QA4EO Implementation Case Study: Marine Optical BuOY (MOBY)

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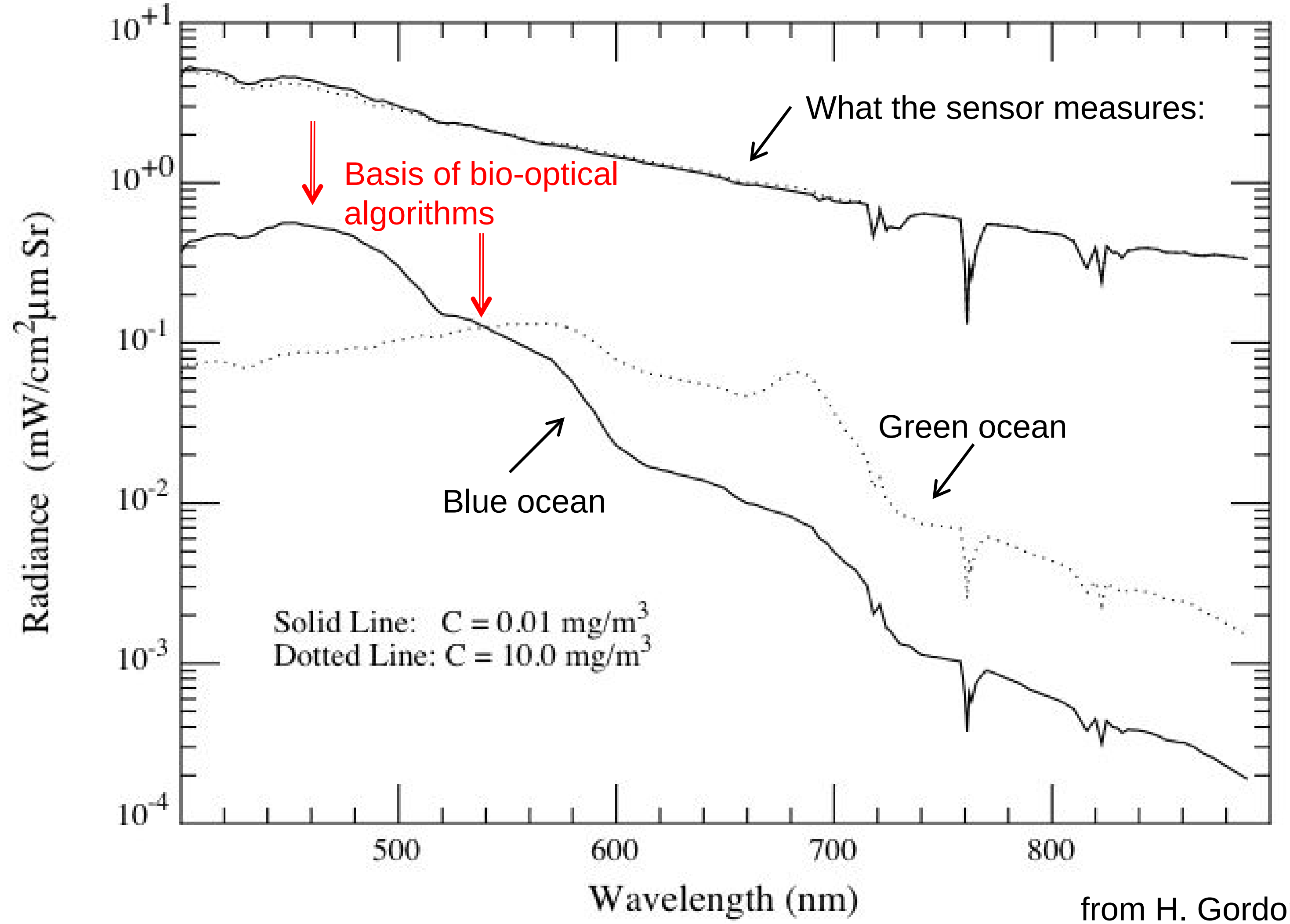
Thanks to all the MOBY Team

Satellite Ocean Color



from H. Gordon

Water-Leaving Radiance L_w

Water-leaving spectral radiance is a small fraction of the top-of-the atmosphere radiance, and it is determined through the atmospheric correction process.

$$L_{\mathrm{t}}(\lambda) = \left[L_{\mathrm{r}}(\lambda) + L_{\mathrm{a}}(\lambda) + t_{\mathrm{d_v}}(\lambda)\left(L_{\mathrm{f}}(\lambda) + L_{\mathrm{w}}(\lambda)\right)\right] t_{\mathrm{g_v}}(\lambda)\, t_{\mathrm{g_s}}(\lambda)\, f_{\mathrm{p}}(\lambda)$$

$L_a(\lambda)$ is estimated from NIR bands for each image element; the assumption is $L_w(\lambda\text{=NIR}) \approx 0$ for purely oceanic sites. Then all the terms on the right hand side are calculable except for the unknown $L_w(\lambda)$.

$$L_{\mathrm{wn}}(\lambda) = \frac{L_{\mathrm{w}}(\lambda)}{\mu_{\mathrm{s}}\, f_{\mathrm{s}} t_{\mathrm{d_s}}\, f_{\mathrm{b}}\, f_{\lambda}}$$

The high level products (e.g., Chl *a*) are derived from the normalized water-leaving radiance, $L_{wn}(\lambda)$: i.e., Sun at the zenith, mean Sun-Earth distance, without atmosphere, and accounting for the non-isotropy of water volume and of the satellite out-of-band effects.

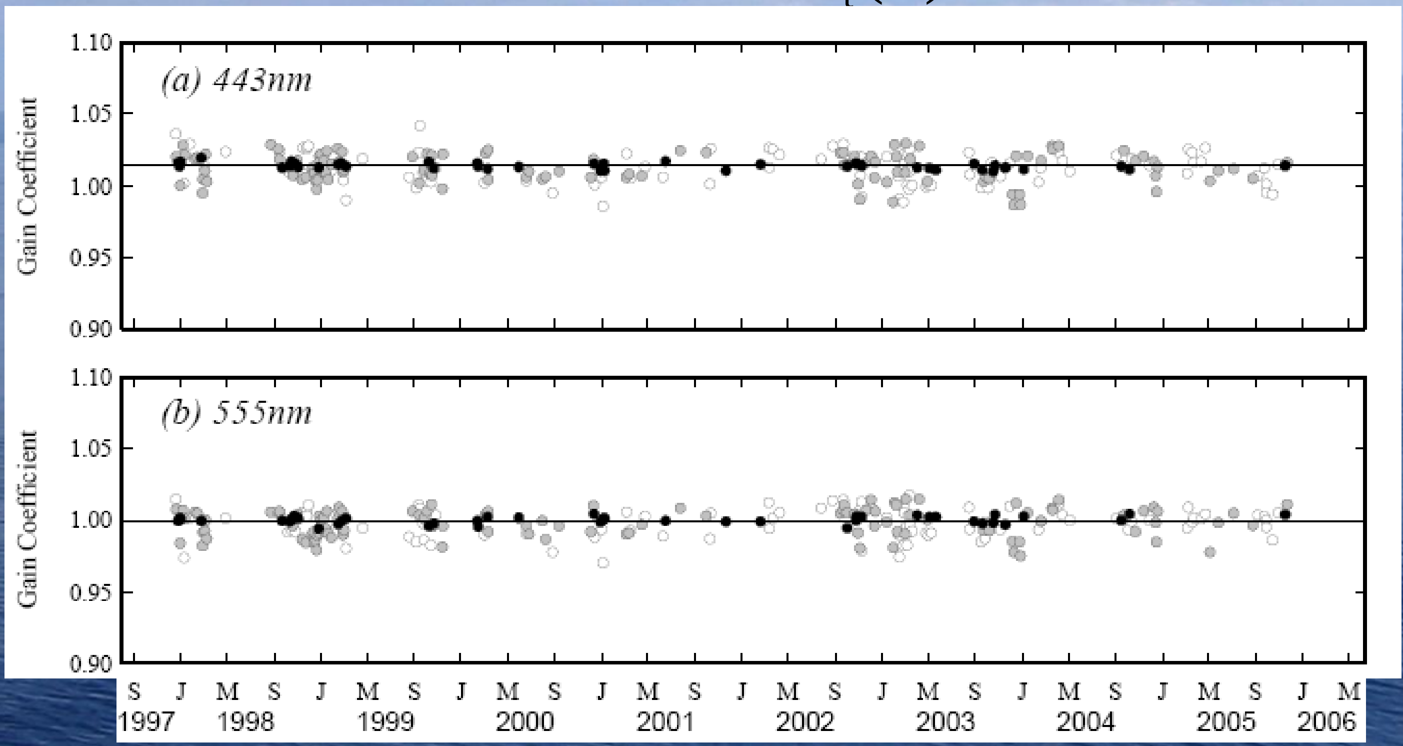
The uncertainty in $L_t(\lambda)$ is stringent, ±0.2%

Vicarious Calibration

Global Observations: $L_{\mathrm{t}}(\lambda) \rightarrow L_{\mathrm{a}}(\lambda) \rightarrow L_{\mathrm{w}}(\lambda) \rightarrow L_{\mathrm{wn}}(\lambda) \rightarrow$ Bio-optical products

Vicarious Calibration (applied to start of mission when accounting for sensitivity change over time of the space sensor):

$$L_{\mathrm{wn}}^{\mathrm{r}}(\lambda) \rightarrow L_{\mathrm{t}}^{\mathrm{r}}(\lambda) \rightarrow \frac{L_{\mathrm{t}}^{\mathrm{r}}(\lambda)}{L_{\mathrm{t}}(\lambda)} =$$ Gain correction factors

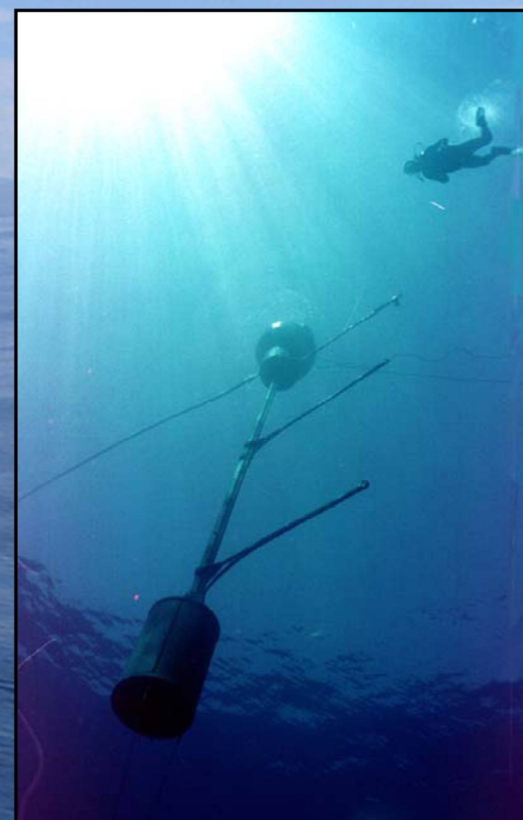


Franz, et al., Applied Optics 46 (22), 5068- 5082 (2007)

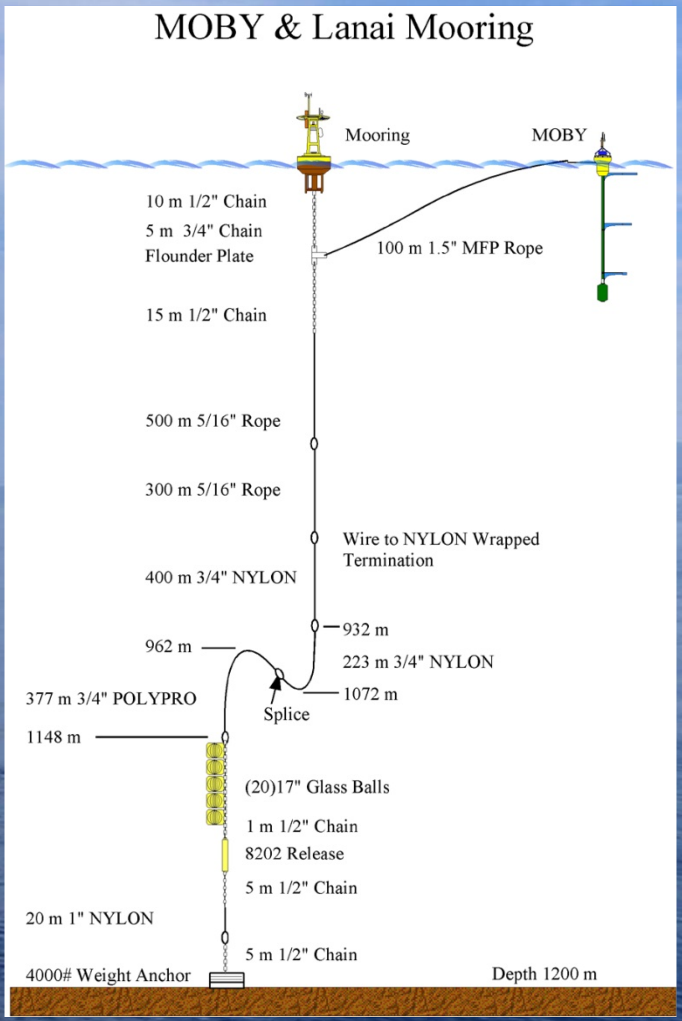
MOBY

- NIST – traceable values for $L_w(\lambda)$
- Quality Indicators are uncertainties, quality flags, and descriptive information

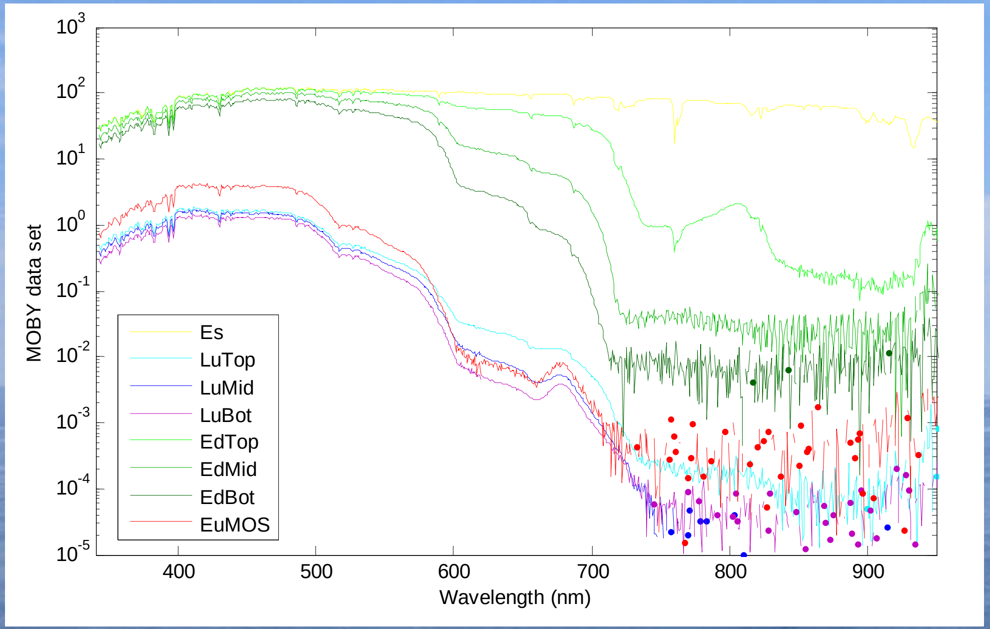
~ 20 km from Lanai



MOBY Measurements



Downwelling irradiance and upwelling radiance



350 – 640 nm
0.6 nm pixel spacing

560 – 960 nm
0.8 nm pixel spacing

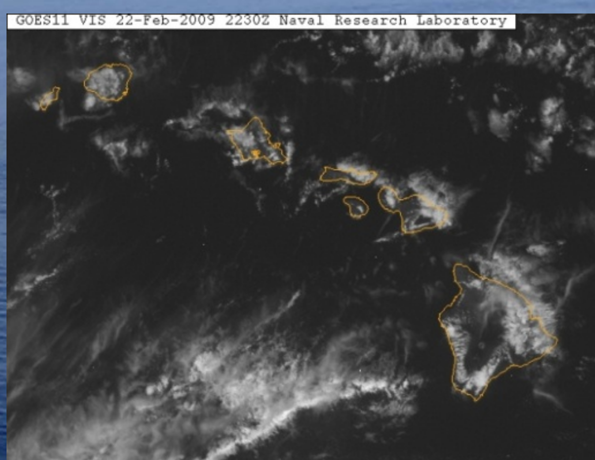
Daily data download
Three to four month deployments
Two systems interchanged in ~ 3 day cruises

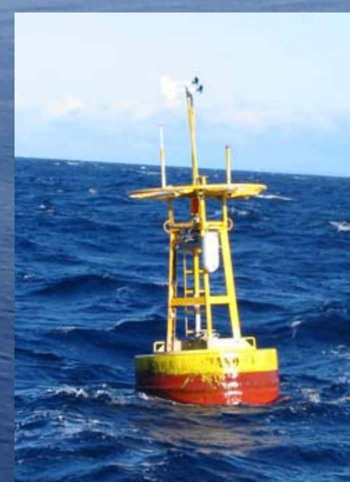
MOBY Attributes

- **Oligotrophic water (1.2 km depth), uniform optical properties (horizontal and vertical), BRDF measured, marine atmosphere**
- **Clouds mostly in the afternoon**
- **NIST participation; SI traceable values**
- **Multiple redundancies in radiometry & other key parameters**
- **Continuous, daily measurements, timed for satellite overpass (SeaWiFS, MODIS-Terra, MODIS-Aqua, MERIS)**
- **High resolution hyper-spectral in the 380 – 950 nm interval**
- **Accessible for servicing (buoy rotations, monthly diver cals.)**
- **Support facilities (University of Hawaii, NOAA ships)**
- **Stable, expert team**
- **System security (ARGOS; local commercial fisherman)**
- **Sun glint (satellite sensor must be able to tilt off to utilize summer observations)**

Atmospheric Properties

- **Radiometry and Sun-photometry: Downwelling surface irradiance at the buoy site and CIMEL-AERONET sun-photometer on Lanai & O'ahu (SeaWIFS and MODIS matchups are typically selected as Oceanic 99, Marine 70, or Marine 90).**
- **Meteorological data: wind, temperature, PAR (these and local Lanai weather information are posted on the MOBY web site http://physoce.mlml.calstate.edu/moby/)**
- **Clouds: GOES-Imagery (NRL Monterey) and cloud index are posted on MOBY web site**



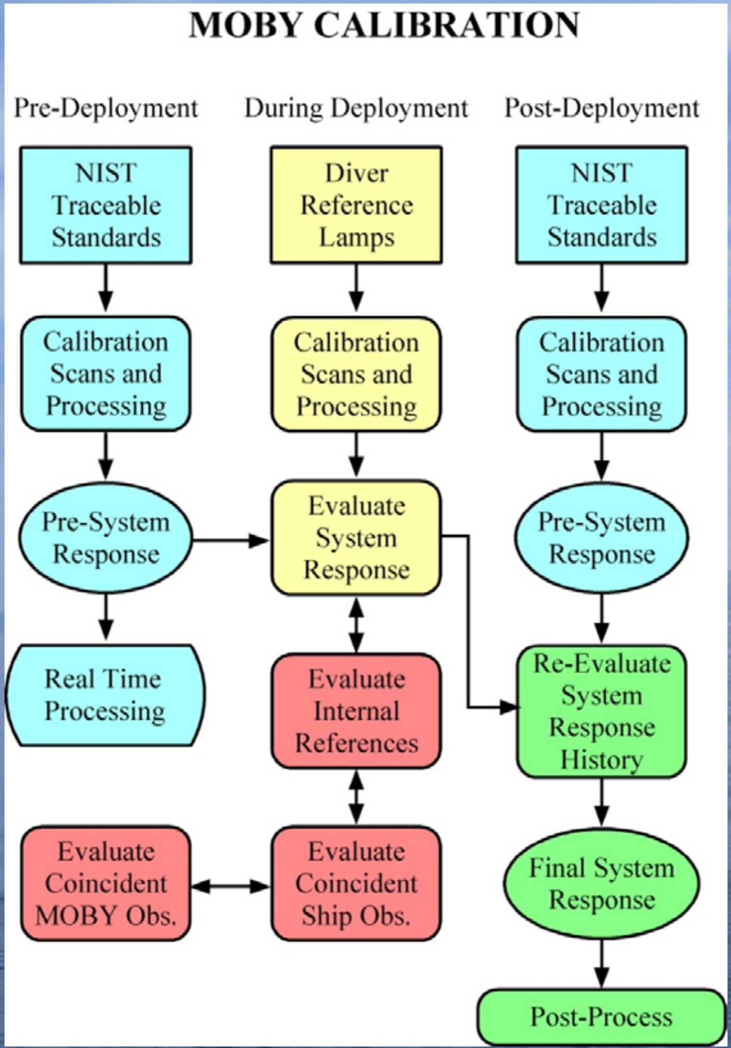


Seawater Properties

- Scientific cruises made under NASA funding with MODIS Science Team participation
    - Apparent optical properties (MOS Profiler), BRDF (NuRADs), horizontal uniformity (via pigment mapping with fluorometry), Secchi depth, beam attenuation, particle absorption, CDOM absorption, non-pigmented particle absorption, phyoplankton absorption, conductivity/temperature/depth profiles, upwelled radiance distribution, particle size data, total suspended particulate matter, particulate organic carbon/nitrogen (activities documented by team members in publications from CHORS, MLML, UM, NIST, and NOAA).

- SORTIE Inter-comparison
    - Site mapping of inherent optical properties (e.g., backscatter and absorption) demonstrating homogeneity at the site.

Radiometric Approach



- **NIST calibrated irradiance and radiance standards**
- **NIST traceable filter radiometers for tracking source standards (SLMs)**
- **Internal LEDs (red, blue) and lamp, with photodiode monitor**
- **Independent validation by NIST with VXR and NPR**
- **Diver deployed stability lamps**
- **Instrument temperature measurements (CCD, electronics, …)**
- **Rigorous calibration schedule**
- **Substantial characterization effort, especially for stray light**

Brown, S.W., S.J. Flora, M.E. Feinholz, M.A. Yarbrough, T. Houlihan, D. Peters, Y.S. Kim, J.L. Mueller, B.C. Johnson, and D.K. Clark (2007). "The Marine Optical BuoY (MOBY) radiometric calibration and uncertainty budget for ocean color satellite sensor vicarious calibration." *Proc. SPIE* **6744**, 67441M1 – 67441M12.

MOBY Uncertainties

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
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	0.20	0.15	0.03	0.03	0.03	0.03
Reproducibility	0.37	0.39	0.42	0.44	0.42	0.30
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
during deployment						
System response	1.59	1.3	1.19	1.11	1.08	0.92
-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	4.0	3.2
Type A (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
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*

<u>To Do</u>

Apply self-shading correction;
Validate immersion factors;
Implement cosine response;
Finalize the stray light correction

Brown, et al., (2007) "The Marine Optical BuoY (MOBY) radiometric calibration and uncertainty budget for ocean color satellite sensor vicarious calibration." *Proc. SPIE* **6744**, 67441M1 – 67441M12.

MOBY Team

- NOAA: Kent Hughes, Mike Ondrusek, Menghua Wang; Contractor: “Sky” Kim;
- MLML: Mark Yarbrough, Mike Feinholz, Terry Houlihan, Stephanie Flora, Darryl Peters
- NIST: Carol Johnson; Contractors: Dennis Clark, Al Parr

Any Question?

Snug Harbor Facility

UH / NOAA R/V’s

Moby Team