Marine Optical BuoY (MOBY)

Radiometric Uncertainty Budget for Ocean Color Satellite Sensor Vicarious Calibration

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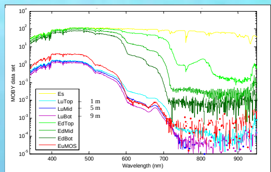
MOBY calibration was a NOAA-NASA-NIST collaborative effort; Goal was 3 % uncertainty (k=1) in water-leaving radiance

MOBY Measurements

Down-welling irradiance & up-welling radiance

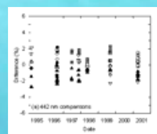


350 nm – 640 nm
0.6 nm pixel spacing

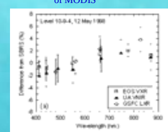
560 nm – 960 nm
0.8 nm pixel spacing

Is 3 % uncertainty a realistic goal?

Results of 7 NASA EOS measurement campaigns



Results of a campaign to measure the radiance source used for the calibration of MODIS



These were laboratory measurements, using high quality transfer standard instruments

the standard uncertainty of the measurements is around 1.5 %

J. Butler, *et al.*, Proc. SPIE 6677, 6677-06 (2007).

MOBY operates for extended periods in a difficult environment

MOBY Site ~ 20 km from Lanai

Uncertainty budget for MOBY top arm up-welling radiance interpolated to MODIS Terra bands

Current L_u Uncertainty Budget

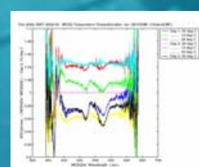
Uncertainty Component	MODIS Terra Band [%]					
	8	9	10	11	12	13
	411.8 nm	442.1 nm	486.9 nm	529.7 nm	546.8 nm	665.6 nm
Responsivity						
Radiometric Calibration Source						
Spectral radiance	0.65	0.60	0.53	0.47	0.45	0.35
Stability	0.41	0.46	0.51	0.53	0.53	0.48
Transfer to MOBY						
Interpolation to MOBY wavelengths	0.2	0.15	0.03	0.03	0.03	0.03
Reproducibility	0.37	0.39	0.42	0.44	0.42	0.3
Wavelength stability	0.29	0.08	0.04	0.03	0.01	0.04
Stray light	0.75	0.3	0.1	0.15	0.3	0.3
Temperature	0.25	0.25	0.25	0.25	0.25	0.25
Measurements of L_u						
MOBY stability during deployment						
System response	1.59	1.3	1.19	1.11	1.08	0.92
In-water internal calibration	0.43	0.42	0.44	0.46	0.51	0.55
Immersion coefficient (?)	0.25	0.25	0.25	0.25	0.25	0.25
Wavelength stability	0.13	0.14	1.12	0.82	1.37	0.65
Environmental						
Type A (good &questionable)	**4.1**	**4.4**	**4.5**	**4.4**	**4**	**3.2**
(good days only)	**0.80**	**0.83**	**0.87**	**1.02**	**0.64**	**1.31**
Temporal overlap	0.3	0.3	0.3	0.3	0.3	0.3
Self-shading (uncorrected)	**1**	**1**	**1.2**	**1.75**	**2.5**	**12**
(corrected)	**0.200**	**0.200**	**0.240**	**0.350**	**0.500**	**2.400**
In-water bio-fouling (?)	1	1	1	1	1	1
Combined Standard Uncertainty (Uncorrected)	4.81	4.93	5.15	5.14	5.25	12.55
Combined Standard Uncertainty (Corrected)	2.46	2.16	2.37	2.28	2.43	3.29

S. W. Brown, *et al.*, Proc. SPIE 6744, 6744M-1 (2007).

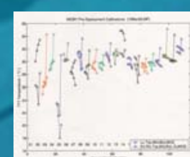
Work still to be done includes:

1. Empirical validation of shadowing model
2. Establishment of uncertainties in immersion coefficient
3. Final stray light characterization of MOBY MOS's
4. Visible Transfer Radiometer (VXR) validation time series
5. Standard Lamp Monitor (SLM) time series
6. Irradiance uncertainty budget
7. Water-leaving radiance uncertainty budget

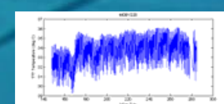
Temperature Correction



MOS204 Response v. TT7 Reading
Correction: 0.45 %/°C



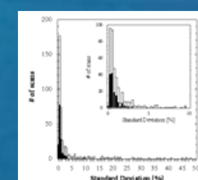
Temperature in tent
during pre-calibrations



Arm	Precal TT7 temp (C)	In-water TT7 Mean (C)	In-water TT7 Stdev (C)	Mean temperature Difference (C)
LuTop	30.963	33.833	0.907	2.870
LuMid	30.961	33.158	1.115	2.197
LuBot	30.929	34.340	0.796	3.411

Temperature during
a deployment (20)

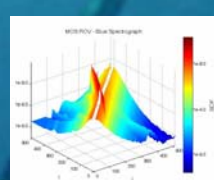
Type A uncertainties over a deployment (31) at 442 nm



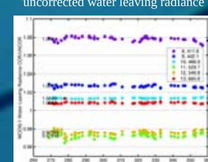
Data filter: Good scans (clear)
Good days & good scans (solid)

Stray Light Correction

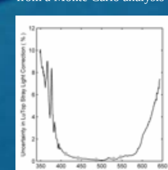
Stray light distribution function matrix



Ratio of stray light corrected over uncorrected water leaving radiance



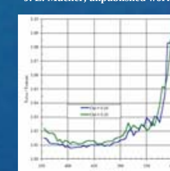
Uncertainty in the stray light correction from a Monte Carlo analysis



M. E. Feinholz, *et al.*, J. Atmos. Oceanic Technol. (accepted)

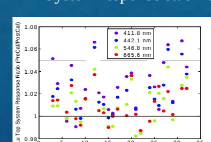
Instrument self-shading

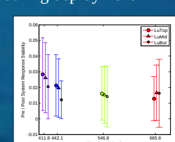
J. L. Mueller, unpublished work.



Spectral distribution of MOBY self-shading factors for backscattering coefficient of 0.01, a solar zenith angle of 30° and azimuth angle of 180°, and phytoplankton chlorophyll-*a* concentrations of 0.10 mg/m³ and 0.20 mg/m³.

System response stability during deployment





Each deployment analyzed individually.

For the time series estimate, assume a rectangular probability distribution with limits 0 and mean plus 1 standard deviation.

Uncertainty = 1/sqrt(12)* limits

Implications for the vicarious calibration of ocean color satellite sensors

Vicarious Calibration of SeaWiFS w. MOBY

Franz, *et al.*, Appl. Opt. 46, 5068- 5082 (2007).

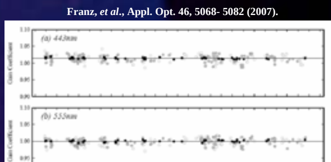


Figure 3. Vicarious gains for SeaWiFS based on calibration samples spanning the mission lifetime.

Table 2. SeaWiFS Vicarious Gain Coefficients

λ	412	443	490	510	555	670	765	865	N^a
$\bar{g}$	1.0377	1.014	0.9927	0.9983	1.000	0.9738	0.9720	1.000	150 (87)
σ^b	0.008	0.009	0.006	0.009	0.006	0.007	0.010	0.0	
$E_{\bar{g}}^c$	0.0007	0.0007	0.0007	0.0007	0.0007	0.0006	0.0011	0.0	

[a]Number of gain samples, g_i, used to compute the mean gain, $\bar{g}$, for λ < 765 (λ = 765).
[b]Standard deviation of the distribution of g_i about $\bar{g}$.
[c]Standard error on the mean, $\bar{g}$, computed as σ/sqrt(N).

The Type A uncertainty in the vicarious calibration of SeaWiFS is approximately 1 % at the satellite sensor (for all channels vicariously calibrated by MOBY). Propagated to the earth's surface, this would correspond to approximately a 10 % Type A uncertainty in the water-leaving radiance. The Type A uncertainty in the water-leaving radiance measured by MOBY is approximately 1 %.

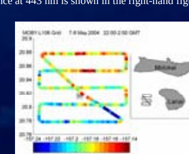
Uncertainty Component [%]	8	9	10	11	12	13
	411.8 nm	442.1 nm	486.9 nm	529.7 nm	546.8 nm	665.6 nm
Good scans and good days	1.00	1.05	1.10	1.48	1.59	2.34

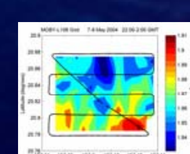
MOBY Type A uncertainty in L_w

There is a large, unresolved discrepancy between the Type A uncertainty in the measurements by the satellite sensor and the Type A uncertainty in the MOBY measurements.

Two logical potential sources for the discrepancy are sub-pixel variability in the water-leaving radiance and larger-than-expected Type A uncertainty in the atmospheric correction.

In May, 2004, a 10 km by 12 km grid of fluorometrically determined chlorophyll-*a* concentration was made by MOBY researchers on-board the University of Hawaii research vessel the R/V Ka'imikai-O-Kanaloa coincident with an Aqua MODIS overpass. The track line and color-coded chlorophyll-*a* concentrations are shown in the left-hand figure below. The mean of the discrete samples measured was 0.083 mg/l; the standard deviation of the measurements was 2.5 %. Converted to water-leaving radiance, the data result in a mean water-leaving radiance at 443 nm of 1.87 mW/cm2/sr/nm and a percent standard deviation of 0.98 %. The spatial variability in water-leaving radiance at 443 nm is shown in the right-hand figure below.





The Aqua MODIS chlorophyll-*a* product values were extracted for the grid coordinates after processing. Excluding duplicate measurements, clouds, and measurements near clouds, the Aqua MODIS mean chlorophyll-*a* concentration over the track line was 0.07 mg/l (for 20 match-ups) with a standard deviation 37 %. The high variability in Aqua-derived chlorophyll-*a* concentrations over this very flat pigment field could be interpreted as being induced by variance in the atmospheric correction (e.g. noise in the NIR bands).

This work has been sponsored by NASA and NOAA/NESDIS