The Marine Optical BuoY (MOBY) Radiometric Calibration and Uncertainty Budget for Ocean Color Satellite Sensor Vicarious Calibration

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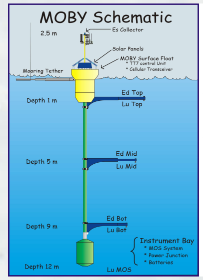
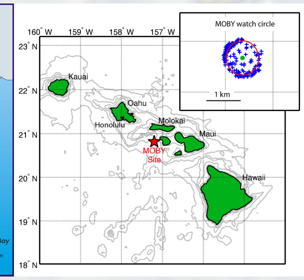
ABSTRACT

For the past decade, the Marine Optical Buoy (MOBY), an autonomous radiometric buoy stationed in the waters off Lanai, Hawaii, has been the primary in-water oceanic observatory for the vicarious calibration of the U. S. satellite ocean color sensors SeaWiFS and MODIS. The MOBY vicarious calibration of these sensors supports international efforts to develop a global, multi-year time series of consistently calibrated ocean color data products. A critical component of the MOBY program has been establishing robust radiometric traceability to the International System of Units (SI); a detailed uncertainty budget is a core component of traceable metrology. We present the MOBY uncertainty budget for up-welling radiance. Consideration of the vicarious calibration uncertainty budget is important as next generation vicarious calibration sensors are being discussed because it gives information about how the resources for the vicarious calibration facility should be allocated and to what extent the measurements may be utilized to address climate change research.

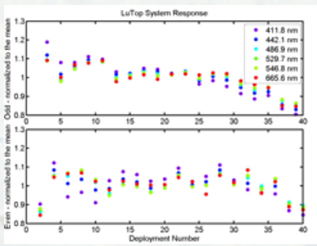


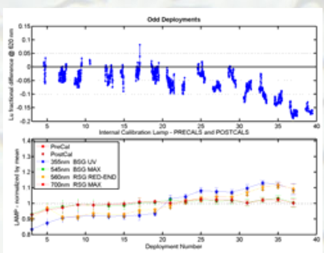


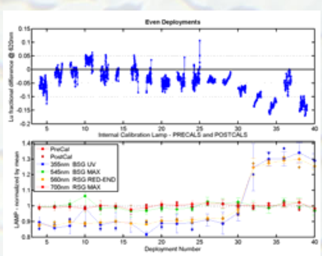
MOBY top arm $Lu(\lambda)$ spectral radiance responsivity, from laboratory calibrations before and after each deployment (top panel), varies because optical components up to, and including the MOS are refurbished, cleaned, replaced, etc. when each buoy is recovered from its field deployment.

MOS stray light performance is monitored by comparing :
A.) Top arm $Lu(\lambda)$ from the BSG and RSG at 620 nm (±5% until deployment 30 where they approach - 15%), and

B.) Internal lamp spectra where the signal is high (~no effect) compared with regions of low signal which are sensitive to stray light.

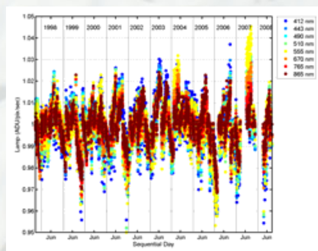


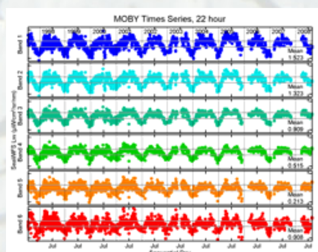


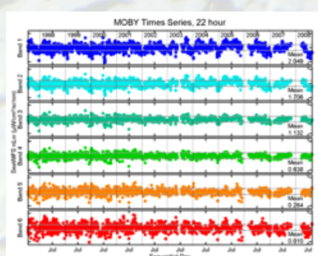


Internal stability sources (ex. incandescent lamp, top panel) measured during field deployments show the stability of MOS over 10 years of operation.

The MOBY $Lw(\lambda)$ and solar - normalized $nLw(\lambda)$ (mid & bottom panels) are shown with gray lines ±10% from the mean for the SeaWiFS ocean color bands. Note the $Lw(\lambda)$ seasonality, which is not evident in $nLw(\lambda)$. Future analysis will focus on the determination and separation of unquantified instrumental artifacts from actual bio - optical variability.







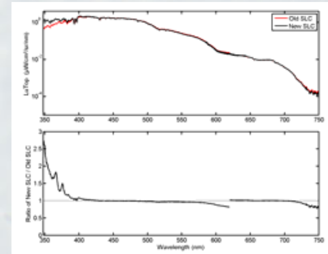
Uncertainty Component [%]	411.8 nm	442.1 nm	486.9 nm	529.7 nm	546.8 nm	665.6 nm
Radiometric Calibration Source						
Spectral radiance	0.65	0.6	0.53	0.47	0.45	0.35
Stability	0.41	0.46	0.51	0.53	0.53	0.48
Transfer to MOBY						
Interpolation to MOBY wavelengths	0.2	0.15	0.03	0.03	0.03	0.03
Reproducibility	0.37	0.39	0.42	0.44	0.42	0.3
Wavelength accuracy	0.29	0.08	0.04	0.03	0.01	0.04
Stray light	0.66	0.29	0.13	0.21	0.36	0.64
Temperature	0.25	0.25	0.25	0.25	0.25	0.25
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
Wavelength stability	0.13	0.14	1.12	0.82	1.37	0.65
Environmental						
Type A (good scans & all days)	4.1	4.4	4.5	4.4	4	3.2
Type A (good days only) *	*0.8*	*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
Self-shading (corrected) *	*0.2*	*0.2*	*0.24*	*0.35*	*0.5*	*2.4*
In-water bio-fouling	1	1	1	1	1	1
Combined Standard Uncertainty	4.8	4.9	5.1	5.1	5.2	12.6
Combined Standard Uncertainty *	*2.4*	*2.1*	*2.4*	*2.3*	*2.4*	*3.3*

Uncertainty (k=1) in $Lu(1m,\lambda)$ from Brown *et al.* (2007) at MODIS bands 8 - 13. The italicized values are determined using the "starred" (*) Type A environmental and self - shading values in place of the "unstarred" values.

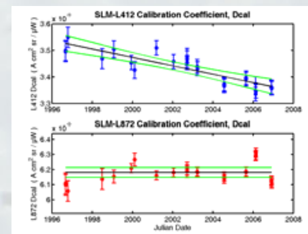
This estimate for Lu applies to the time interval in which NIST calibrated the MOBY radiance standards, beginning in 2002. Prior to 2002, Optronic Laboratories (OL) performed the spectral radiance calibrations. The OL reported expanded uncertainties are 3% to 5% (k=2), about a factor of 3 greater than the NIST values. The values for source stability during a lamp cycle are preliminary; once a systematic evaluation of the SLM stability and the source monitoring time series is complete these values can be finalized. The NIST measurements using the SXR and VXR during yearly intercomparisons in Hawaii are also being examined systematically, in order to evaluate the entire validation data series and use the results to produce the best estimate of the radiometric values on the MOBY radiometric reference standards as a function of time. The stray light characterization measurements were performed in 2001 and 2002, with uncertainties taken from the current stray light correction algorithm, dated Jan. 2005, described in Feinholz *et al.* (2008).

FUTURE RESEARCH

Determination of the uncertainty budget for the water-leaving spectral radiance, Lw is the next step in our activities. Additional components to be considered are those associated with the uncertainty in depth, the immersion coefficients, and the uncertainty in K_L. The uncertainty in K_L depends on the uncertainties in Lu, Es, the vertical homogeneity of the water, depth, tilt, and environmental conditions. The Type A uncertainty component for the *in situ* values of Lw is mirrored in the Type A uncertainty of the satellite gain coefficients that are derived from multiple matchups, but reduced in magnitude because the atmosphere dominates the at-satellite radiance. Thus thorough understanding of the MOBY uncertainty components may aid in the development of the satellite uncertainty budgets.



In June 2008 we had the opportunity to ship MOS205, used for odd MOBY deployments, to NIST for full stray light characterization on SIRCUS. Preliminary evaluation of these new data indicate improved retrievals in the overlap region and that the values for $Lu(\lambda)$ in the UV increase. The best approach to applying the new laser characterization data to the existing data set, in particular from 2005 to the present, is an area of future research.



Results for the spectral radiance responsivity determinations for the Standard Lamp Monitors (SLMs) operated in radiance mode as a function of time at 412 nm and at 872 nm. The standard uncertainties for the absolute calibration of the SLMs are indicated by the vertical lines. These results are preliminary and we anticipate refinement. However, analysis of these results indicates the long term drift in the 412 nm SLM is statistically significant, about -0.46%/year, with the relative standard uncertainty in the drift correction expected to be between 0.23% and 0.42% over the indicated temporal interval (the light bracketing lines indicate the expanded k=2 uncertainty). The combined standard uncertainty in these SLM calibrations is between 0.6% and 1.2%, which is less than the uncertainties in spectral radiance provided by OL for the calibration interval from 1992 to 2002. It is necessary to understand the history of SLM calibration factors before using them to assess source drift.

SUMMARY

We have presented a preliminary uncertainty budget for $Lu(\lambda)$ measurements that apply to a recent deployment, MOBY231. We have identified sources of bias that remain under investigation, with self-shading and changes in the stray light performance with time at the top of the list. Field experiments are required for the self-shading work and a full stray light characterization on the even buoy is recommended at the NIST SIRCUS facility. We have a 10 year record of radiometric validation measurements for documenting and possibly correcting for bias in both the radiance and irradiance radiometric references standards. The next steps are to develop preliminary uncertainty budgets for $Es(\lambda)$ and $Lw(\lambda)$ and to apply the analysis to the entire data set.

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