The Marine Optical Buoy (MOBY) protocols and use in Satellite System Vicarious Calibration

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MOBY-Net by NASA OBB program.
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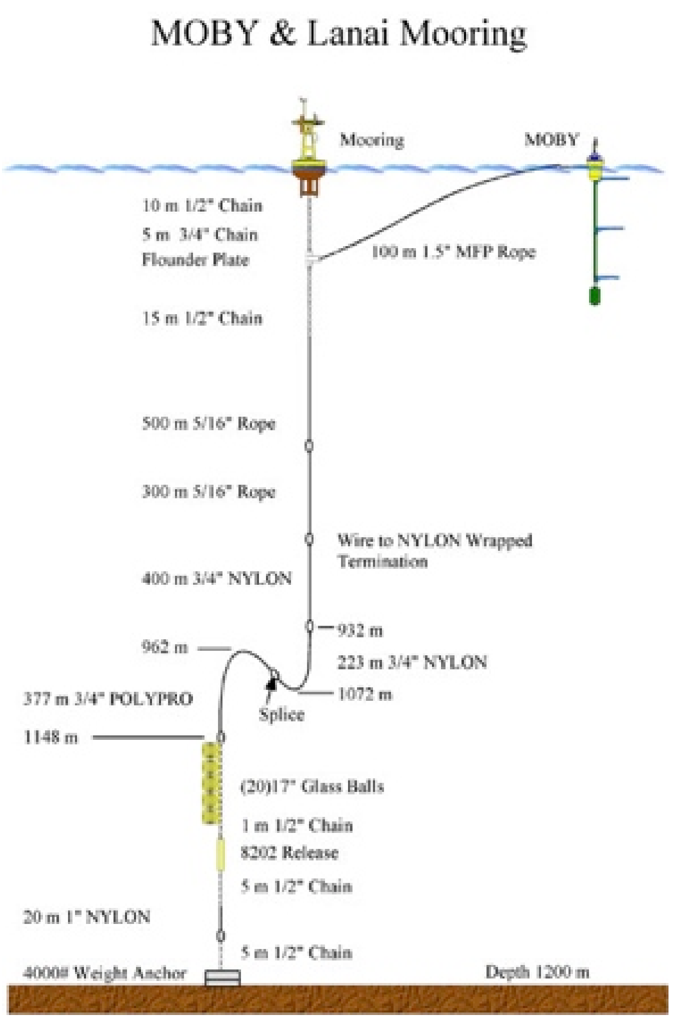
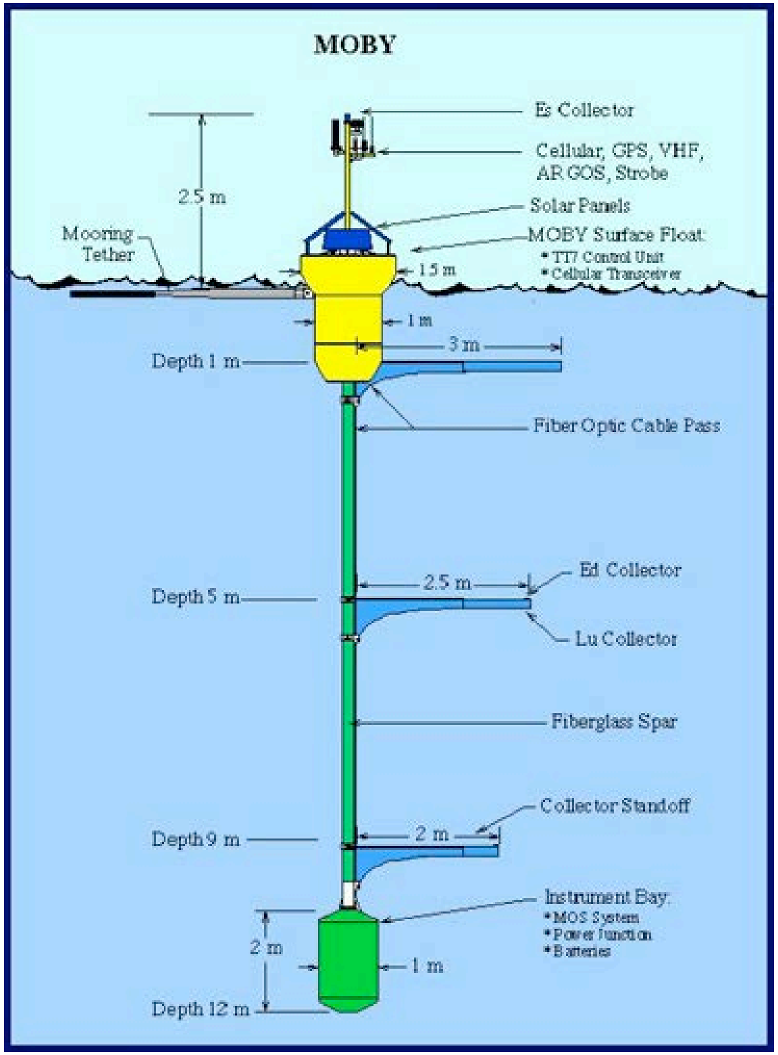
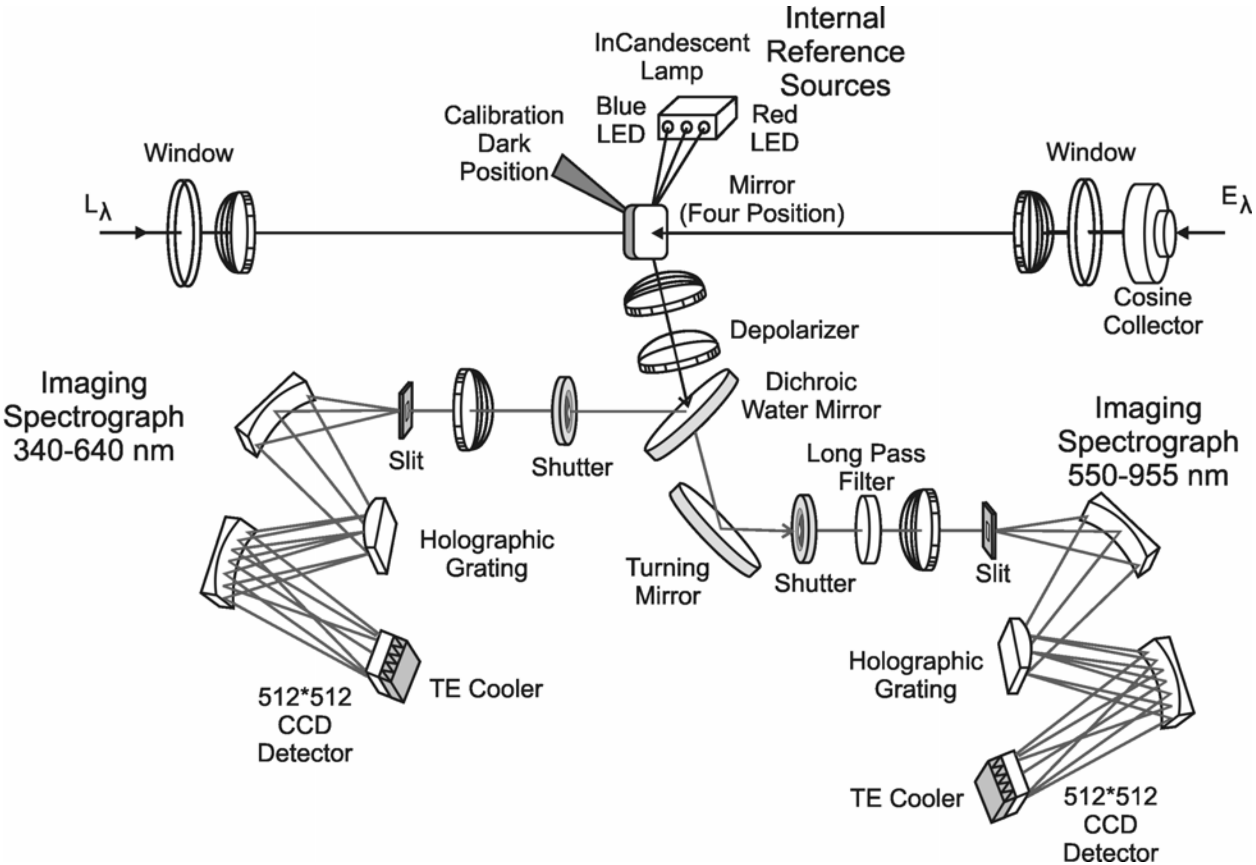
MOBY/MOBY-Refresh/MOBY-Net have same basic structure:





Biggest difference is in the optical system:

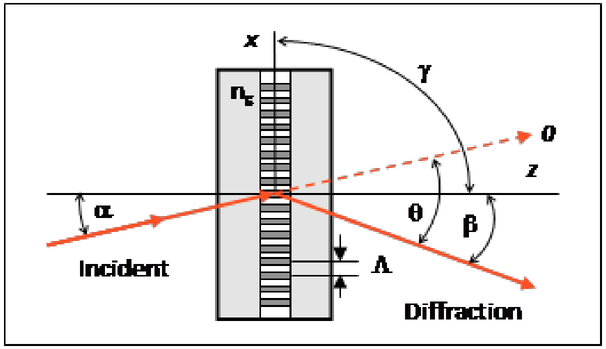
Current optical system, MOS, is a combination of two holographic reflective grating spectrometer systems



Hyper spectral:
0.6-.9 nm spacing,
0.8-1 nm FWHM

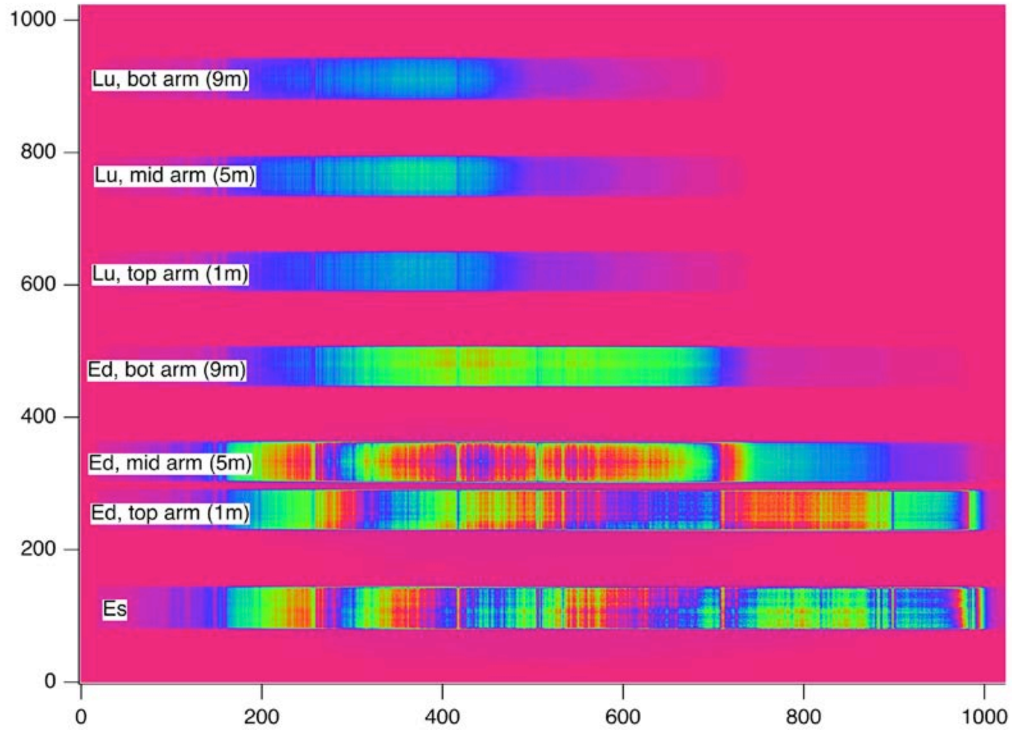
Different optical measurements must be done sequentially.

The MOBY-Refresh (NOAA supported) and MOBY-Net (NASA supported) optical system consists of dual in-line volume phase holographic grating systems. Allows simultaneous spectra to be acquired



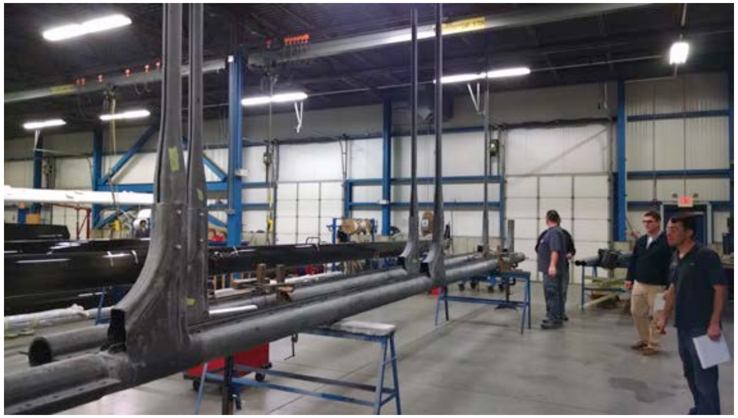
From http://www.bayspec.com/technical-support/definitions/vpg/

Example spectra from field measurements with blue spectrometer

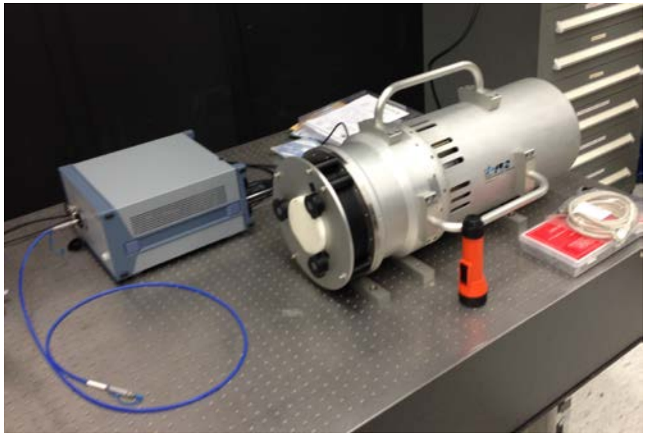


MOBY-Net is aimed at supporting an additional remote field site with instrumentation consistent with the Hawaiian location, and common calibration.

Requires: Structure that allows optics to be installed and removed intact



Source and monitor to verify performance before and after deployment



The operational MOBY program has two fully instrumented buoys (soon to be three) that are swapped at nominally 4 month intervals.

When an instrument is recovered from the field it is:

1) fully re-calibrated (post calibration)
2) refurbished/repaired as necessary.
3) re-characterized as necessary depending on repairs required.
4) fully re-calibrated(pre calibration)

Data Flow during deployment:

1) Data transmitted from buoy by cell modem link, through Miami servers to Moss Landing.

2) Data is inspected for irregularities, associated data (GOES images) are acquired and inspected.

3) Data is processed, (including hand processing of data spectral spikes) and a combination of data inspection and associated data is used to determine quality (good, questionable, bad).

4) Data is posted to the NOAA Coast watch site for downloading by users. (typical data latency is 1-2 days).

5) After deployment, post calibration data is used to improve the calibration during deployment of the instrument, and post calibrated data is posted to Coastwatch site (typical latency is 1 year, moving to 4 months).

6) Final processing performed when end-of-life recalibration is done on the calibration lamp.

Fundamental equations are given below for water leaving radiance, diffuse upwelling radiance attenuation, and normalized water leaving radiance (all terms are wavelength dependent).

$$Lw = Lu(z)\exp(KL(z_1,z_2)z)t / n^2$$

$$KL(z_1,z_2) = -\frac{\ln(Lu(z_2) / Lu(z_1))}{z_2 - z_1}$$

$$Lwn = \frac{Lw}{Es} F_o(r)$$

Other terms are measured surface irradiance (Es), surface transmittance (t), index of refraction of water (n), extra terrestrial irradiance (Fo)

The normal MOBY products are (up to 3 times/day):
Hyper spectral Lw1 and Lwn1: Lu(1m), KL(1m, 5m)

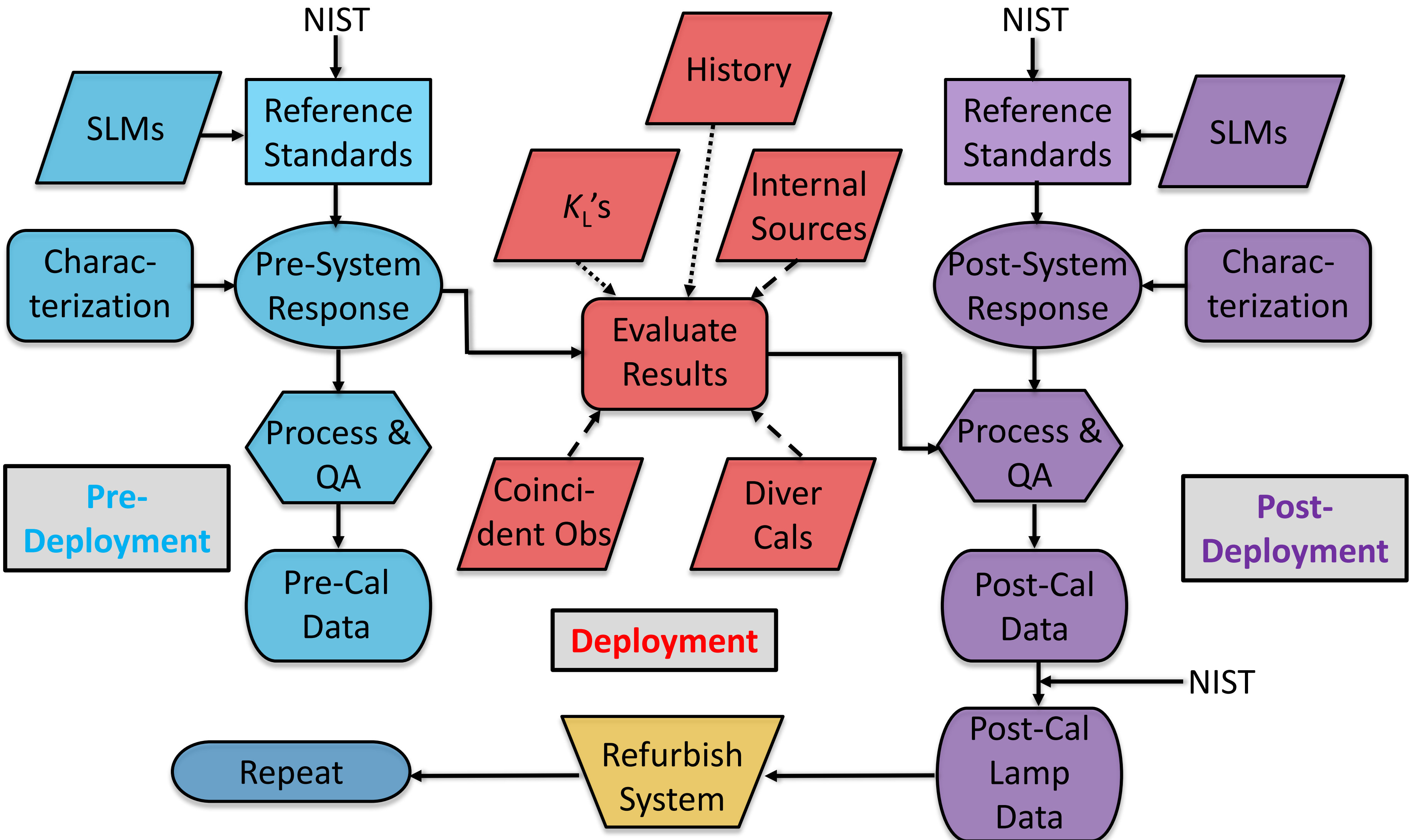
Hyper spectral Lw2 and Lwn2: Lu(1m), KL(1m, 9m)

Hyper spectral Lw7 and Lwn7: Lu(5m), KL(5m,9m)

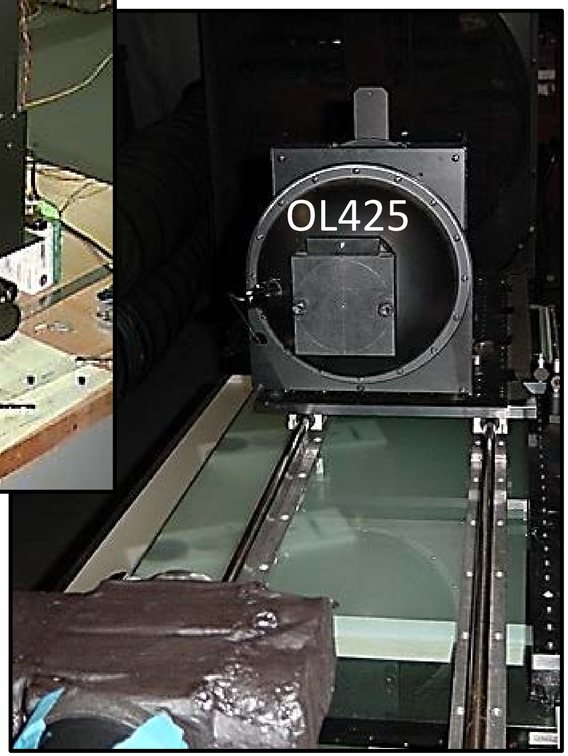
With each of these there is a new product (Lw2x, Lwn2x) which uses RTE modeling to improve the product above 575 nm.

For each of these products there are associated satellite integrated in-band and total-band products.

Traceability and Redundancy



Radiometric Calibration for MOBY – $L_u(\lambda)$

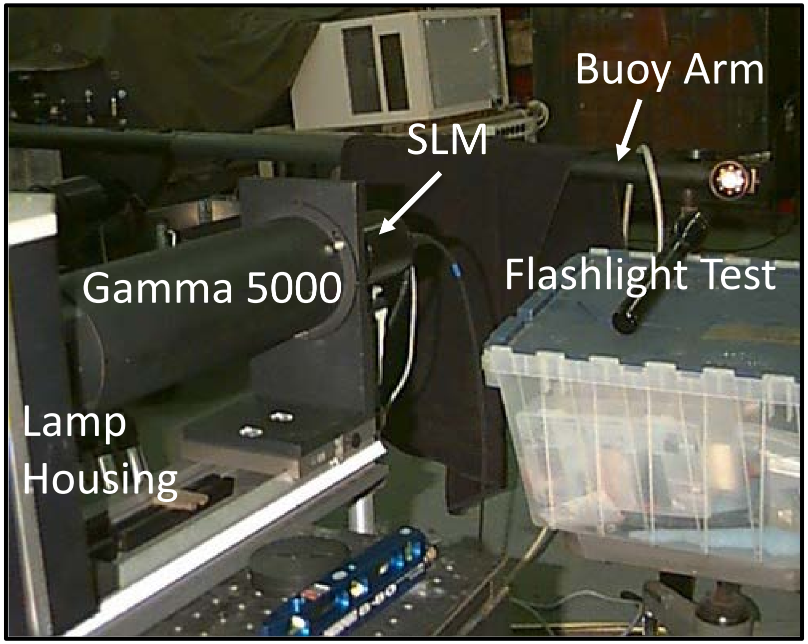


Two integrating spheres are used, OL420 & OL425

Features
Externally illuminated, TQH lamps
Large dynamic range (OL420)
Photopic monitor PD (OL425)
Operating data recorded
Lamps replaced every 50 h burn time
NIST beginning-of-life (BOL) cals
NIST end-of-life (EOL) cals

Monitored using NIST custom filter radiometers (SLMs)

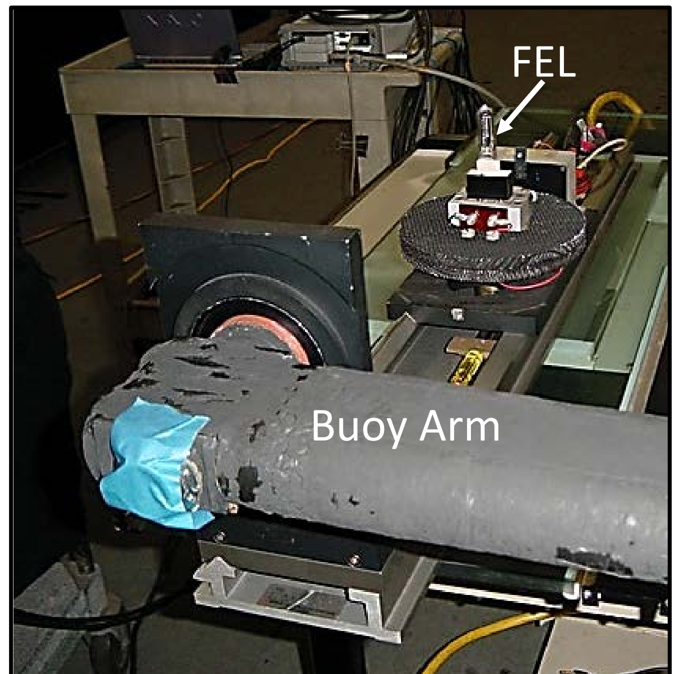
Radiometric Calibration for MOBY – $E_{d,s}(\lambda)$



Gamma 5000 with SLM E head

Various FEL lamps used in
Gamma Scientific Model 5000
FEL 1000 W Lamp Standard

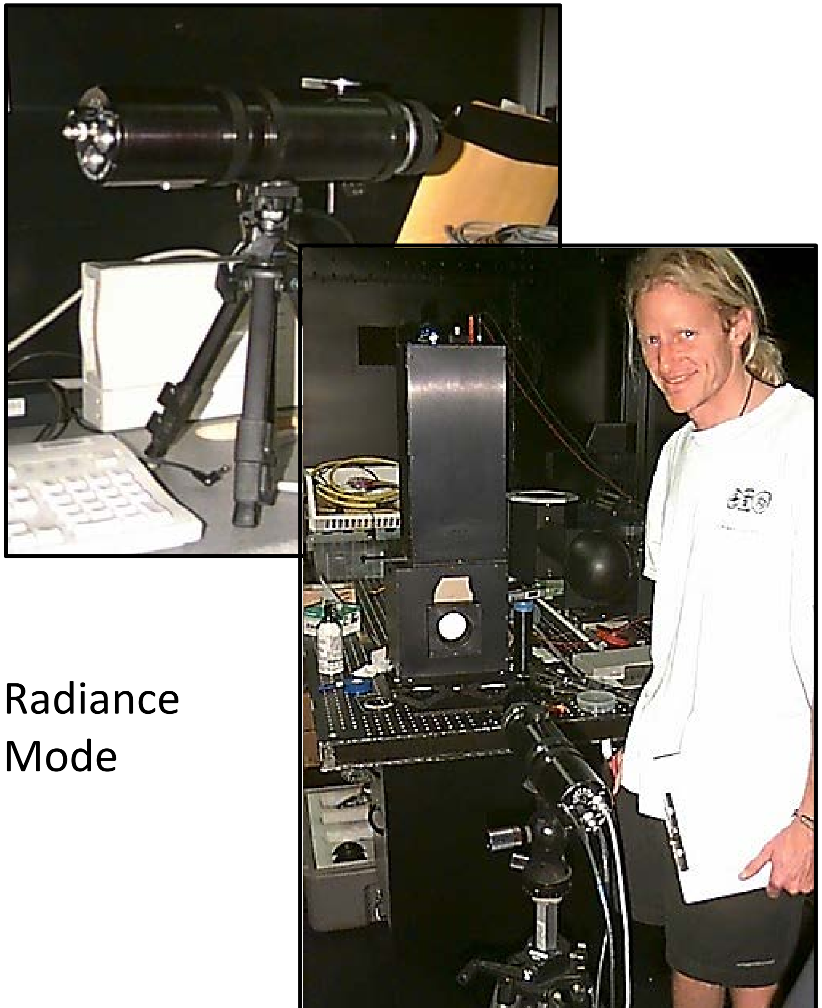
Gamma 5000 w/o baffle tube



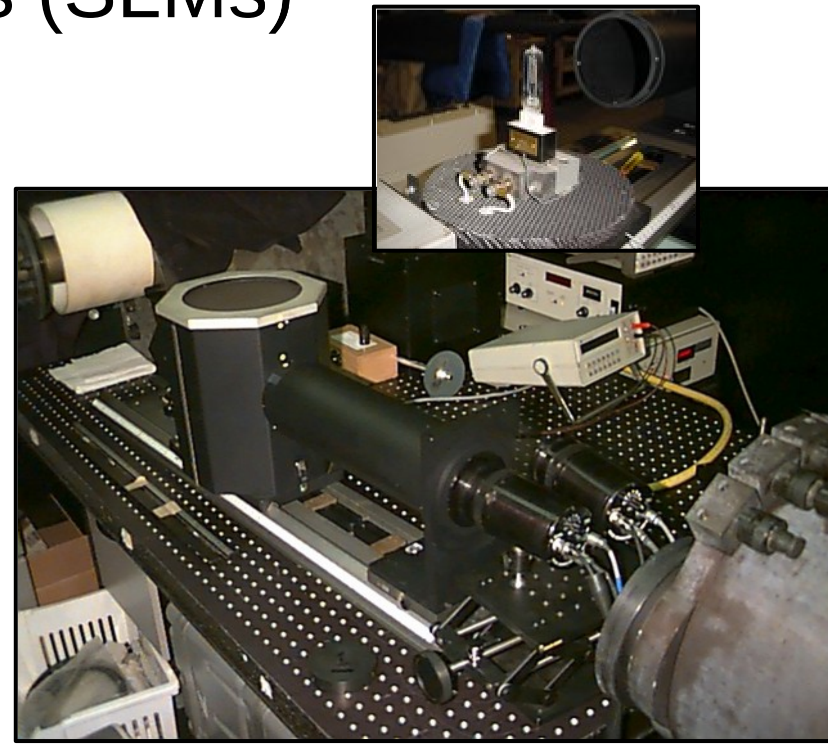
Features
Recalibrated every 50 h burn time
NIST calibrations entire time series

Monitored using NIST custom filter radiometers (SLMs)

Standard Lamp Monitors (SLMs)



Radiance
Mode



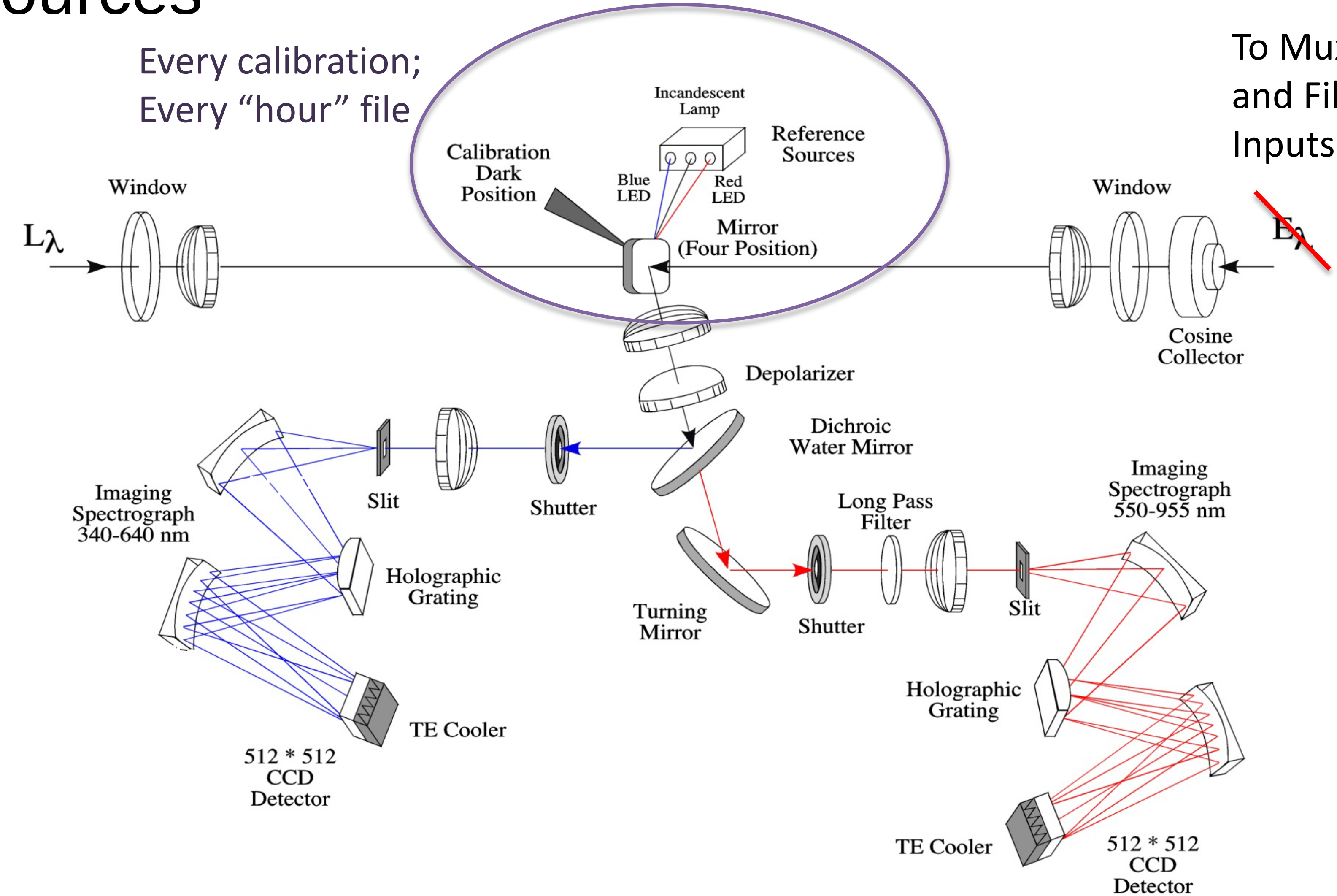
Irradiance
Mode

SLMs monitor the calibration sources when they are used to calibrate MOBY

Marine Optical System (MOS) Internal Cal Sources

Every calibration;
Every "hour" file

To Mux and Fiber Inputs



Uncertainty Budget, LuTOP

Uncertainty Origin	Type	410 nm	443 nm	486 nm	551 nm	671 nm
Reproducibility	B	1.428	1.124	0.952	0.869	0.743
In situ Meas Unc	A	0.880	0.739	0.756	1.033	1.659
Sphere Cal	B	0.809	0.720	0.606	0.534	0.462
Stray Light Corr	B	1.790	0.600	0.240	0.550	0.390
Sphere Drift	B	0.416	0.461	0.509	0.528	0.488
Wavelength	B	0.384	0.294	0.222	0.139	0.063
Uniformity	B	0.197	0.197	0.197	0.197	0.197
Cal Meas Unc	A	0.514	0.206	0.215	0.123	0.102
Integration Time	B	0.150	0.150	0.150	0.150	0.150
Inst Temp	B	0.157	0.157	0.157	0.157	0.157
Interpolation	B	0.200	0.150	0.030	0.030	0.030
Immersion	B	0.050	0.050	0.050	0.050	0.050
RSS, $k = 1$		2.72	1.77	1.53	1.68	2.01
Expanded, $k = 2$		5.44	3.45	3.07	3.36	4.01

Uncertainty Budget, Es

Uncertainty Origin	Type	410 nm	443 nm	486 nm	551 nm	671 nm
In situ Meas Unc	A	2.677	2.514	2.566	2.673	2.717
FEL Drift	B	0.771	0.755	0.687	0.665	0.609
Reproducibility	B	1.142	0.918	0.762	0.689	0.525
FEL Cal	B	0.522	0.463	0.429	0.392	0.337
Stray Light Corr	B	1.070	0.350	0.110	0.050	0.270
Bench Effect	B	0.485	0.485	0.485	0.485	0.485
Wavelength	B	0.338	0.252	0.187	0.123	0.055
Cal Meas Unc	A	0.312	0.140	0.098	0.060	0.057
Integration Time	B	0.150	0.150	0.150	0.150	0.150
Inst Temp	B	0.157	0.157	0.157	0.157	0.157
Interpolation	B	0.100	0.100	0.100	0.100	0.100
RSS, k = 1		3.31	2.91	2.86	2.92	2.92
Expd, k = 2		6.63	5.81	5.72	5.84	5.84

Adding uncertainties due to environmental factors for Lw….**work in progress**

Uncertainty Origin	Type	410 nm	443 nm	486 nm	551 nm	671 nm
Immersion Factor	B	0.1	0.1	0.1	0.1	0.1
Polarization	B	0.2	0.2	0.2	0.2	0.2
Shading	B	1	1	1	1	3
BRDF	B	0.3	0.3	0.3	0.3	0.3
Depth-extrapolation	B	1	1	1	1	1
Surface propagation	B	0.25	0.25	0.25	0.25	0.25
Lu factors (from other sheet)	B	2.72	1.77	1.53	1.68	2.01
RSS, $k = 1$		3.1	2.3	2.1	2.2	3.8
Expd, $k = 2$		6.2	4.6	4.2	4.4	7.6

Conclusions

- Very quick run through, longer talks available at
https://frm4soc.org/index.php/activities/workshop-on-vicarious-infrastructure/

- We are currently replacing the many of the components of the MOBY system (Optical system, control system, buoy structure).

- We will be doing a careful one year crossover between the current optical system and the new optical system to maintain continuity in our 20 year time series.

- The success of MOBY has depended on careful attention to calibration/characterization details and continuous investigation and improvement of these processes by a dedicated group of researchers.