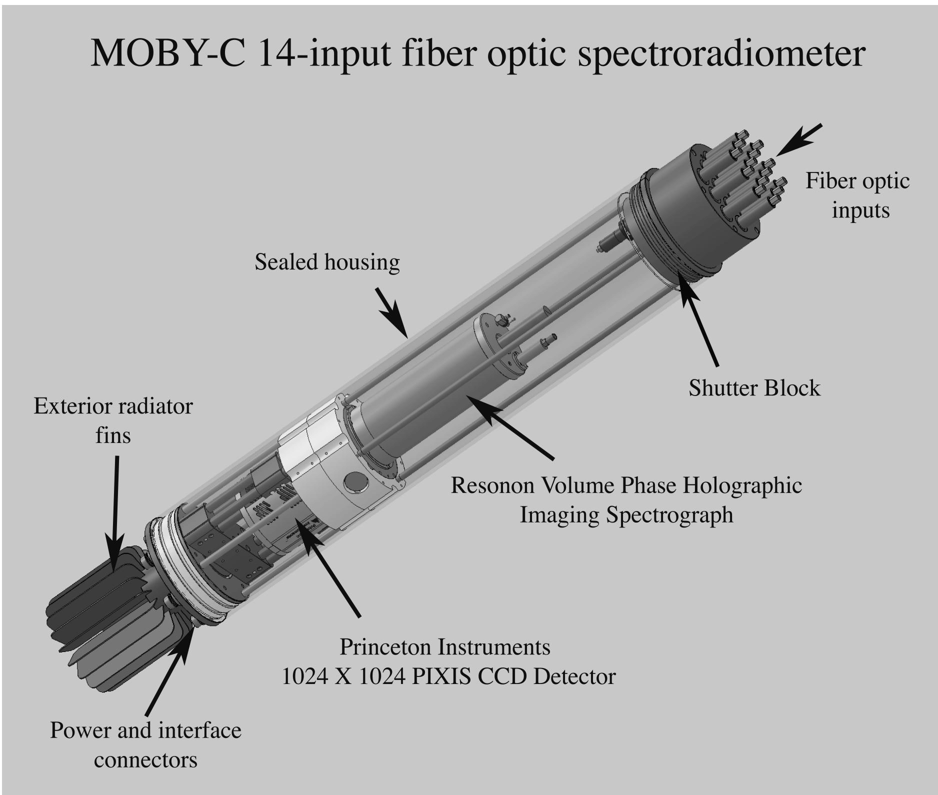


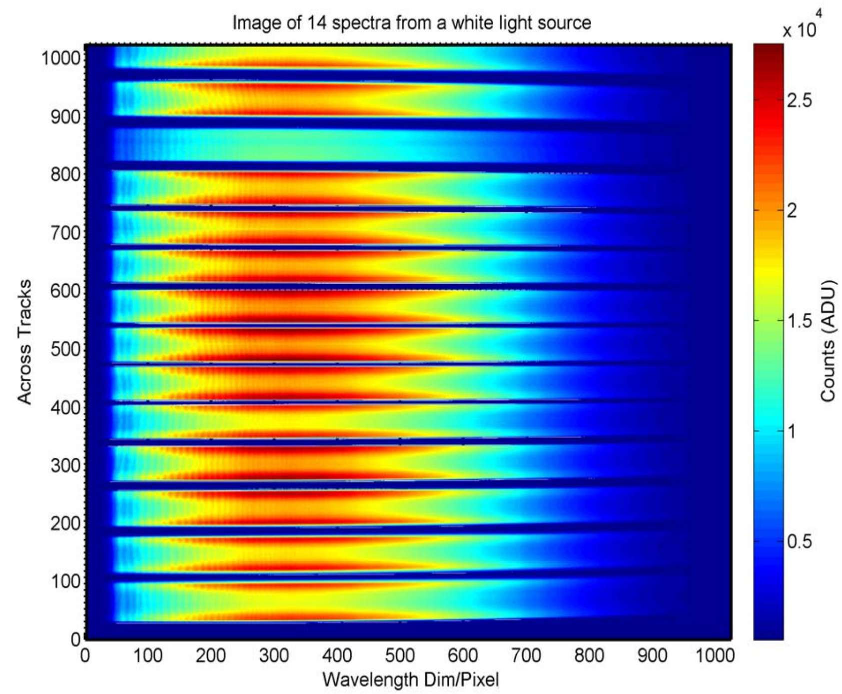
Mean 1.01-1.02

Std 0.04-0.05

Basically no consistent offset, noise consistent with random environmental noise.

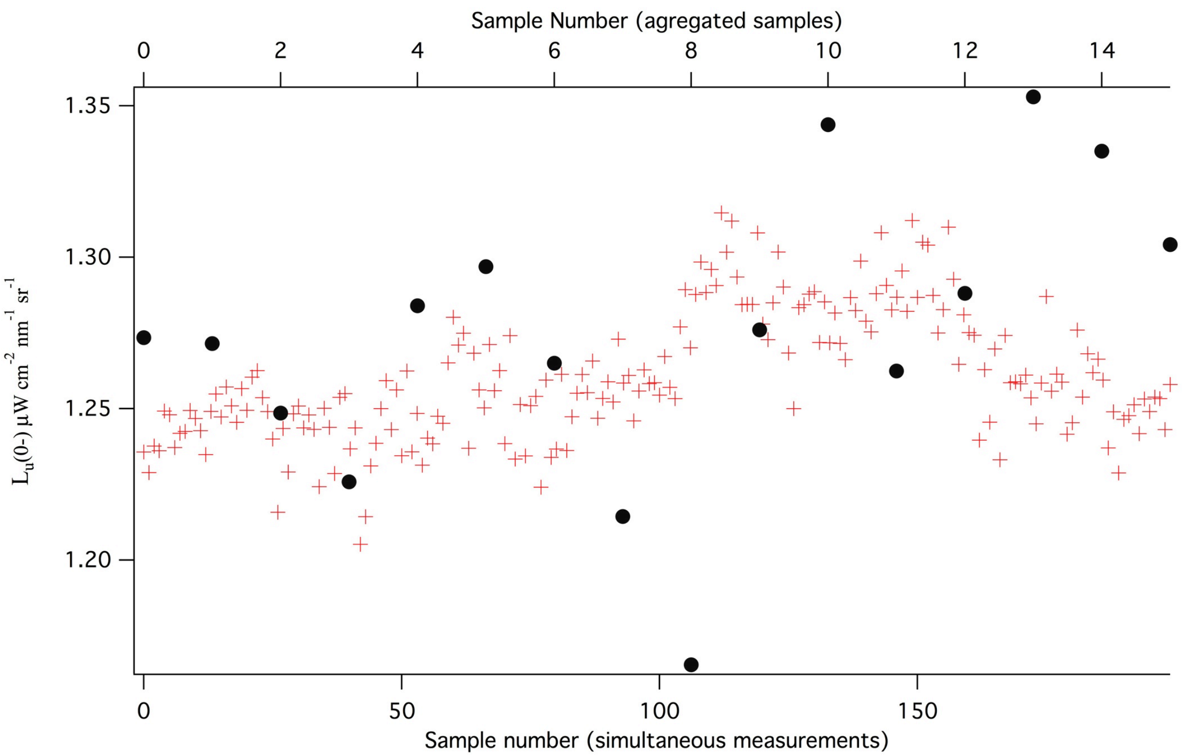
MOBY Refresh





Reduced Environmental Noise with new instrument

Comparison of simultaneous measurements and sequential with test data set. Sequential measurement has %std around 0.04, while simultaneous has 0.01. Because of correlations, simultaneous much better. Reduced noise here reduces noise in *g*, reducing number of matchups required to obtain *g* within desired accuracy.

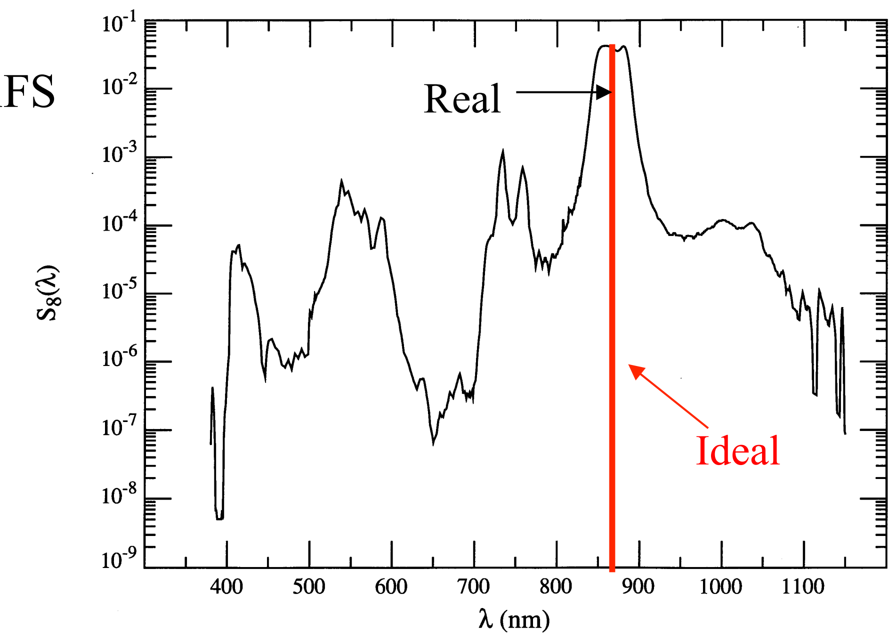


Instrument used was a prototype of the new optical system with simultaneous measurements at different depths.

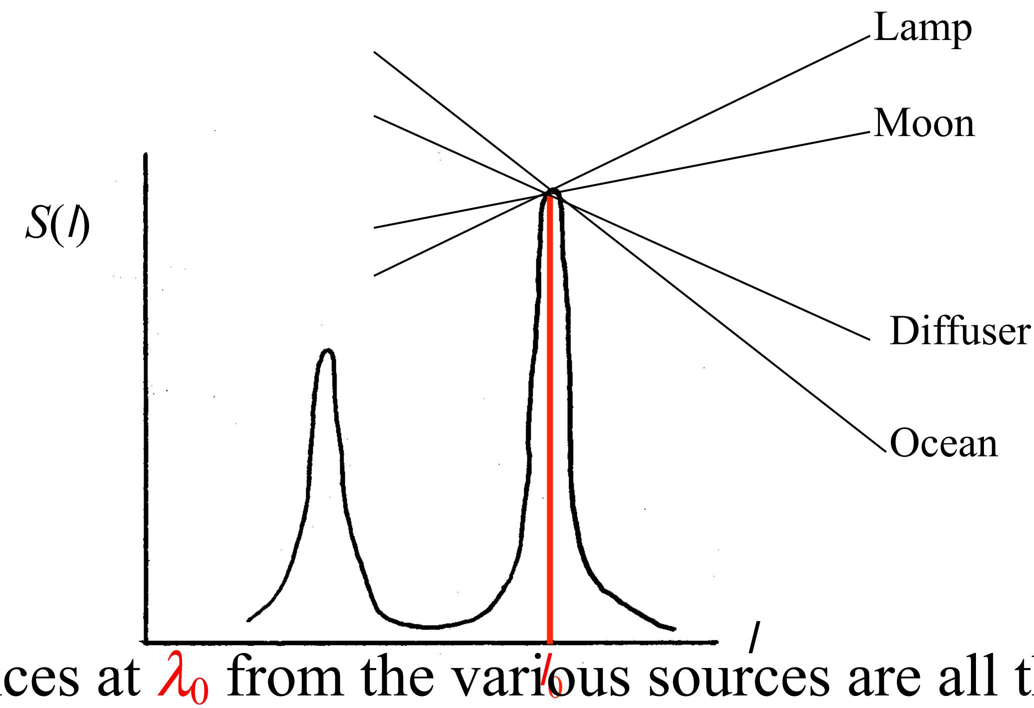
Other calibration issues: Out-of-Band Response: Sensors with Broad Spectral Bands

Sensors do not view the earth with infinitesimally narrow spectral bands (as we have been assuming, e.g., SeaWiFS Band 8 (865 nm).

$S_8(\lambda)$ is the electrical output of SeaWiFS from nearly monochromatic input of radiance 1 mW/cm^2-μm-Sr at λ.



Note that with significant out-of-band, the “measured” radiance is dependent on the spectral distribution of the calibration source, which could be the moon, a calibration lamp, solar diffuser, or the ocean.



Even if the radiances at λ_0 from the various sources are all the same, the “measured” radiances will be different. This suggests vicarious calibration, i.e., looking at the ocean, will be the best, but characterization of the out-of-hand response is still essential. Also, it is important to validate calibration with sites with different spectral characteristics.

Conclusions

Vicarious calibration is required for ocean color measurements

MOBY provides the best measurements for vicarious calibration, in a suitable site, with sufficient spectral resolution to accommodate multiple satellite sensor missions.

Beyond the vicarious calibration in one site, other sites are required to validate both the atmospheric correction and characterization of the out-of-band response for varied atmospheres and “colored” scenes.