An overview of the Marine Optical Buoy (MOBY): Past, present and future

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and the MOBY Team (Mark Yarbrough, Stephanie Flora, Michael Feinholz, Terry Houlihan, Darryl Peters, Sandy Yarbrough, and Sean Mundell, Moss Landing Marine Lab) and Art Gleason, University of Miami

MOBY and MOBY-Refresh are supported by NOAA's Joint Polar Satellite System (JPSS)
MOBY-Net by NASA OBB program.
Past support from NOAA (STAR/Dennis Clark and Research and Operations Program) and NASA (Earth Observing System Program, SeaWiFS Project, and the Ocean Biology and Biogeochemistry Program.

1st talk (KV)

1. Description of why MOBY and why MOBY is in Hawaii.
2. Description of MOBY/MOBY-Refresh/MOBY-Net
3. What do we do in the operational MOBY program
4. Data Processing chain of MOBY data

2nd Talk, (BCJ), tomorrow morning

1. Radiometric calibration, validation and verification processes.
2. Uncertainties in the radiometric calibration

3rd Talk, (KV) Tomorrow morning

1. QA
2. Estimated environmental uncertainty budget

4th Talk, (KV) Tomorrow morning

1. The 20-year time series of MOBY data.
2. What has been difficult in the MOBY project
3. Status of MOBY-Refresh and MOBY-Net

The driving force for MOBY came out of CZCS experience

- Coastal Zone Color Scanner (CZCS) launched 10/24/1978
- Required on-orbit calibration
- 3 post launch validation cruises:
  - Gulf of Mexico, R/V Athena (14 days)
  - Baja California, Gulf of California, R/V Velero IV (22 days)
  - East coast US, R/V Athena (25 days)
- These 61 days of ship time with 55 stations, resulting in only 9 stations suitable for calibration.

Site requirements:

-Reasonable clear sky statistics

-clean atmosphere: do not stress atmospheric correction, give a good fundamental calibration number

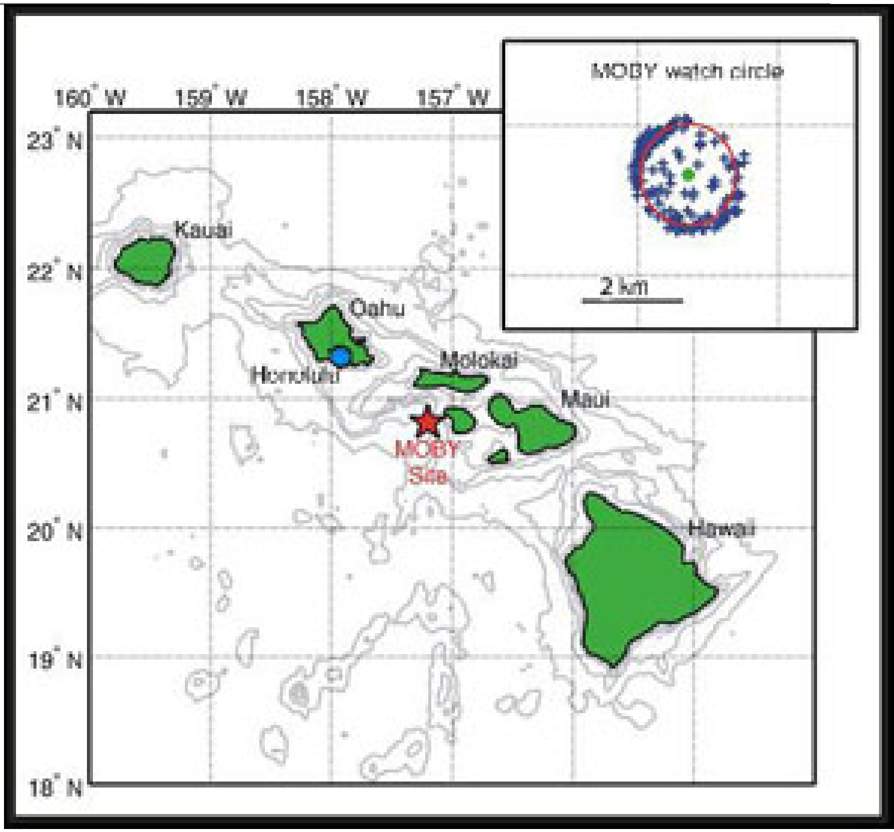
-Horizontally homogeneous water: avoid spatial inhomogeneity to allow point measurement to represent satellite pixel

-Logistically possible: close to a source of ships, reasonable chance of low sea state, simplify customs import/export

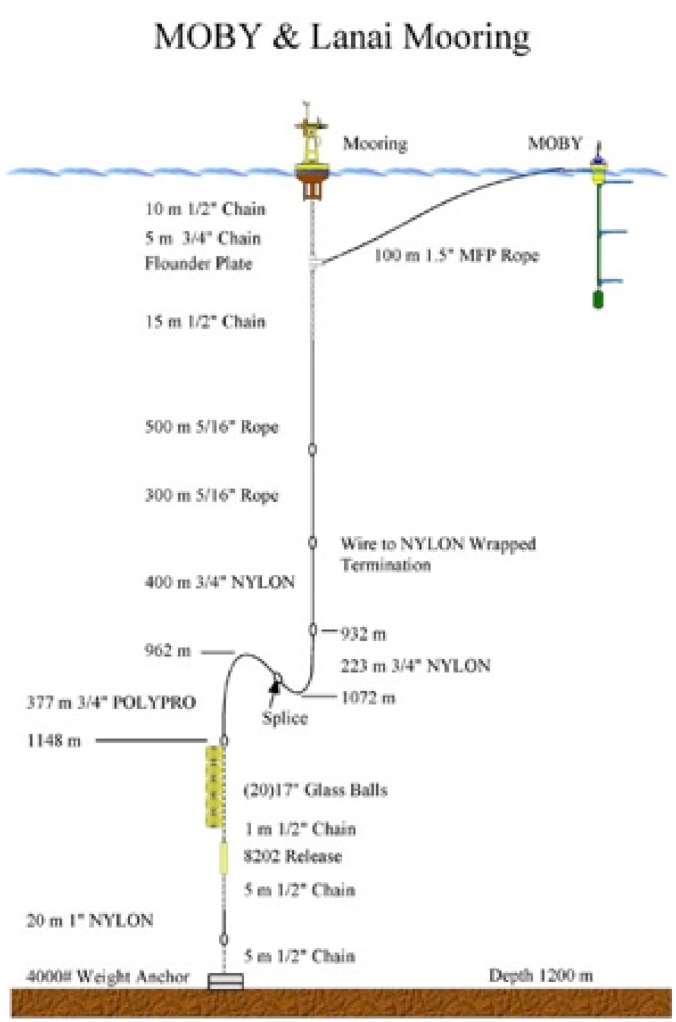
-Communication daily: cell phone to allow more data volume

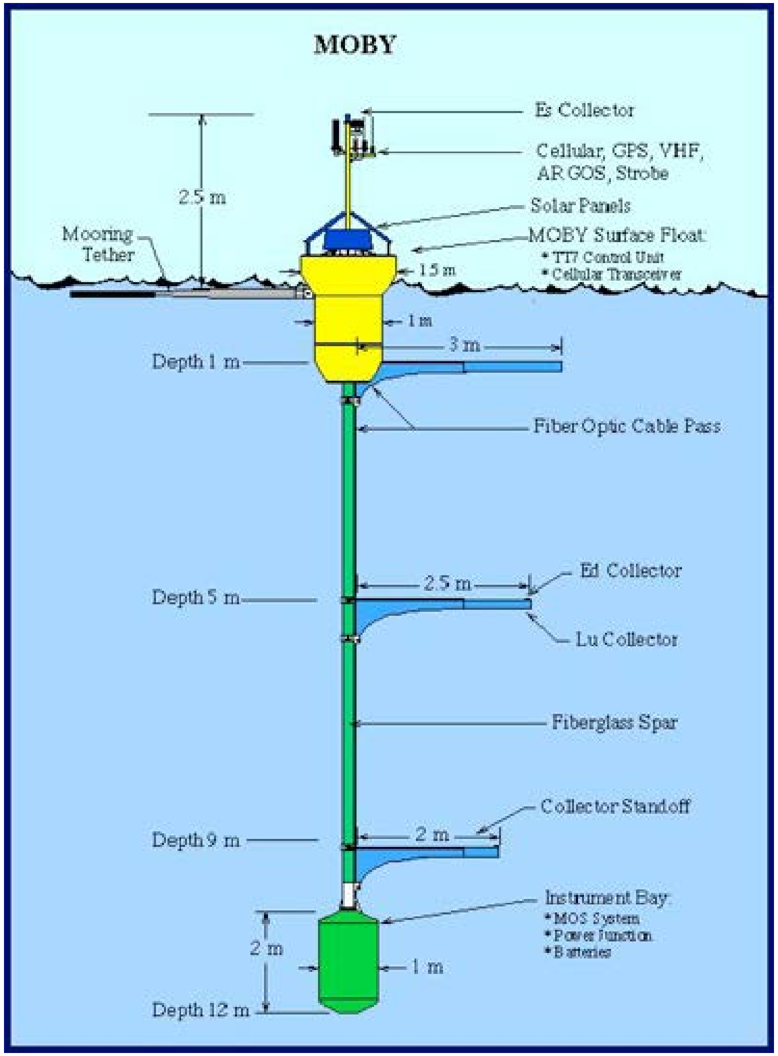
Description of why MOBY and why MOBY is in Hawaii.

Hawaii works



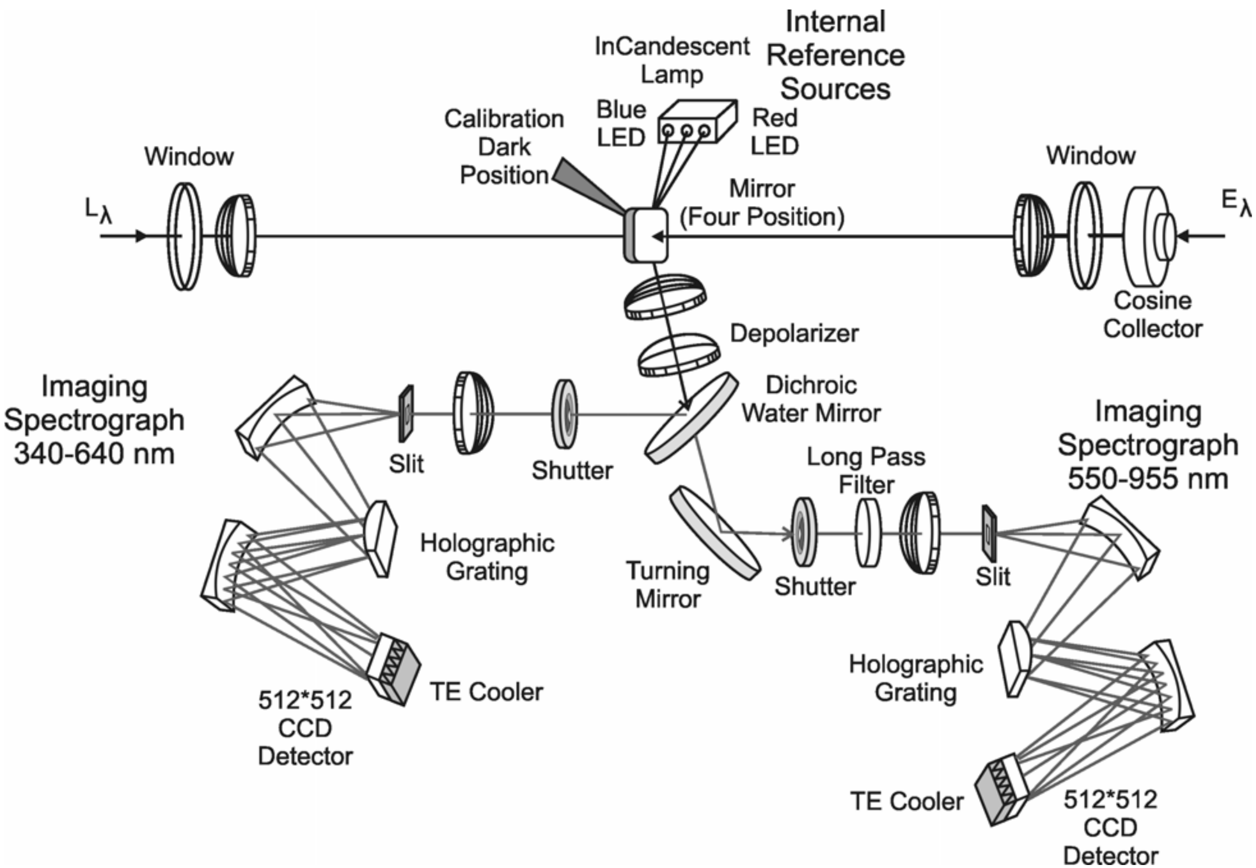
All three have same basic structure:





Biggest difference is in the optical system:

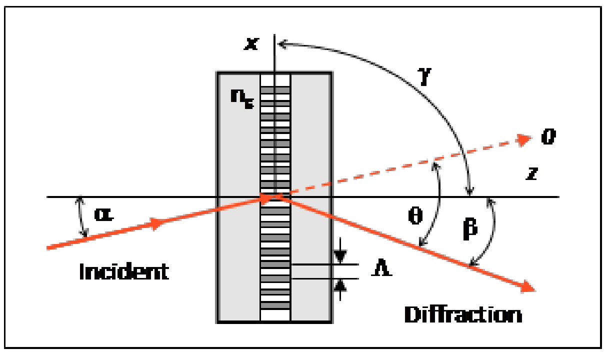
Currently, Marine Optical System (MOS), is a combination of two holographic reflective grating spectrometer systems



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

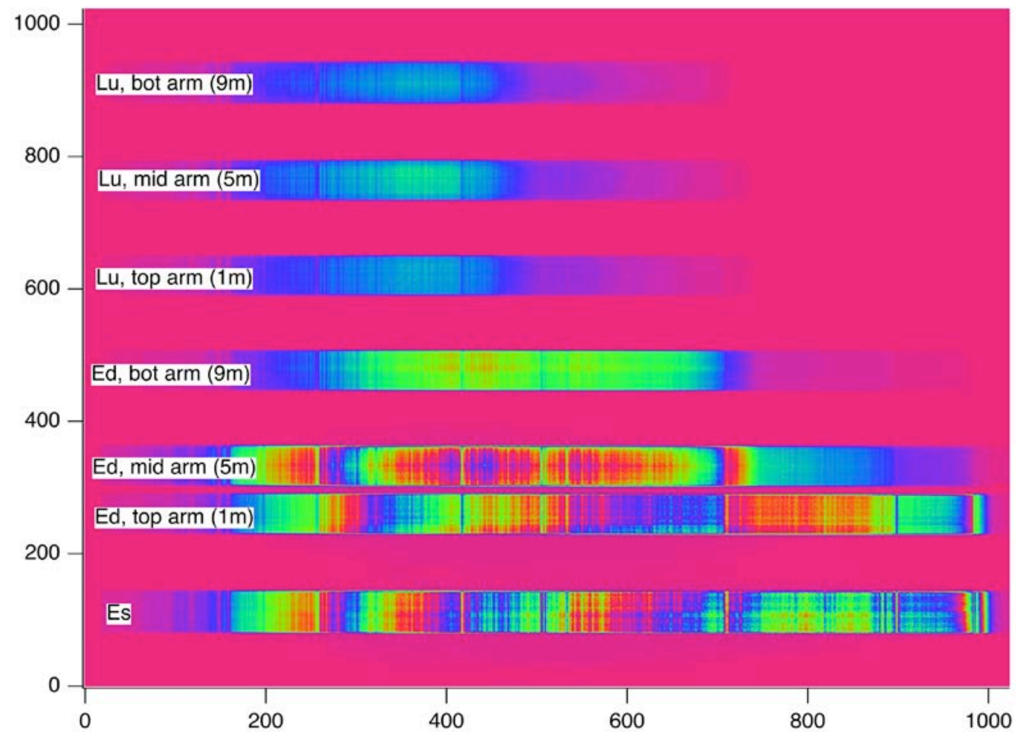
Different optical measurements must be done sequentially.

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/

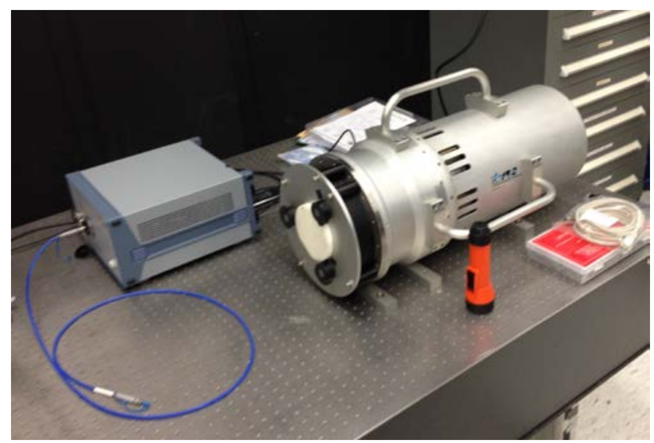
Example spectra from field measurements with blue spectrometer



The difference between MOBY-Refresh and MOBY-Net, is that 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 (Geostationary Operational Environmental Satellite, 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 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 (water leaving radiance, diffuse upwelling radiance attenuation, and normalized water leaving radiance.

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

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

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

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

We are currently taking data in the following order:

Es (3x)
Lumid (5x)
Es(3x)
LuTop(5x)
Es(3x)
LuBot(5x)
Es(3x)
Es(3x)
Edmid(5x)
Es(3x)
Edtop(5x)
Es(3x)
Edbot(5x)
Es(3x)
Blue calibration LED(3x)
Red calibration LED(3x)
Incandescent lamp(3x)

There are 3 Es measurements taken each time, and 5 of the other measurements (Ed or Lu).

Dark images are taken before and after each measurement sequence at integration times matching the light measurement.

Measurements are obtained at 10AM, 12AM, and 2PM local time (the 2PM measurement sometimes shows up as 3PM...depending on exact time of acquisition.

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.

In the next few talks that Carol and I give we will go over:

- Radiometric calibration and uncertainties in MOBY program
- Estimate of environmental uncertainties
- MOBY time series
- What we have learned
- Status of MOBY-Refresh and MOBY-Net

Talk 1, Extended Abstract

An overview of the Marine Optical Buoy (MOBY): Past, present and future

FRM4SOC Workshop, Feb 21 – 23, 2017, Frascati, Italy

K. Voss, C. Johnson, M. Yarbrough, Art Gleason, S. Flora, M. Feinholz, D. Peters, T. Houlihan, S. Mundell, S. Yarbrough

This talk provided an overview of the MOBY project and the work we are doing now to move the MOBY instrumentation forward into the future. This is the first of 4 talks we gave at this workshop on various aspects of the MOBY project.

1) Description of MOBY and why it is in Hawaii

MOBY's existence grew out of Dennis Clark's experiences in vicariously calibrating the Coastal Zone Color Scanner (CZCS) in the late 1970's. In the initial work for this, 61 days of shiptime on 3 cruises and 55 stations resulted in only 9 stations suitable for vicarious calibration. Dennis realized that an autonomous buoy was required to do this calibration correctly, particular if merging multiple satellite missions was required.

The requirements for a site for this buoy were clear sky, clean atmosphere, reasonably horizontally homogeneous waters, and logistic accessibility (but also remote enough to avoid vandalism). It was also desirable to have cell phone coverage for good communication and large data volume transfers. The site chosen was off of the island of Lanai, Hawaii. This site had all the requirements, including access to ships from the University of Hawaii Marine Center.

The MOBY buoy is moored in 1200 m of water with a slack line mooring. The buoy itself is approximately 15 m long, with arms to measure upwelling radiance and downwelling irradiance at 1 m, 5 m, and 9 m depth. The optical system in the heritage MOBY is called MOS, and is held in a container at the bottom of MOBY to maintain a relatively constant temperature environment. At the top of the buoy are solar panels, to allow autonomous operation, an Argos transmitter, cell phone modem, and the computer control system. The Marine Optical System (MOS) system consists of two reflective holographic gratings, one to handle blue wavelengths and one to handle red wavelengths. The system also includes blue and red LED reference sources and an incandescent lamp reference source. The optical system is hyperspectral with 0.6-0.9 nm spacing of the individual channels and 0.8-1 nm full width half-maximum (FWHM) spectral resolution.

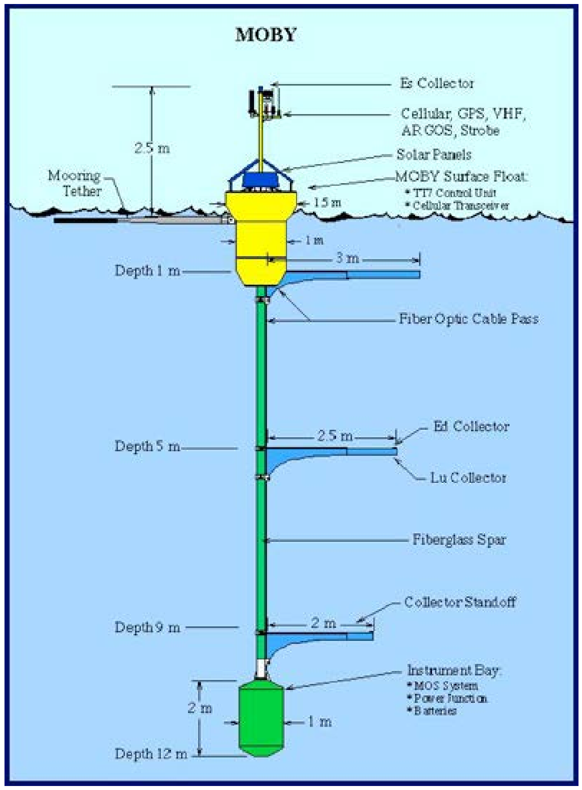


Figure 1) Cartoon illustration of the MOBY buoy.

2) The difference between MOBY/MOBY-Refresh/MOBY-Net

The new optical system on MOBY-Refresh (supported by the National Oceanic and Atmospheric Administration, NOAA) and MOBY-Net (supported by the National Aeronautics and Space Administration, NASA) will have dual in-line volume phase holographic gratings that allows simultaneous spectra at the different arms to be acquired. We have already gotten sample field data with the new blue spectrograph systems. For MOBY-Net, which is meant to be a system operated remotely from our Hawaii site, we have designed a new carbon fiber structure which will allow the optical system to be installed and removed from the buoy structure without disassembly of the optical system. By shipping the optical system intact back to the central MOBY calibration facility, this allows a remote site to maintain a common calibration with the Hawaii buoy. In addition, we are testing out a stability source and monitor which will travel with the MOBY buoy to verify the performance of the MOBY-Net optical system before and after deployment.

3) The MOBY operational program

In this talk we also gave some information on the current MOBY operational program. Currently we have two buoys that are deployed alternately in 4-month intervals. When an instrument is recovered from the field we fully calibrate it (post-deployment calibration), repair as necessary, and calibrate it for the next deployment (pre-calibration). 3 sets of data are obtained each day, and data is downloaded from the buoy daily and sent to the processing center in California. There the data is inspected, and auxiliary Geostationary Operational Environmental Satellite (GOES) images are also inspected to look for cloud free conditions. After the data is processed it is posted to the NOAA Coastwatch site, usually within 1-2 days. After the deployment ends the post-calibration is performed and a comparison is made between the pre- and post- calibrations. Depending on the individual deployment characteristics the information from both pre- and post- calibrations are used to inform reprocessing of that deployments calibration. A final scheduled reprocessing is done when the calibration lamps are recalibrated at the National Institute of Standards and Technology (NIST) after a certain number of hours (detailed in the second MOBY talk by Carol Johnson).

The normal measurement sequence for a MOBY acquisition consists of 5 samples each of the in-water optical measurements (downwelling irradiance, Ed, or upwelling radiance, Lu) with 3 samples of the downwelling surface irradiance before and after the in-water measurement. Dark images at appropriate integration times are taken before and after each sequence of set of optical measurements. Typically three measurements are obtained per day, associated with different satellite missions.

The normal MOBY products are the hyperspectral water leaving radiance, Lw, and normalized water leaving radiance, Lwn, using different arm measurements and arm pairs to derive the diffuse upwelling radiance attenuation coefficient, KL. The normal version of these products is Lw1, and Lwn1, which uses the top arm Lu, and KL derived from the top and middle arm. Another version, Lw2 and Lwn2, uses the top arm, and KL derived from the top and bottom arm. The final version is Lw7 and Lwn7, which uses the mid arm, and the KL derived from the mid and bottom arm. There is an associated product Lw21, Lw22, Lw27, Lwn21, Lwn22, and Lwn27 which uses radiative transfer models to improve the product for wavelengths above 575 nm, where Raman scattering interferes with the derived KL. Associated with each of these hyperspectral products are products for each satellite program which integrate the hyperspectral data over the specific satellite bandpass.

The rest of the MOBY project, along with MOBY-Refresh and MOBY-Net, will be described in later talks.

MOBY Radiometric Calibration and Associated Uncertainties

B. Carol Johnson, National Institute of Standards and Technology

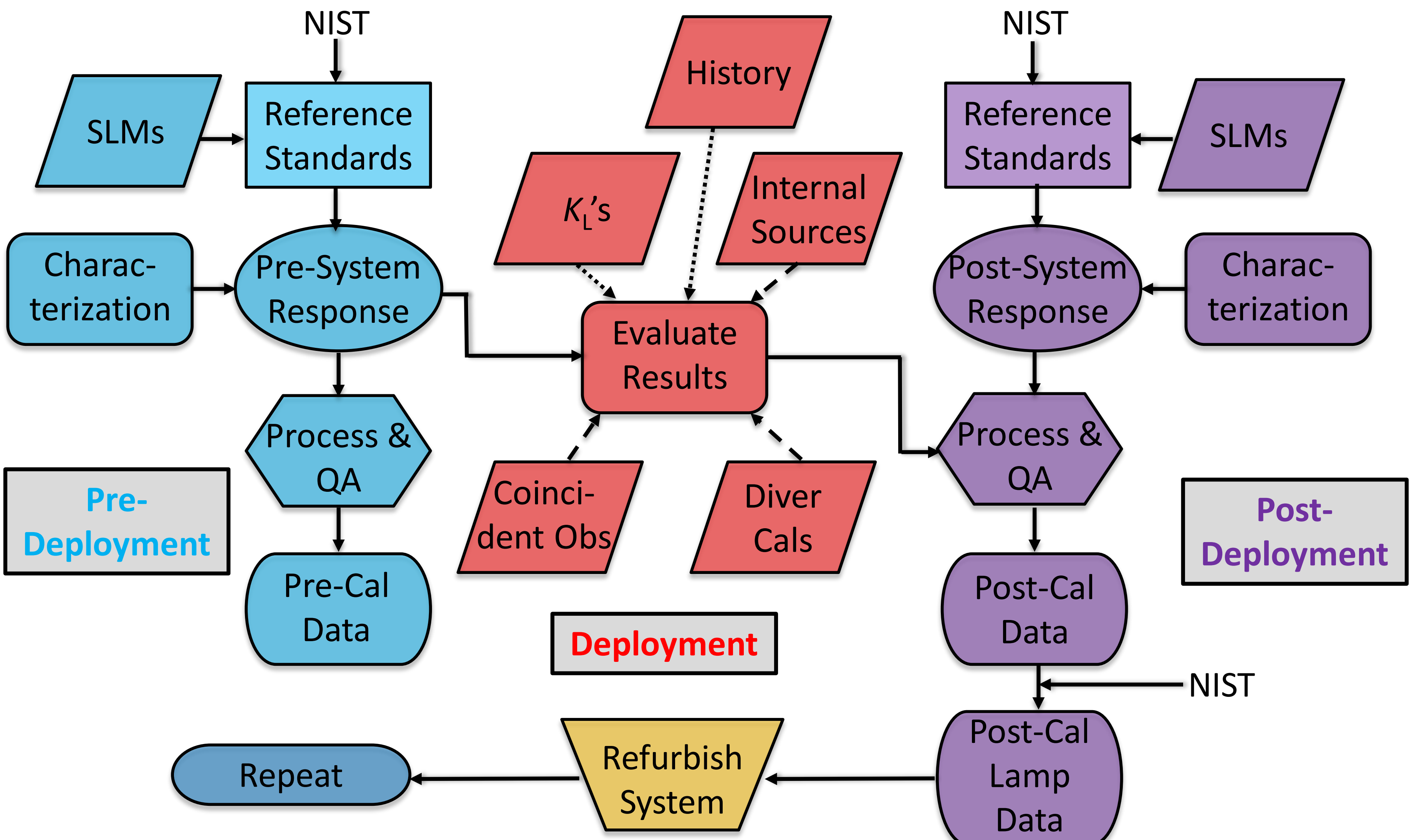
Kenneth Voss, University of Miami

and the MOBY Team (Mark Yarbrough, Stephanie Flora, Michael Feinholz, Darryl Peters, Terrence Houlihan, Sean Mundell, Sandy Yarbrough, Moss Landing Marine Lab)

MOBY and MOBY-Refresh supported by NOAA's Joint Polar Satellite System (JPSS), MOBY-Net by NASA's Ocean Biology and Biogeochemistry Program

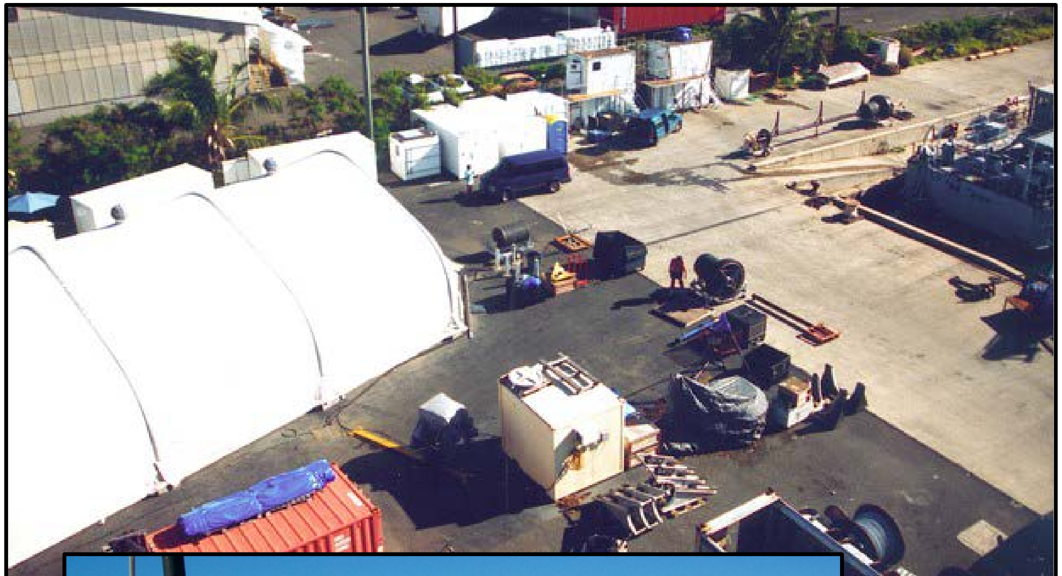
Past support from NOAA (STAR/Dennis Clark & Research and Operations Program) and NASA (Earth Observing System Program, SeaWiFS Project, & the Ocean Biology & Biogeochemistry Program)

Traceability and Redundancy



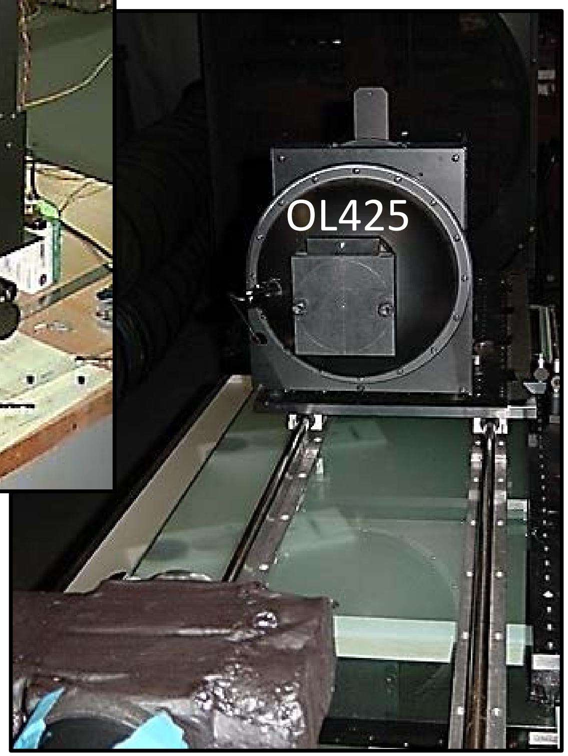
MOBY Facility

Calibration & Characterization in the Tent (fibered inputs) and the Cal Hut (MOS input)



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

Two integrating spheres are used, OL420 & OL425



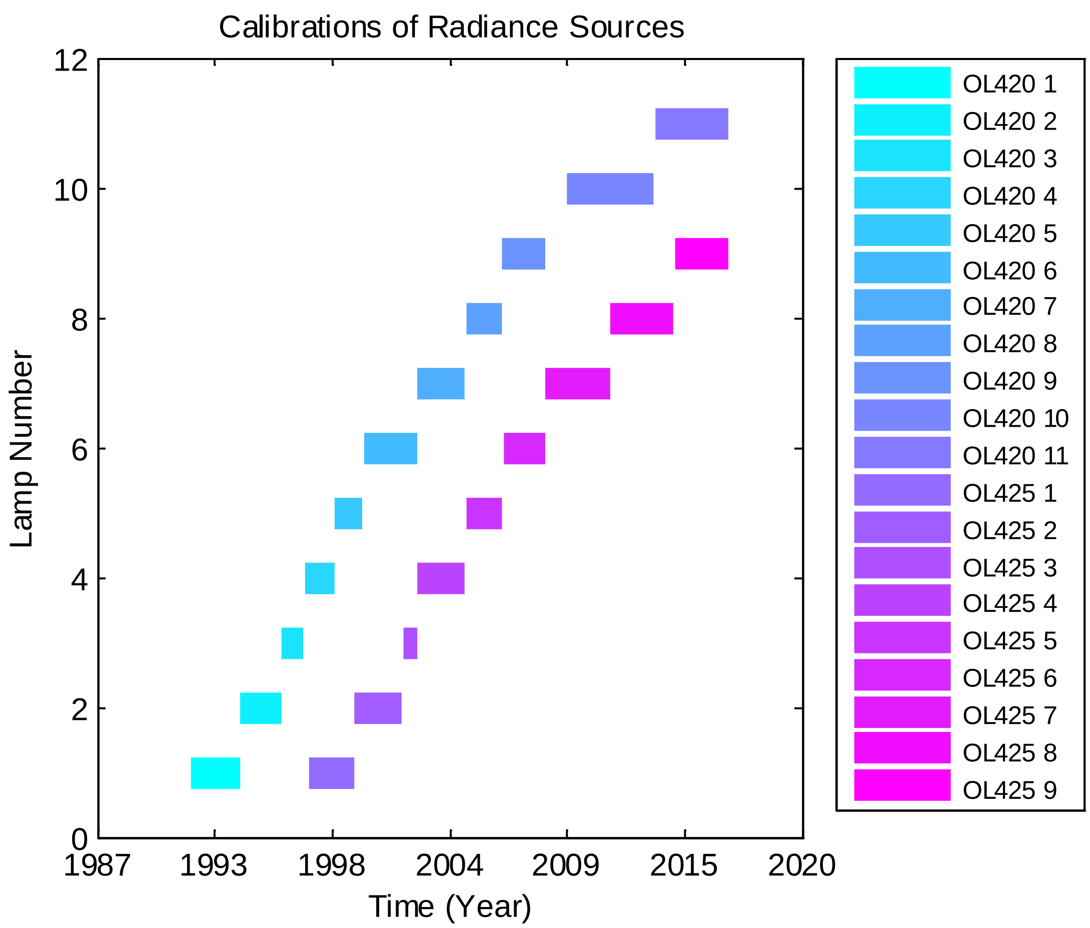
Features
Externally illuminated, TQH* lamps
Large dynamic range (OL420)
Photopic monitor PD (OL425)
Operating data recorded
Lamps replaced every 50 h burn time
NIST beginning-of-life (BOL) cals
NIST end-of-life (EOL) cals

Monitored using NIST custom filter radiometers (SLMs)

*tungsten quartz halogen

Sphere Calibration History

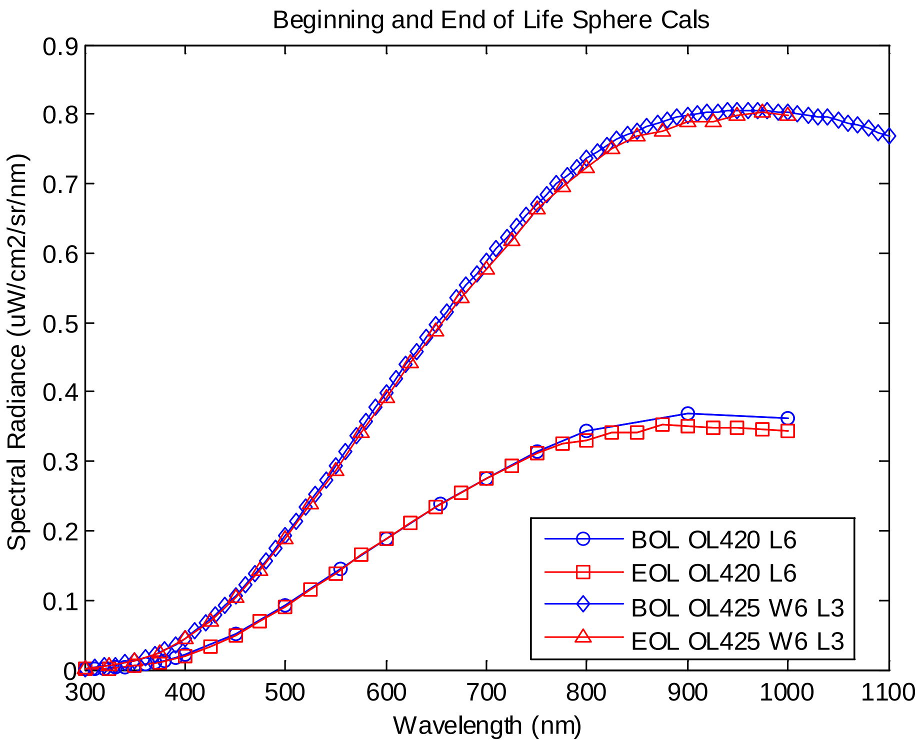
All calibrations after (& including) Aug 2002 were at NIST

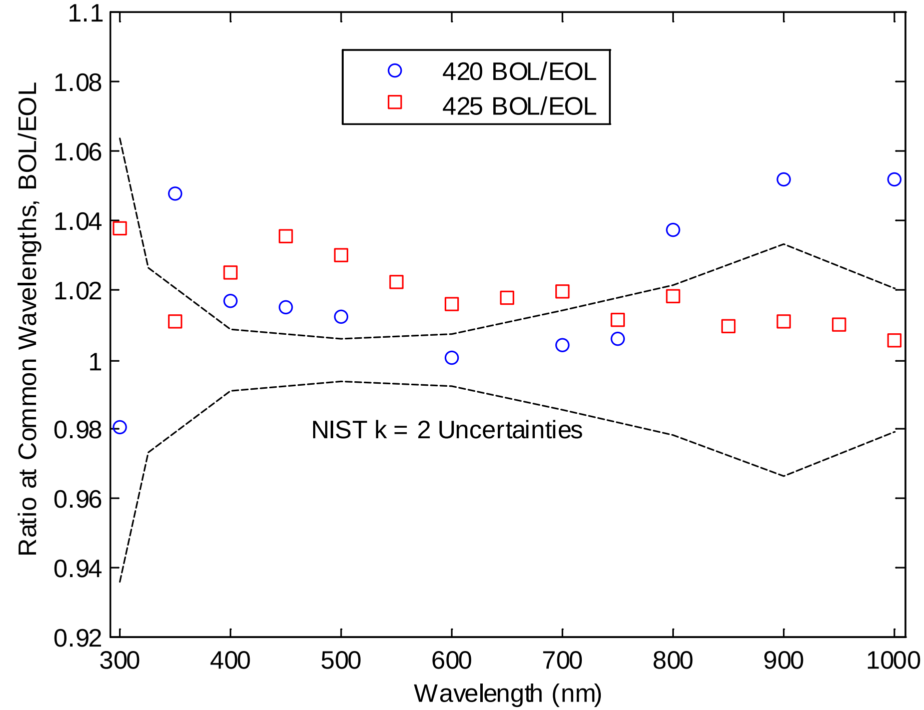


Two Spheres, 20 Lamps, 40 Calibrations, 25 years

Source Beginning/End of (Lamp) Life, $L_u(\lambda)$

BOL was by Optronic Labs
EOL was NIST
All cals after Aug 2002 at NIST

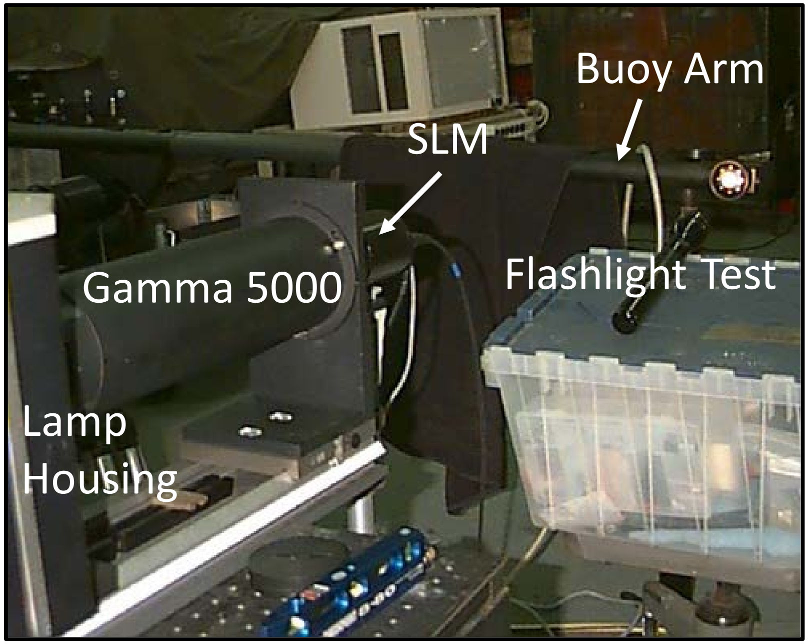




Ratio at common wavelengths. Plotted: k = 2 uncertainties for Aug 2002 OL420 EOL NIST

Optronic Labs k = 2 uncertainties were:
Bright: 3% (350 nm) to 2% (550 nm)
Dim: 10% (350 nm) to 8% (550 nm)

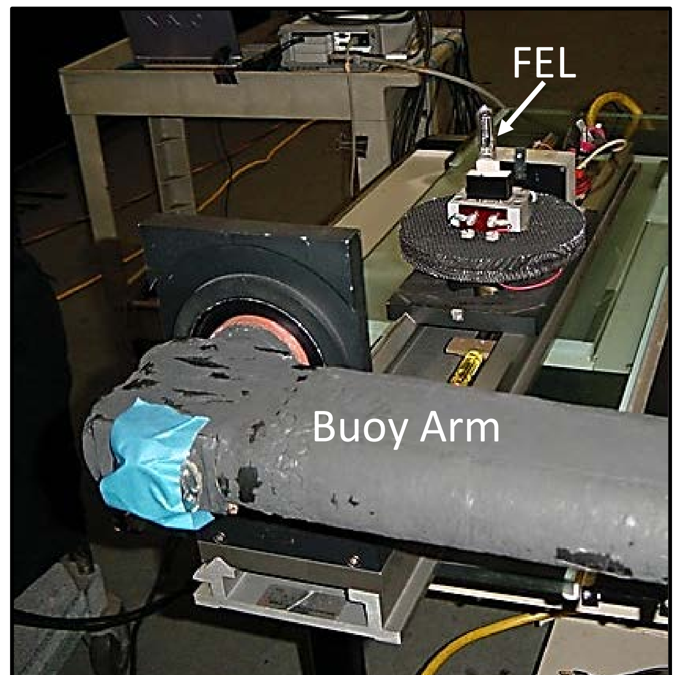
Radiometric Calibration for MOBY – $E_{d,s}(\lambda)$



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

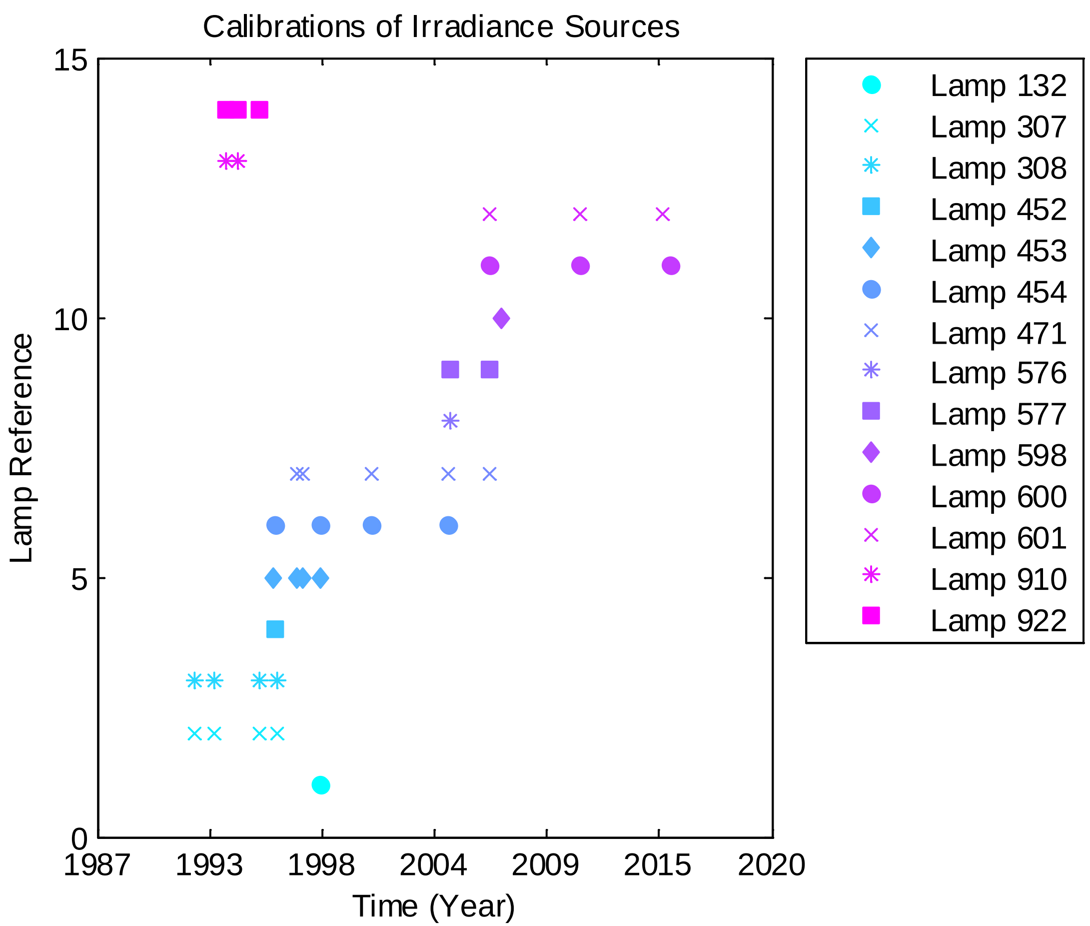


Features:
Recalibrated every 50 h burn time;
NIST calibrations entire time series;
Monitored using NIST custom filter;
radiometers (SLMs).

*Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

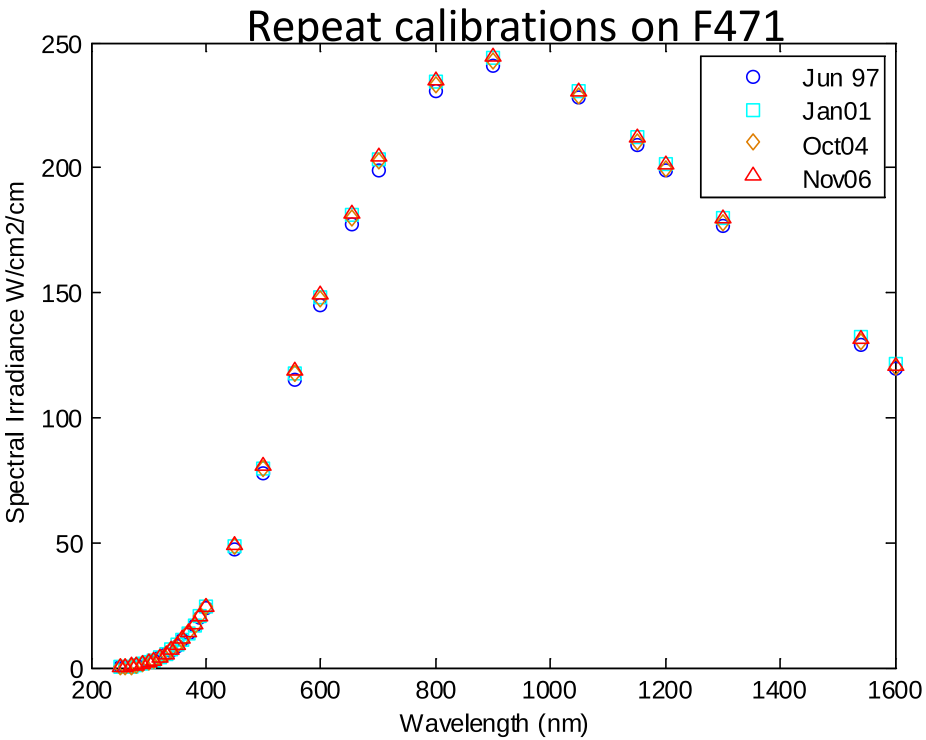
FEL Calibration History

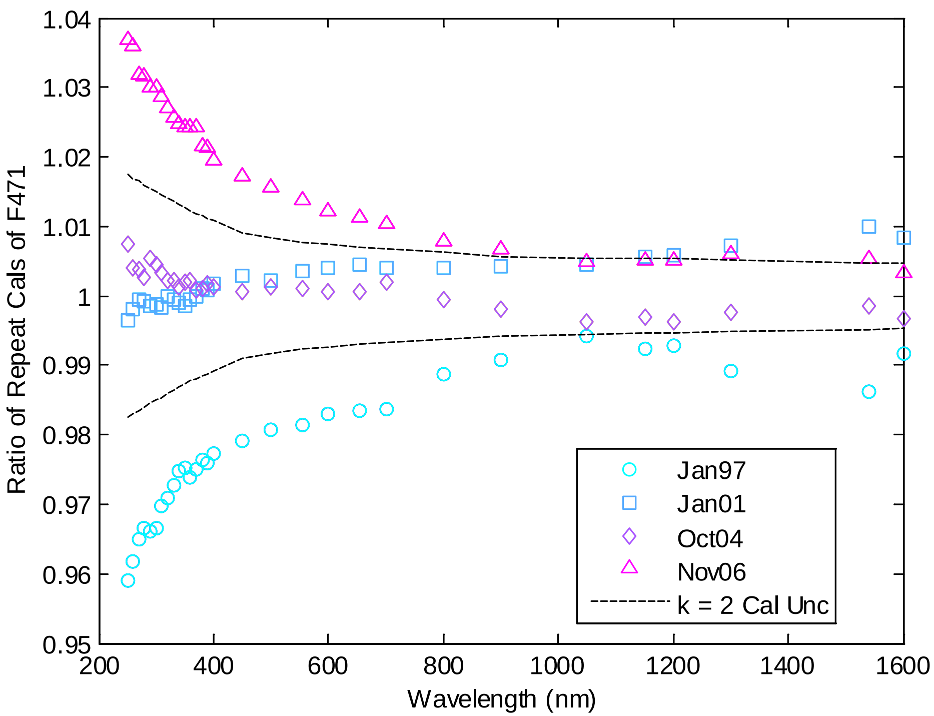
All calibrations were at NIST; some validation measurements done at Gamma Scientific



Fourteen FEL lamps, 38 calibrations, 24.5 years

FEL Lamp Calibrations, $E_{d,s}(\lambda)$

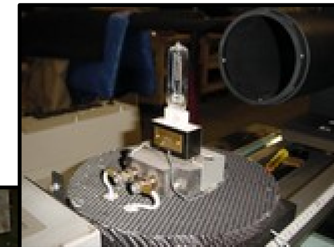


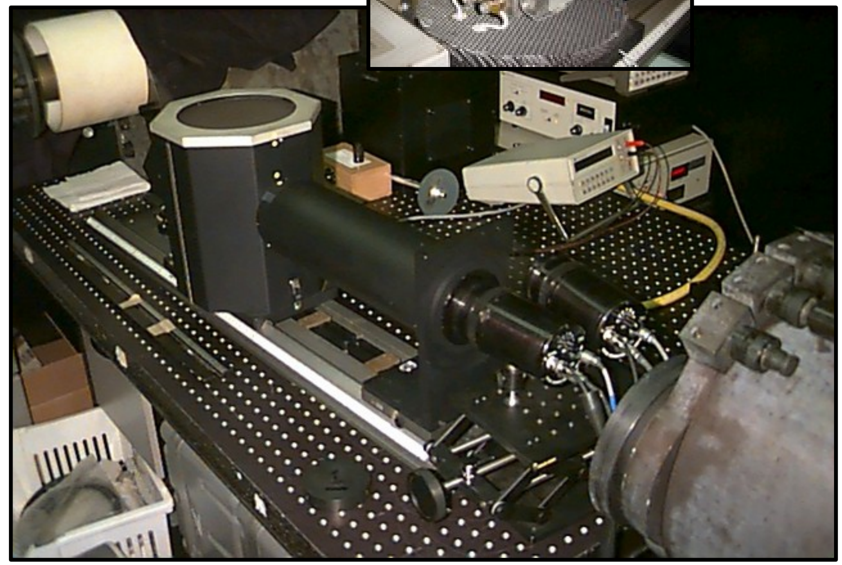


Ratio to mean and k = 2 uncertainties for NIST calibrations (typical)

Standard Lamp Monitors (SLMs)

Radiance
Mode

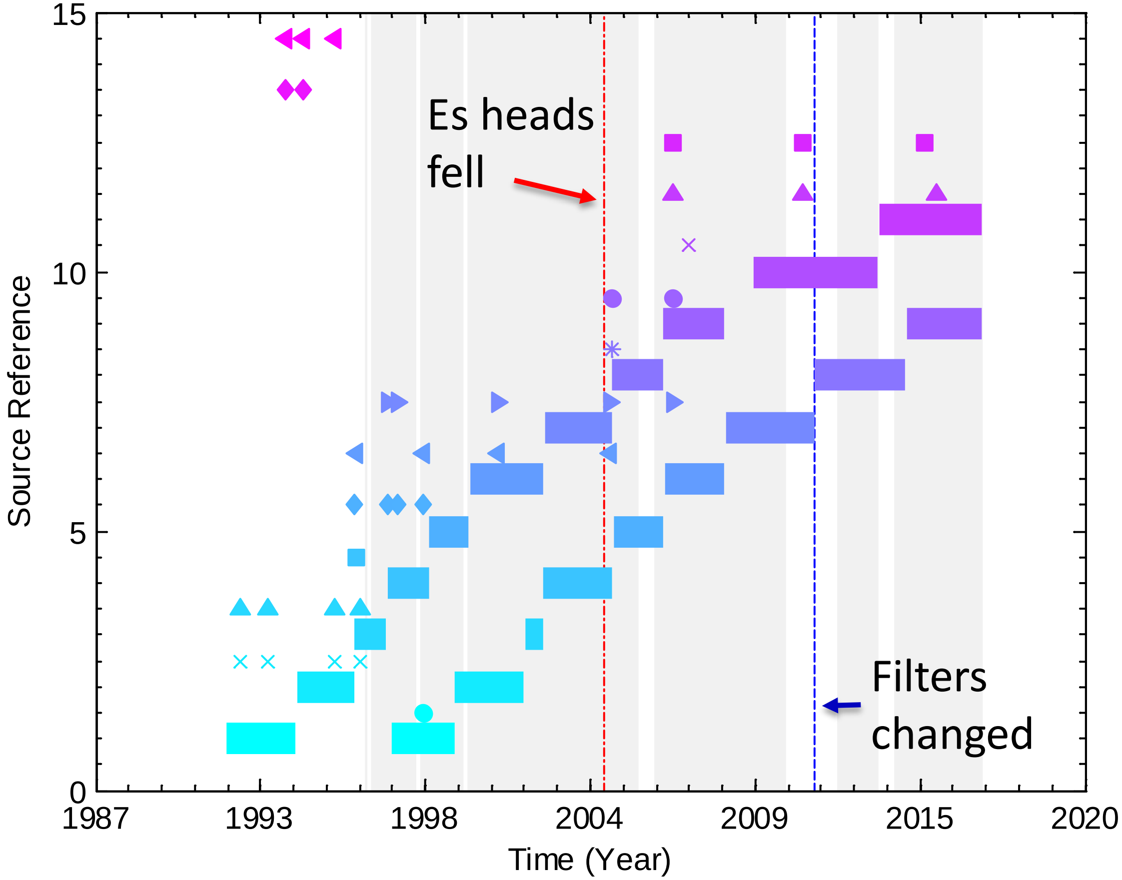




Irradiance
Mode

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

SLM Operation

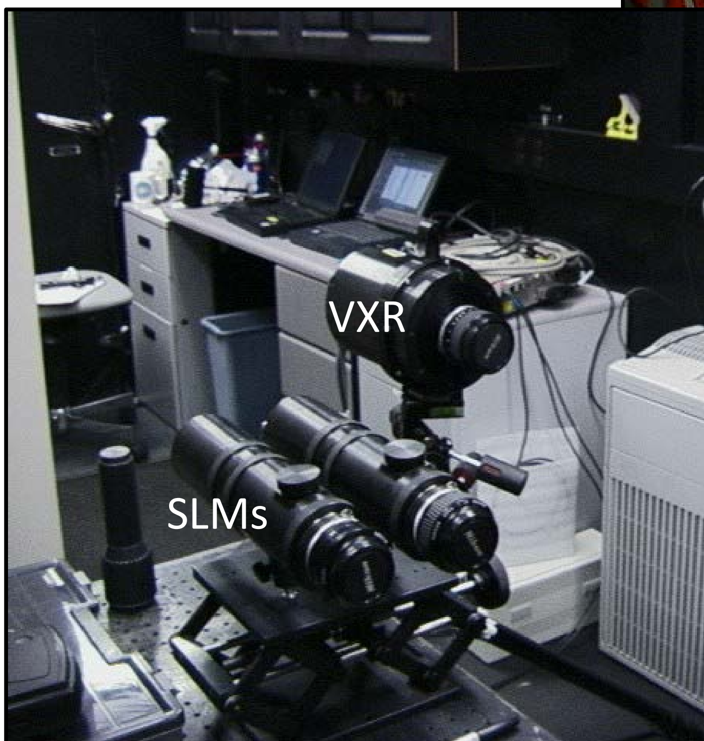


SLMs commissioned September 1996

Gray – Used with MOBY
White – At NIST for calibration or repair

As of Jan 2017, 421 SLM measurements of the OL420 and OL425

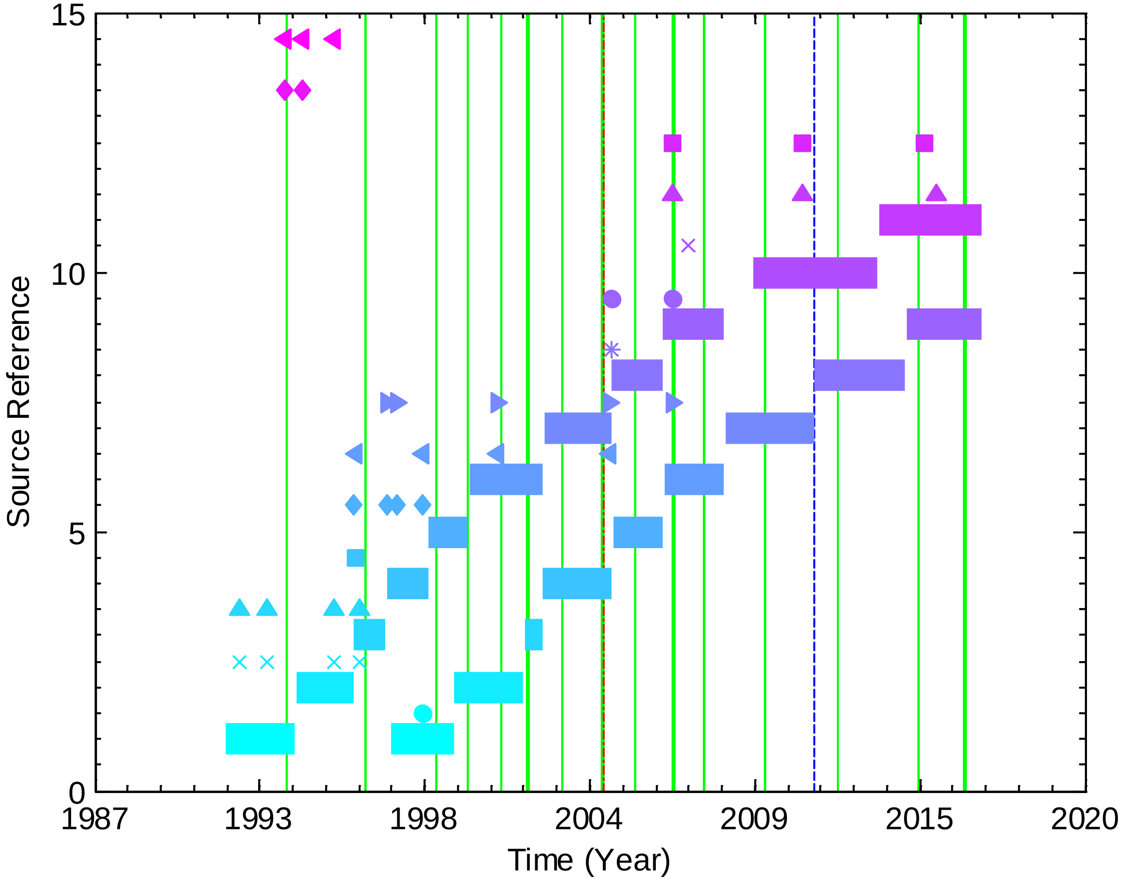
VXR and NPR



Validation of the MOBY radiance sources using NIST's Portable Radiance source (NPR) and Visible Transfer Radiometer (VXR)

Thirteen trips 1999 – 2016; Two trips with the SXR in 1994 and 1996

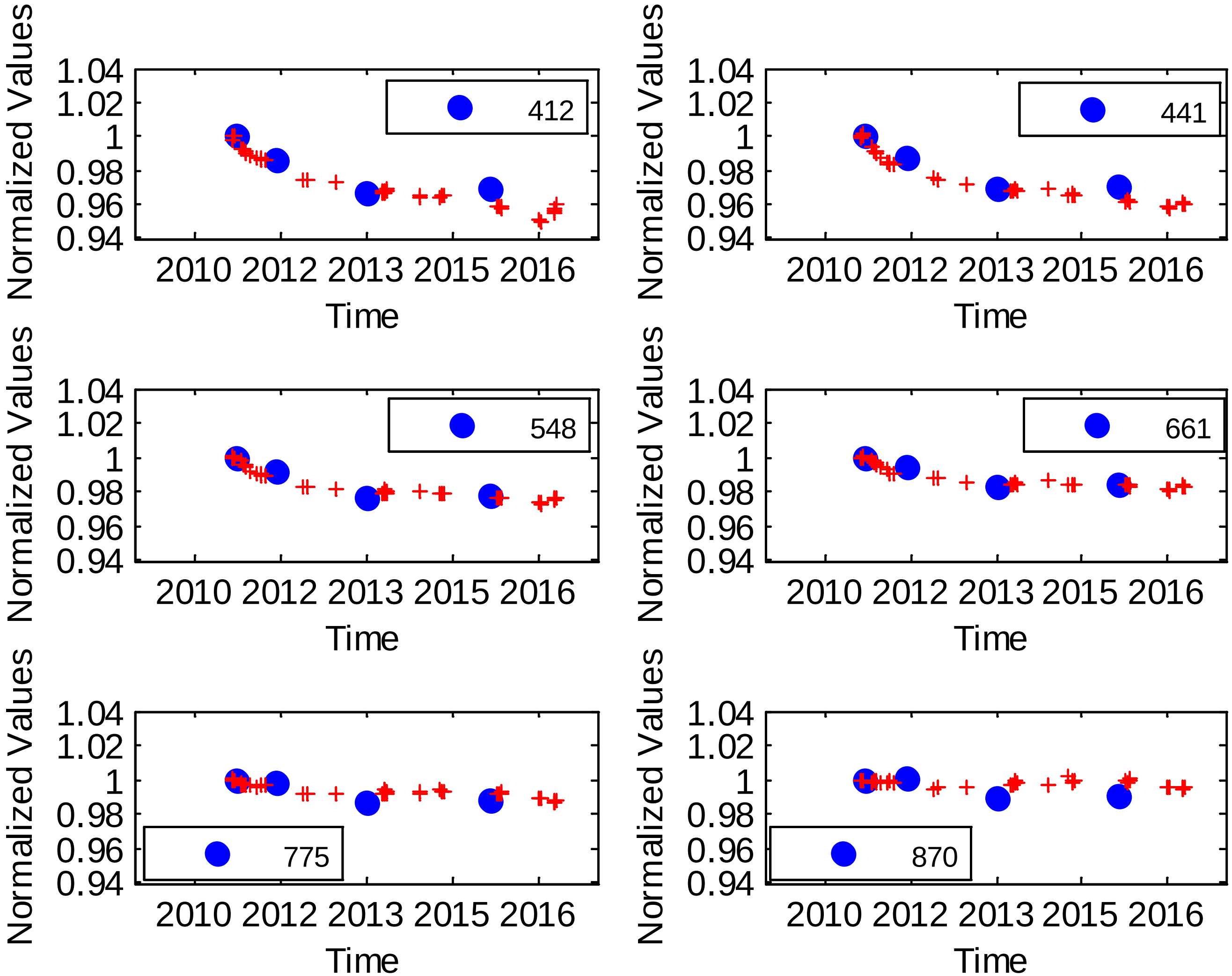
VXR and NPR



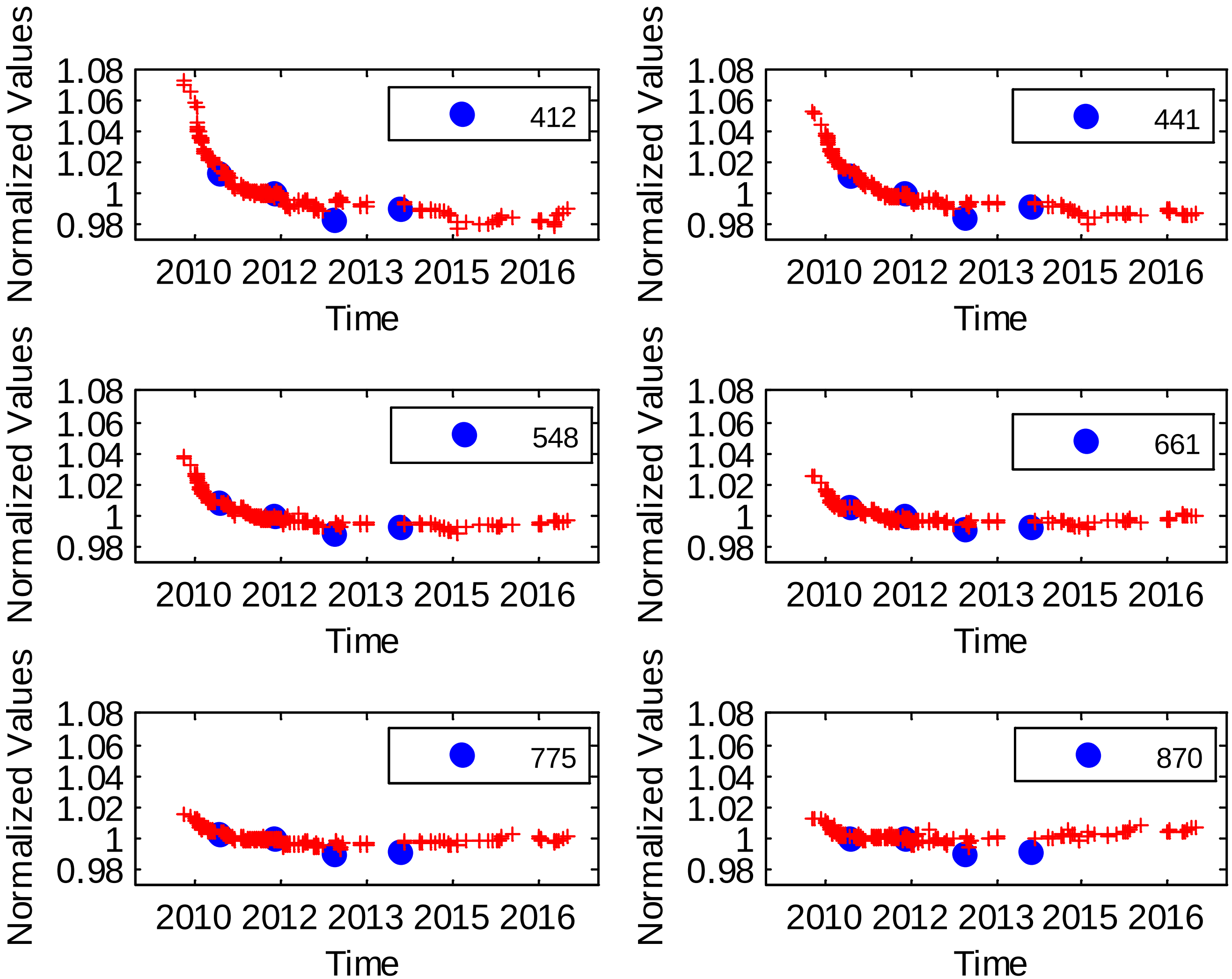
"HONO" Time Series

Note: HONO14 & 15 included an irradiance comparison

Stability of VXR/NPR-2 (NII) system



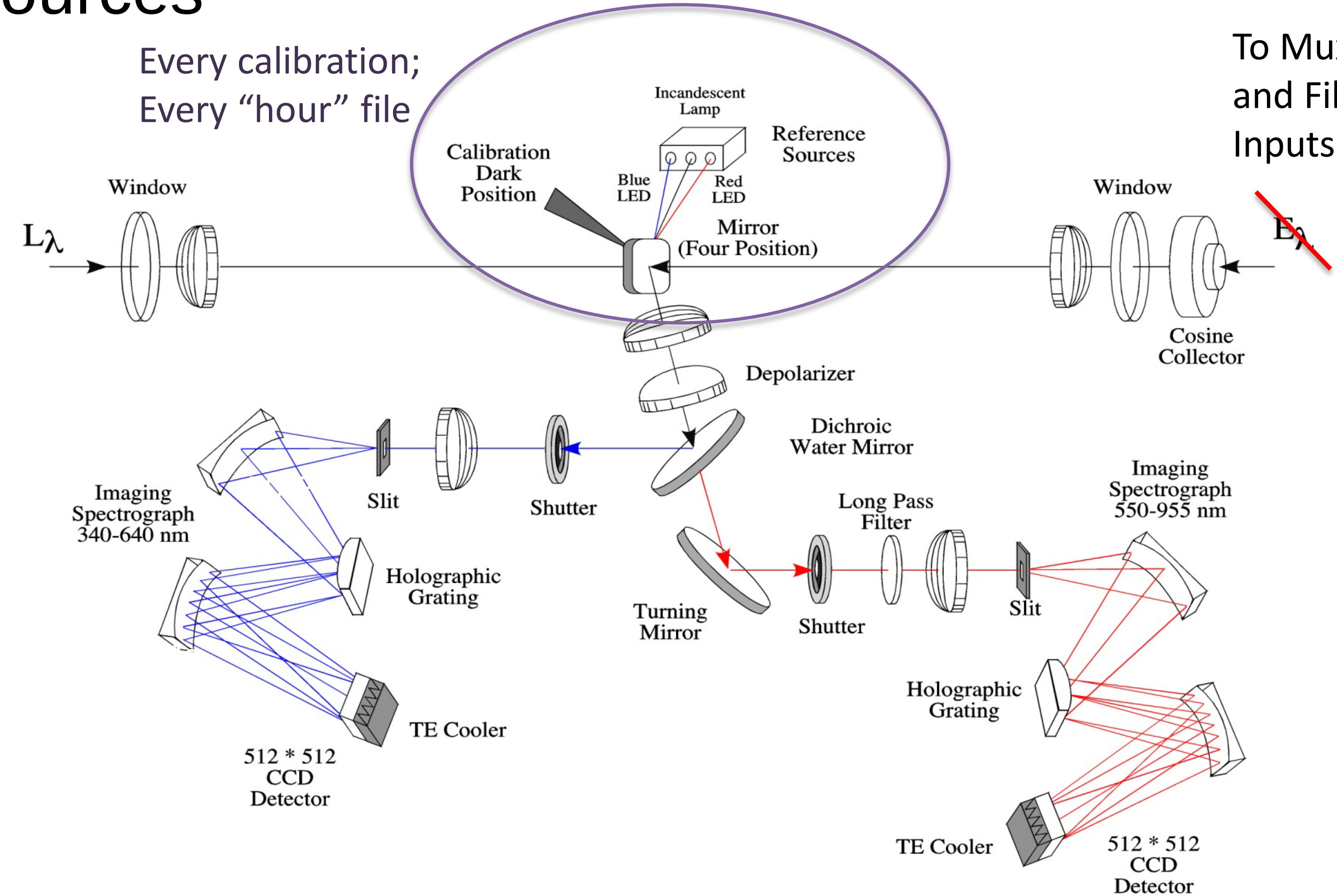
Stability of VXR/NPR system



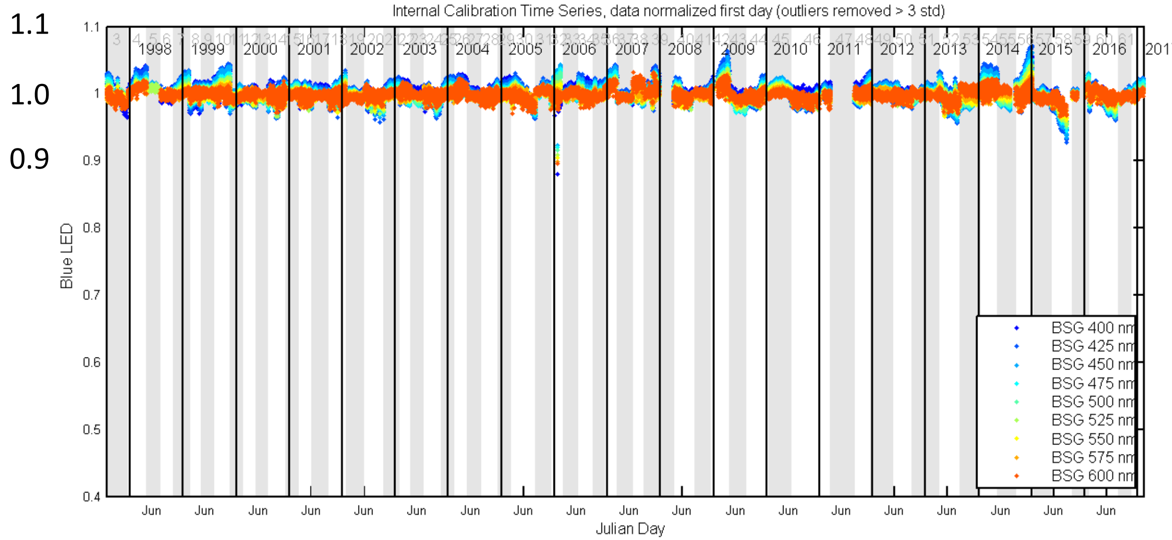
Marine Optical System (MOS) Internal Cal Sources

Every calibration;
Every "hour" file

To Mux
and Fiber
Inputs

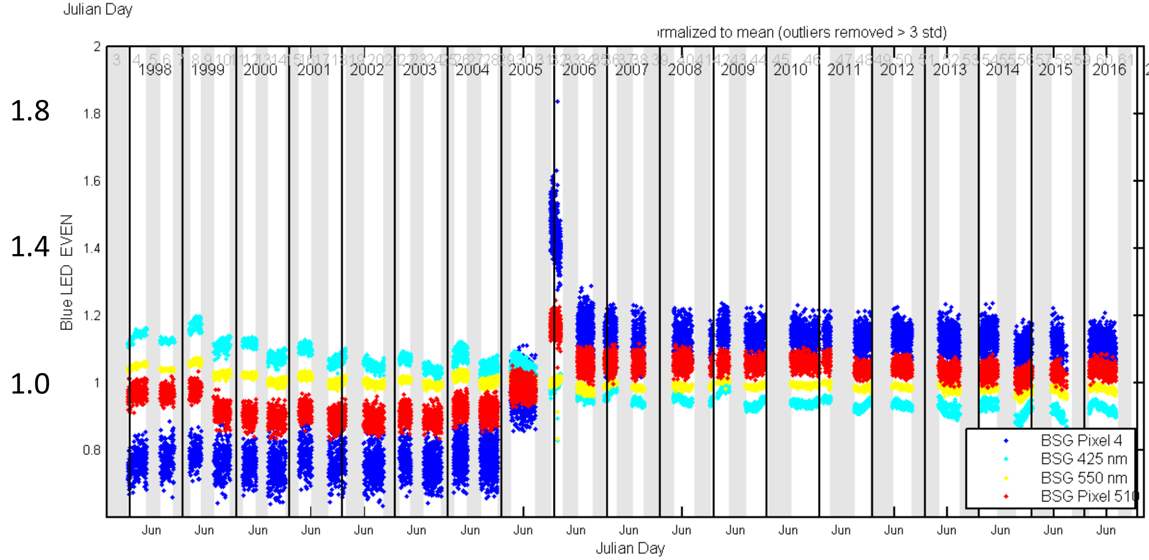


Internal Source Time Series

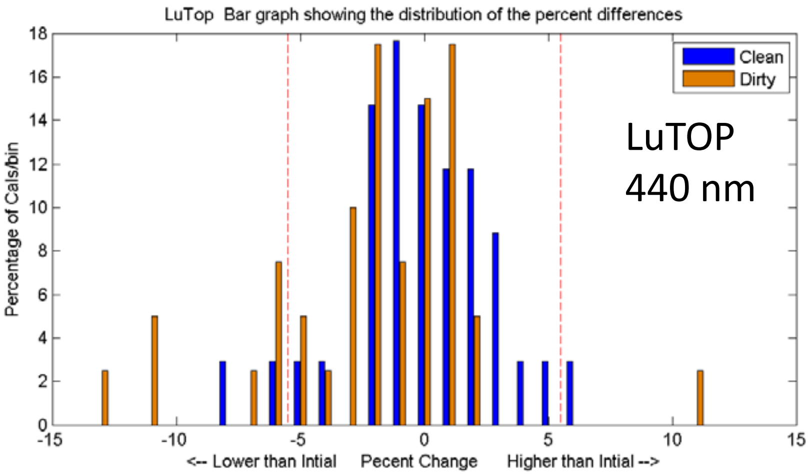


Example: Blue LED, blue spec, data normalized to the first reading for each deployment

Example: Blue LED, blue spec, Even buoy (MOS 204), normalized to the mean of all deployments. The shift is attributed to changes in stray light (grating scatter)



Diver Cleaning & Cal Lamps



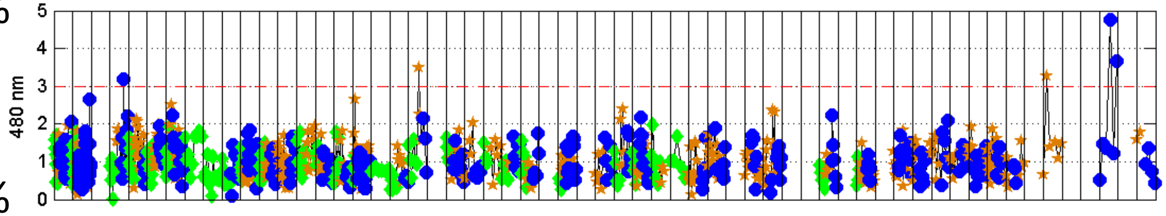
LuTOP
440 nm

-5% +5%

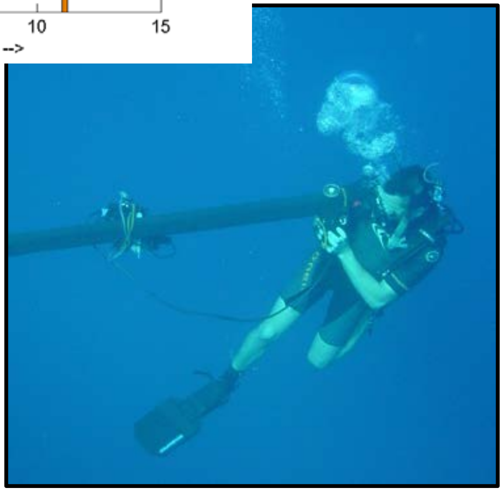
Deployments w initial diver lamp calibrations (DCLs)

Deviations w/in each DCL set (LuTOP, 480 nm)

5%



0%



Characterizations

- CCD bin factor (along-slit direction)
- Full images (saturation checks)
- Behavior of dark counts
- Integration time correction factor (shutter delay)
- Linearity with optical flux (double aperture; variable radiance source)

Characterizations, continued

- Temperature sensitivity (water bath)
- Wavelength calibration – atomic line emission sources (pre/post), Fraunhofer lines (field)
- Spectral stray light (many studies with lasers)
- Cosine response (Es)
- Polarization sensitivity
- Immersion factors

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
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		2.57	1.61	1.34	1.32	1.13
Expanded, k = 2		5.15	3.23	2.67	2.65	2.26

Uncertainty Budget, Es

Uncertainty Origin	Type	410 nm	443 nm	486 nm	551 nm	671 nm
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, $k = 1$		1.95	1.46	1.26	1.18	1.07
Expd, $k = 2$		3.91	2.91	2.52	2.35	2.14

Thank You

Talk 2, Extended Abstract

MOBY Radiometric Calibration and Associated Uncertainties

Fiducial Reference Measurements for Satellite Ocean Color (FRM4SOC) Workshop, Feb 21 – 23, 2017, Frascati, Italy

C. Johnson, K. Voss, M. Yarbrough, S. Flora, M. Feinholz, D. Peters, T. Houlihan, S. Mundell, S. Yarbrough

The values of the MOBY radiometric retrievals of spectral radiance (Lu) and spectral irradiance (Ed, Es) are traceable to NIST reference standards via MLML integrating sphere sources and Moss Landing Marine Labs (MLML) lamp standards of spectral irradiance [1]. The complete paradigm is illustrated in Fig. 1.

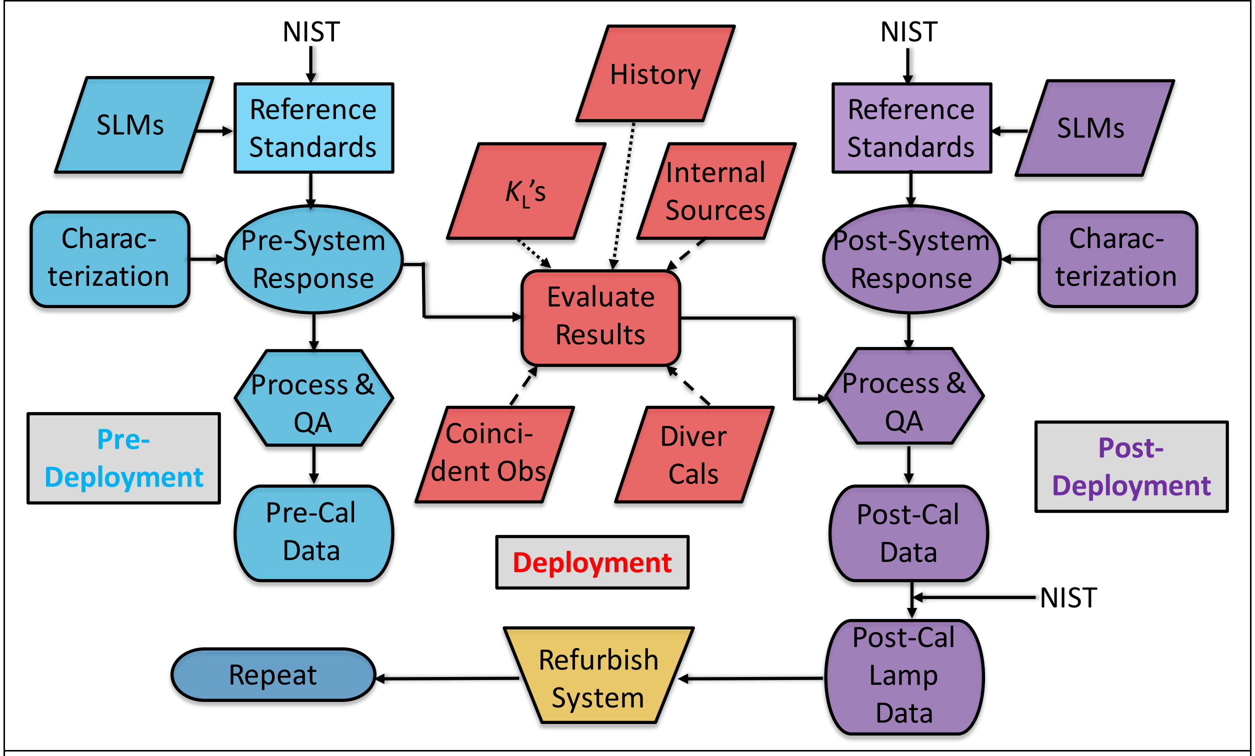


Figure 1. MOBY Radiometric procedures produce values traceable to NIST and generate levels of redundancy as part of the quality assurance program.

The blue, red, and, purple boxes represent activities performed pre-, during-, and post-deployment. The reference standards are calibrated at NIST every 50 h of burn time. The FEL lamps are recalibrated and reissued unless there are indications they are starting to drift. The lamps in the sphere sources are changed upon calibration. This results in two calibrations, a beginning of lamp life (BOL) and an end of lamp life (EOL). During operation at MOBY, the reference sources are monitored using the NIST-designed Standard Lamp Monitors (SLMs). The four MOBY Es and Ed channels and the three arm Lu channels, all of which use fiber optics for coupling light into the spectrographs, are calibrated in the tent. The MOS Lu port is calibrated in the Cal Hut (through buoy M260) or the new laboratory at Pier 35 (from buoy M261 and forwards). Extensive characterizations are performed pre- and post-deployment by M. Feinholz. These include wavelength calibration, verification of stray light response, checks for system partial saturation, integration time normalizations, response to the internal sources, and repeatability. As needed, additional characterizations are performed, for example polarization sensitivity, cosine response, sensitivity of the radiometric responsivity to ambient temperature, full stray light characterization, Lu immersion coefficient, and linearity. The pre-deployment system responsivities are evaluated and delivered to S. Flora for incorporation into the deployment retrievals. During deployments, data are taken with the internal sources with each hour file, and monthly visits by the team include cleaning of the optic and tests with diver calibration lamps before and after the cleanings. During the deployments, the values and consistency of Es and the three versions of KL (top/mid, top/bottom, mid/bottom) are used, along with the time series, to perform quality control and monitor for exceptions. The stability of the wavelength calibration is monitored using measured positions of Fraunhofer lines. The chromaticity coordinates, spectral purity, and dominant wavelength are calculated using the hyperspectral data and the established CIE functions. These parameters are sensitive to spectral shape and can be an indication of bio-fouling. The magnitude of the “blue/red” offset is monitored as a quality check on the stray light correction. After the buoy is retrieved, it is recalibrated, and re-characterized for wavelength calibration. The post-deployment radiometric responsivities are compared to the pre-deployment values, and, taken together with the presence of any deployment-specific anomalies, final post-deployment responsivities are assigned. When the radiometric reference source is returned to NIST for the EOL calibration, a third system response (which may be the same as the second) is assigned to the individual channels for each deployments corresponding to this BOL/EOL interval.

There are two integrating sphere sources, the OL420 and the OL425. Both have external lamps, barium sulfate interior coatings, the ability to vary the radiance levels without substantial changes to the relative spectral distribution, and exit apertures large enough for entrance pupil of the fibered Lu heads. Lamp current is monitored using a shunt resistor in series with the lamp, and the voltage drop at the lamp is monitored using a four-wire connection at the FEL kinematic lamp base. The OL425 has a photopic monitor photodiode installed to view the interior wall, and the NIST spectral radiance values are scaled by the ratio of the monitor photodiode during use to those during the NIST calibrations. To date, there have been 20 lamps used in the two spheres, for a total of 40 calibrations. The spectral radiance calibrations cover 300 nm to 1000 nm with NIST uncertainties of about 0.6 % $k = 2$ at 500 nm. Prior to Aug 2002, the spheres were calibrated by Optronic Laboratories. The primary reason for switching to NIST was to obtain lower uncertainties.

The irradiance calibrations are performed using a Gamma Scientific 5000[1] irradiance bench, which has a housing around the 1000 W FEL lamp, a baffle tube, and an end plate that mates to

[1] Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

the mechanical surface of the MOBY Ed, Es heads so the diffuser is 50 cm from the front of the lamp bi-posts. As with the lamps in the spheres, the lamp current and voltage drop are monitored. Ambient temperature and relative humidity are recorded during all radiometric calibrations.

To date, fourteen FEL lamps have been used, some with multiple calibrations at approximately 50 h burn time, for a total of 38 calibrations. The sphere and FEL calibration history spans 25 years.

The two SLMs are filter radiometers, one channel per instrument [1]. They date from 1996. The foreoptics are interchangeable, one for irradiance with a cosine collector and mechanical design identical to the MOBY heads, and the other with a “Pritchard” design foreoptic. This design provides an alignment axis by mounting a mirror at 45° on the optical axis. A central hole in the turning mirror allows flux to reach the detector while the rest of the mirror provides a view of the source – think of a single lens reflex camera viewfinder where the flip mirror is permanently in place, but it has a central aperture. The SLMs began life with a 412 nm and an 870 nm channel, both using ion-assisted beam deposition filters with out-of-band specified to be OD 6 and full width half-maximum (FWHM) bandpasses of about 10 nm in radiance mode. In August 2004, the Es heads fell from a table and hit the concrete floor of the tent. As no obvious damage was observed, they were kept in use. In July 2011, the SLMs were refurbished. The 870 nm channel was replaced with a filter at 665 nm. The SLMs are measured for absolute spectral (ir)radiance responsivity on the NIST Spectral Irradiance and Radiance responsivity Calibrations using Uniform Sources (SIRCUS) and validated at NIST using broadband sources. As of January 2017, there have been 421 SLM radiance measurements of the OL420 and the OL425.

As an additional validation of the MOBY radiometric scales, NIST makes routine site visits and deploys independent artifacts. The VXR (Visible Transfer Radiometer) is a six channel filter radiometer with filters from the same lot as the SLM and designed to match the Sea-Viewing, Wide Field-of-View Sensor and the Moderate Resolution Imaging Spectrometer (SeaWiFS and MODIS) bands (412 nm, 441 nm, 443 nm, 551 nm, 665, and 870 nm) [2]. The NPR (NIST Portable Radiance) source is a Spectralon® sphere[2] illuminated internally with four 30 W lamps [3]. Typically, it is calibrated at this bright (land-like) level. There are two monitor photodiodes, one in the visible and the other in the short wave infrared. The NPR was made to travel and is mounted in a shipping container. It is calibrated routinely for spectral radiance at the same NIST facility used for the MLML spheres (FASCAL, Facility for Automated Spectroradiometric Calibrations, [4]). Hence, a field deployment at MOBY is a validation of the reproducibility of the sphere spectral radiance values and the stability of the SLM/OL42x/VXR/NPR systems. To date, 13 trips have been made with the VXR and NPR. Prior to the development of the VXR in 1996, an earlier version, the SeaWiFS Transfer Radiometer (SXR, [5]) was deployed twice. We are working on a critical compilation of these time series, to both validate the MOBY responsivity time series and to identify and then correct any biases that may be revealed in the process.

[2] Labsphere, Inc., North Sutton, NH, USA

Starting in Jan 2015, NIST deployed an irradiance bench for the purpose of validating the Gamma 5000 and the MOBY irradiance values. This has been done twice. The first time, we used a commercial photodiode array-based spectrograph from Spectra Evolution fiber-coupled to a MOBY irradiance head, and the second time we used a charge-coupled device based spectrograph, a CAS 140CT-156, from Instrument Systems fiber-coupled to an irradiance collector from the manufacturer.

We have started the VXR/NPR time series critical compilation. The two figures are for measurements of the VXR and NII (a non-traveling sphere, made to the same specifications as NPR) and the VXR and NPR. In each case, the history for one lamp set is illustrated. The blue solid circles represent NIST spectral radiance calibrations of the sphere. These spectral radiance values have been reported at different spectral coverage and with different wavelength sampling over the years. The VXR channel wavelengths for each set of calibration values were determined according to $\lambda_i = \dfrac{\int \lambda L(\lambda) R_i(\lambda) d\lambda}{\int L(\lambda) R_i(\lambda) d\lambda}$, where $L(\lambda)$ is the spectral radiance of the NPR or NII, and $R_i(\lambda)$ is the absolute spectral radiance responsivity of the i^{th} VXR channel. Note that this definition holds if only the relative spectral radiance responsivity is known.

It is clear interpolation in wavelength in the spectral radiance values and the spectral responsivity values is necessary. The results to date are based on analytical fits, but investigations are continuing. Interpolation errors can introduce bias for the narrow bands of the VXR.

By identifying the VXR file closest in time to one of the FASCAL calibrations for the sphere's lamp set, the "VXR band-averaged" FASCAL radiances (equal to $L(\lambda_i, t)$) and the VXR net signals can be compared by normalizing each set by the corresponding value at the matchup time. The VXR data (red crosses) are consistent with the normalized FASCAL spectral radiances, indicating the VXR's spectral responsivity was stable over this time interval. This time series will be finalized for VXR/NPR, the VXR/NII and also the SLMs/OL42x and the SLMs/FELs.

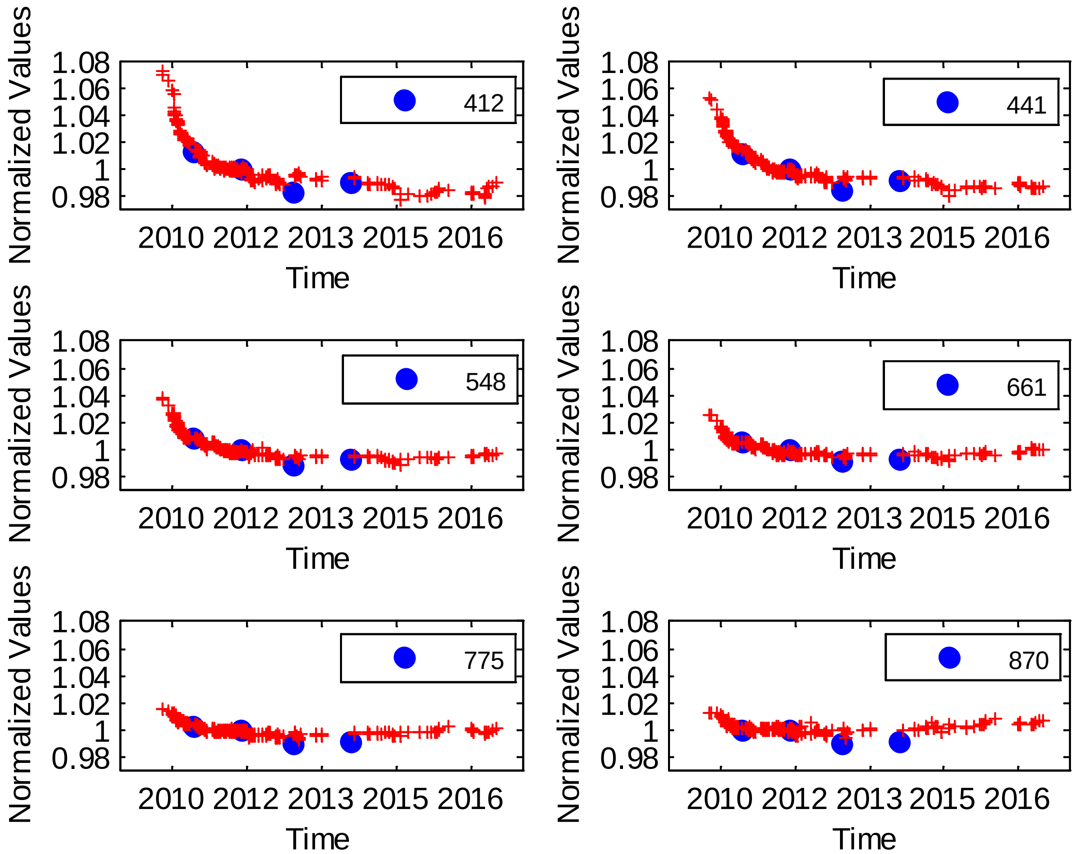


Figure 2. Time series of normalized VXR and FASCAL measurements of the NPR sphere at the VXR spectral bands.

The internal LEDs and incandescent lamp are used during radiometric calibration and every hour file for the deployments. Pre- and post-deployment results are compared to assess reproducibility. Stability during a deployment is evaluated by normalizing to the first reading. In both cases, a range of wavelengths where the LED signal is measurable allows an evaluation of spectral stability. If we look at a time history of LED signals for all deployments for wavelengths near the peak of the LED output as well as the extreme edges, we see discontinuities in the normalized signals. This is attributed to changes in the stray light characteristics of the grating in the spectrographs, and introduces additional uncertainty in the MOBY stray light correction algorithm because laser characterizations were not performed at the beginning of the MOBY project.

Monthly diver trips from Lanai include measurements at system level with modified commercial dive lamps. The sequence is to measure, clean the optics, and remeasure. For some deployments, readings with the diver lamps were acquired at the start of the deployment. The history of the diver lamps for these deployments shows variability of a few percent with negligible bias, that is, cleaning does not seem to make a difference statistically.

Over the 25 years, various radiometric characterizations have been performed. Camera-dependent (CCD detector) characterizations include dark current, noise, bin factor, and integration time correction factor. Later, full images were studied to sort out issues with partial saturation. The temperature sensitivity of the spectrographs, electronics, and optical multiplexer was measured for one of the systems using a water bath. Numerous full stray light characterizations were performed [6] and the level of stray light is checked at a few wavelengths for each deployment. Pre- and post-deployment wavelength calibrations are performed, with the process improving over the years by the addition of additional atomic emission lines. The stability of the wavelength calibration is monitored during deployments using Fraunhofer and atmospheric lines. The Ed immersion factor was determined experimentally at the beginning of the MOBY project, and recently the theoretical value for the Lu immersion factor was verified experimentally. Preliminary values for the Es cosine response were determined initially, with recent experiments providing final values. The polarization sensitivity of the Lu heads on the MOBY arms was measured and resulted in the addition of a depolarizer.

The uncertainty table for Lu and Es reflect our current understanding. For Lu, the dominant terms reflect the reproducibility of the radiometric calibration as determined by comparing pre- and post-deployment results, the NIST uncertainty in the spectral radiance calibrations, and the temporal drift in the calibration sources. At the ends of the spectral coverage for either spectrograph, the uncertainty in the stray light correction contributes. The story is similar for Es, except we have added a component to reflect the unusual nature of the FEL operation inside the Gamma 5000 housing. The resulting uncertainties, reported at the VIIRS ocean color bands, are between 2.6 % and 1 %, depending on wavelength and sensor type.

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[3] S. W. Brown, and B. C. Johnson, "Development of a portable integrating sphere source for the Earth Observing System's calibration validation program," Int. J. Remote Sensing, 24(2), 215 - 224 (2003).

[4] J. H. Walker, R. D. Saunders, and A. T. Hattenburg, [Spectral Radiance Calibrations] U.S. Government Printing Office, Washington, D.C.(1987).

[5] B. C. Johnson, J. B. Fowler, and C. L. Cromer, [The SeaWiFS Transfer Radiometer (SXR)] NASA Goddard Space Flight Center, Greenbelt, Maryland, 58 (1998).

[6] M. E. Feinholz, S. J. Flora, M. A. Yarbrough, K. R. Lykke, S. W. Brown, B. C. Johnson, and D. K. Clark, "Stray light correction of the Marine Optical System," J. Atmos. and Oceanic Technol., 26, 57 - 73 (2009).

MOBY: QA/QC and environmental uncertainties in the final MOBY product

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B. Carol Johnson, National Institute of Standards and Technology

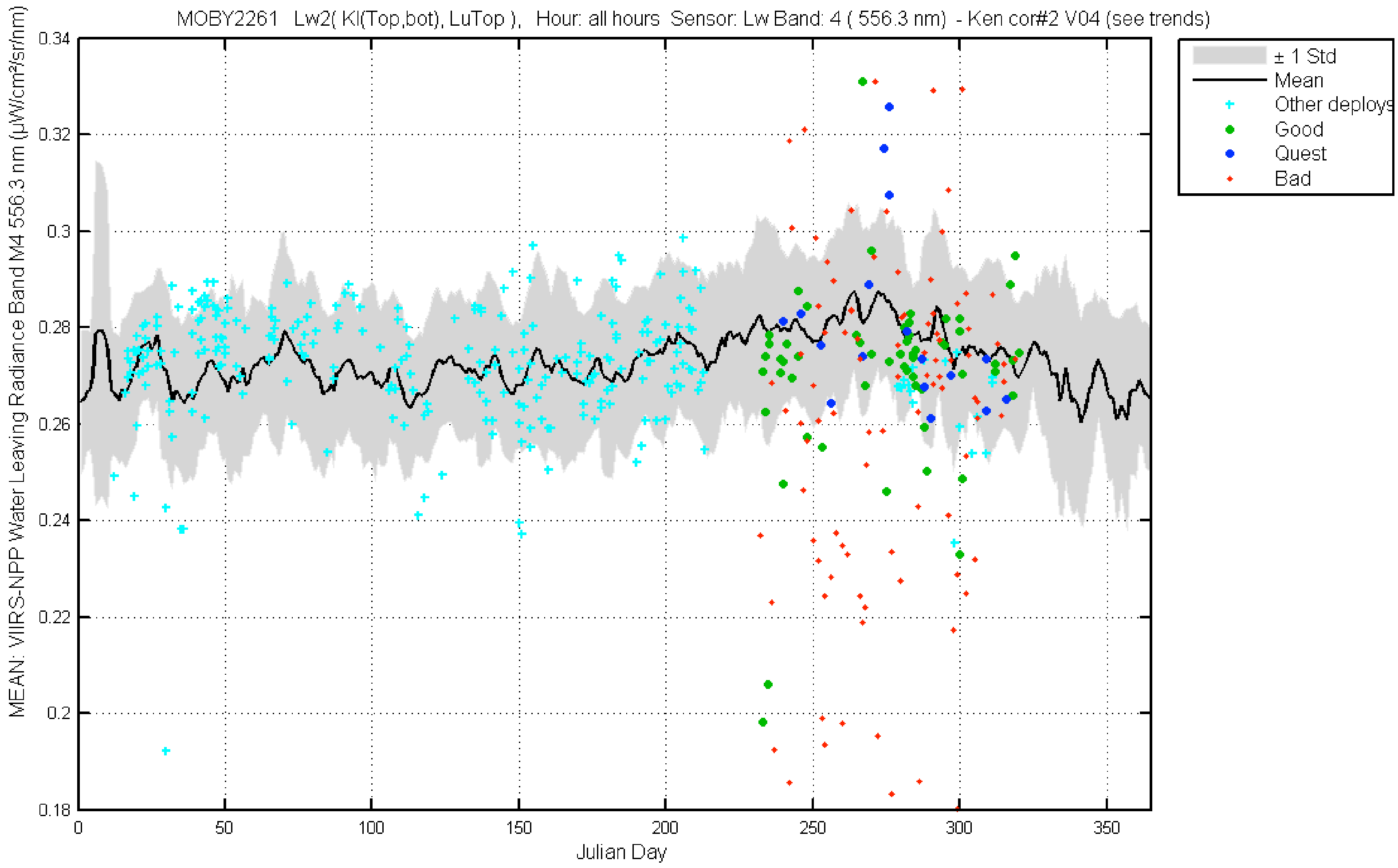
and the MOBY Team (Mark Yarbrough, Stephanie Flora, Michael Feinholz, Terry Houlihan, Darryl Peters, Sandy Yarbrough, and Sean Mundell, Moss Landing Marine Lab) and Art Gleason, University of Miami

MOBY and MOBY-Refresh are supported by NOAA's Joint Polar Satellite System (JPSS, MOBY-Net by NASA OBB program.
Past support from NOAA (STAR/Dennis Clark and Research and Operations Program) and NASA (Earth Observing System Program, SeaWiFS Project, and the Ocean Biology and Biogeochemistry Program.

1. Quality Assurance (QA) steps
2. Environmental uncertainty budget

1) Download relevant GOES imagery for visual inspection of clouds.
2) look at data in raw counts for consistency with historical data set, filter out measurement spikes manually.
3) Es variation between sets and before and after other optical measurements.
4) comparison between KL's generated from arm pairs.
Determines Good, Questionable, or Bad
Note: individual scans (Es or Lu) maybe discarded if obviously spurious.
Two other checks are consistency in overlap region between two spectrometers and with the historical time series

Lots of these graphs are automatically generated for QA and tracking purposes.



There are several places in the equations below, into which uncertainty is introduced. Previous talk on MOBY discussed radiometric uncertainties, from the calibration process. I will cover other environmental uncertainty factors.

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

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

$$nLw(\lambda) = \frac{Lw(\lambda)}{Es(\lambda)} F_o(\lambda, r)$$

Some of the places where uncertainty enters is through:

light field fluctuations: affect both Lu and KLu

Polarization sensitivity: can affect both Lu and KLu

Tilt: can affect Lu, KLu (BRDF* effect) and depth (through arm length)

index of refraction of water: effects immersion factor and air-sea transmission.

Wave height: affects measurement depth, sea surface roughness

*bi-directional reflectance distribution function (BRDF)

Next couple of slides I am going to:

1) develop one of these (light field fluctuations)

2) show our tilt statistics

3) List our current estimates for the different factors

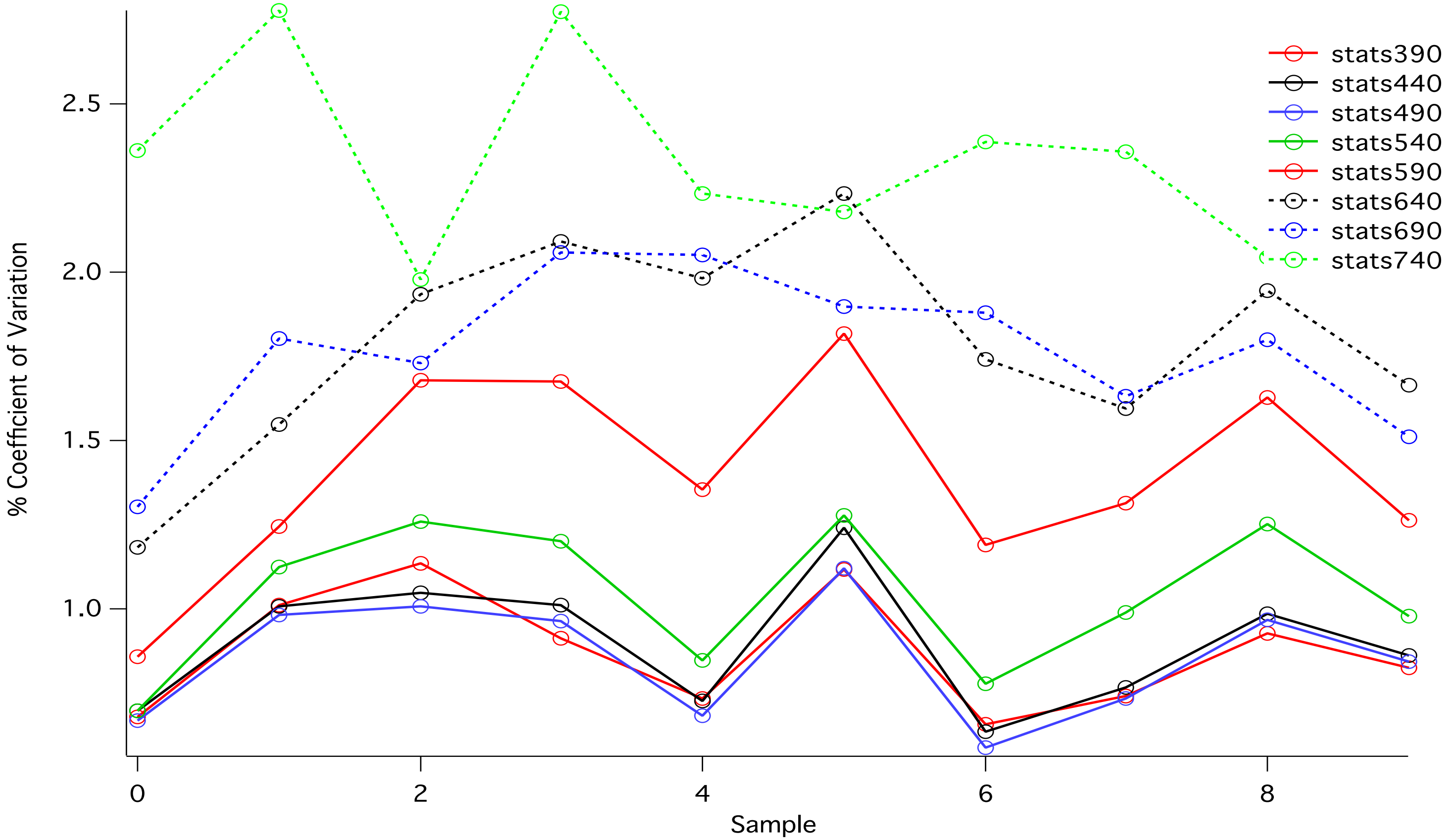
Working on a paper to really discuss how the estimates were made….much too long to discuss in detail in a short talk.

Our MOBY collections of Lu have 30-60 second integration times

Stramska and Dickey (1998) had the peak in the power spectrum for upwelling light at 0.4Hz.

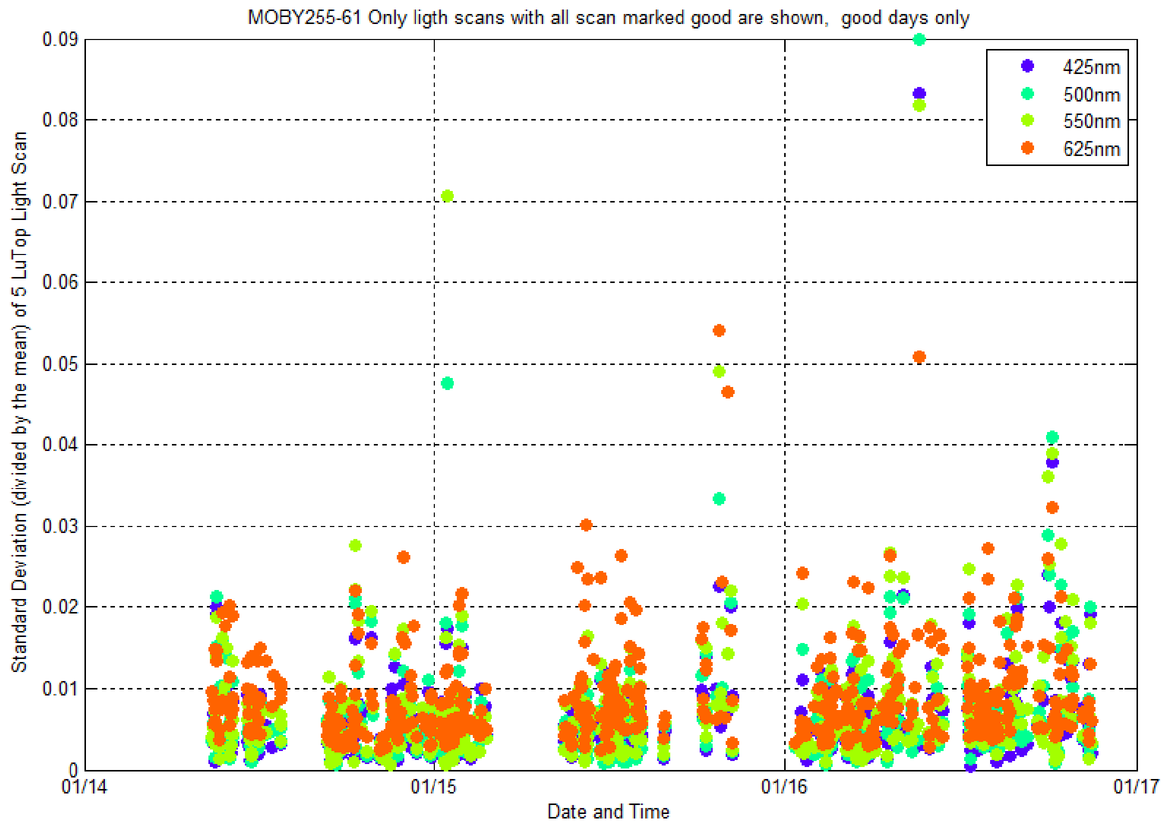
They saw a coefficient of variation (6Hz sampling time) of 4.5%, 8.7%, and 13% at 412 nm, 555nm, and 650 nm, respectively at noon. Lower (2.1-2.8% later in the day).

We did an experiment with 4 s integration times, bursts of 20 measurements, then 7 s gap between bursts. When adjusted for integration time, matches Stramska and Dickey measurements.



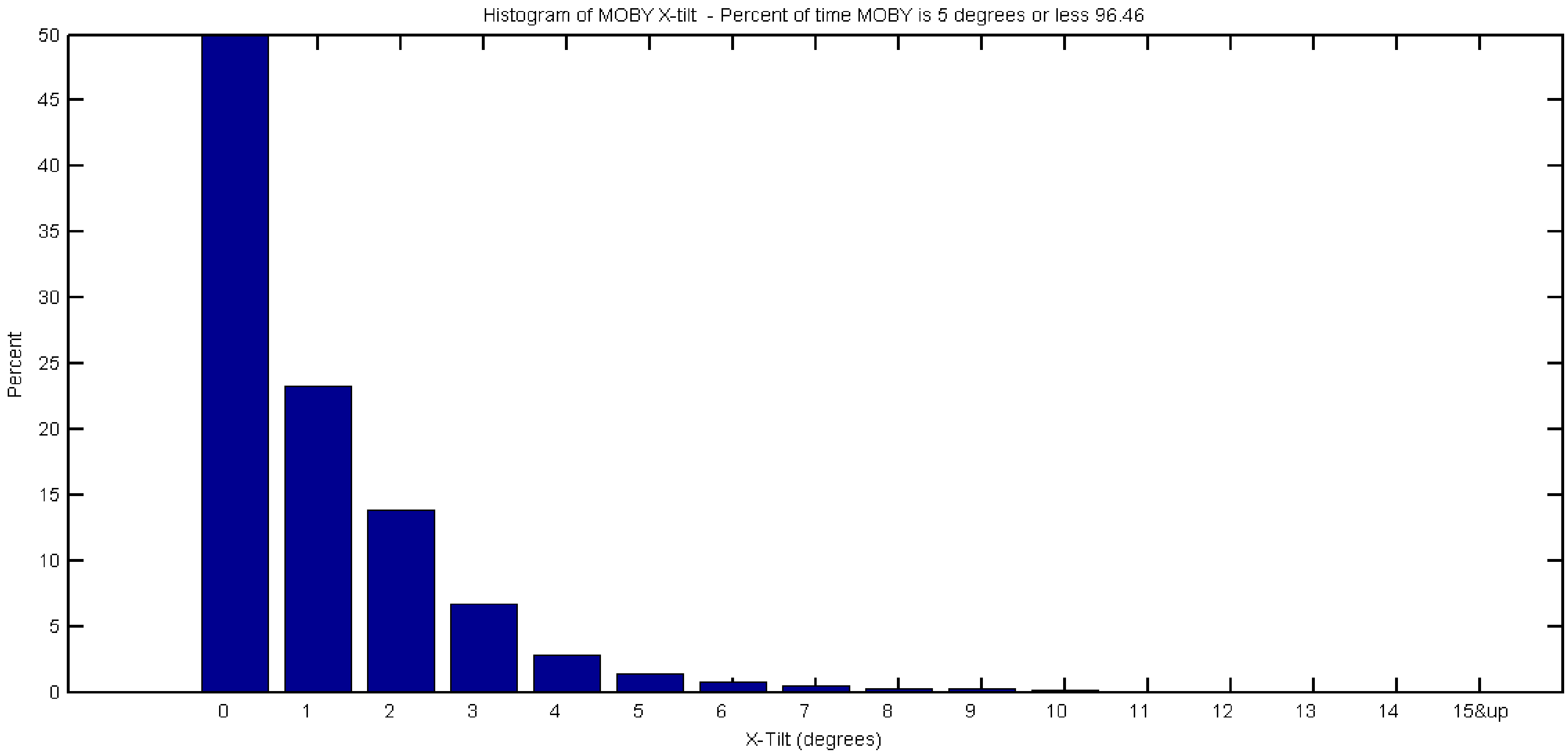
In the case of MOBY (60 s, 5 samples averaged), this effect is estimated to vary between 0.1% and 0.2% from 412 nm-650 nm.

Statistics at MOBY seem to validate this



Coefficient of Variation for the 5 Lu measurements in a set

Next problem might be tilt, important to note that MOBY doesn't tilt much



0-1 deg 75% of the time, 90% < 2 degree tilt..99% < 5 degree tilt

Unfortunately, not enough time to go through all of these but in summery:

A) Immersion uncertainty, 0.05% driven by index of refraction of water variations.

B) Fluctuations: 0.1-0.2% from blue-red, based on experiment results

C) Tilt: no correction for less than 2 deg, 0.2% BRDF uncertainty
Greater than 2 deg, correct with Morel et al, 1% uncertainty

D) Polarization: after August 2016, none, before a function of wavelength and solar zenith angle. Table from model for this uncertainty.

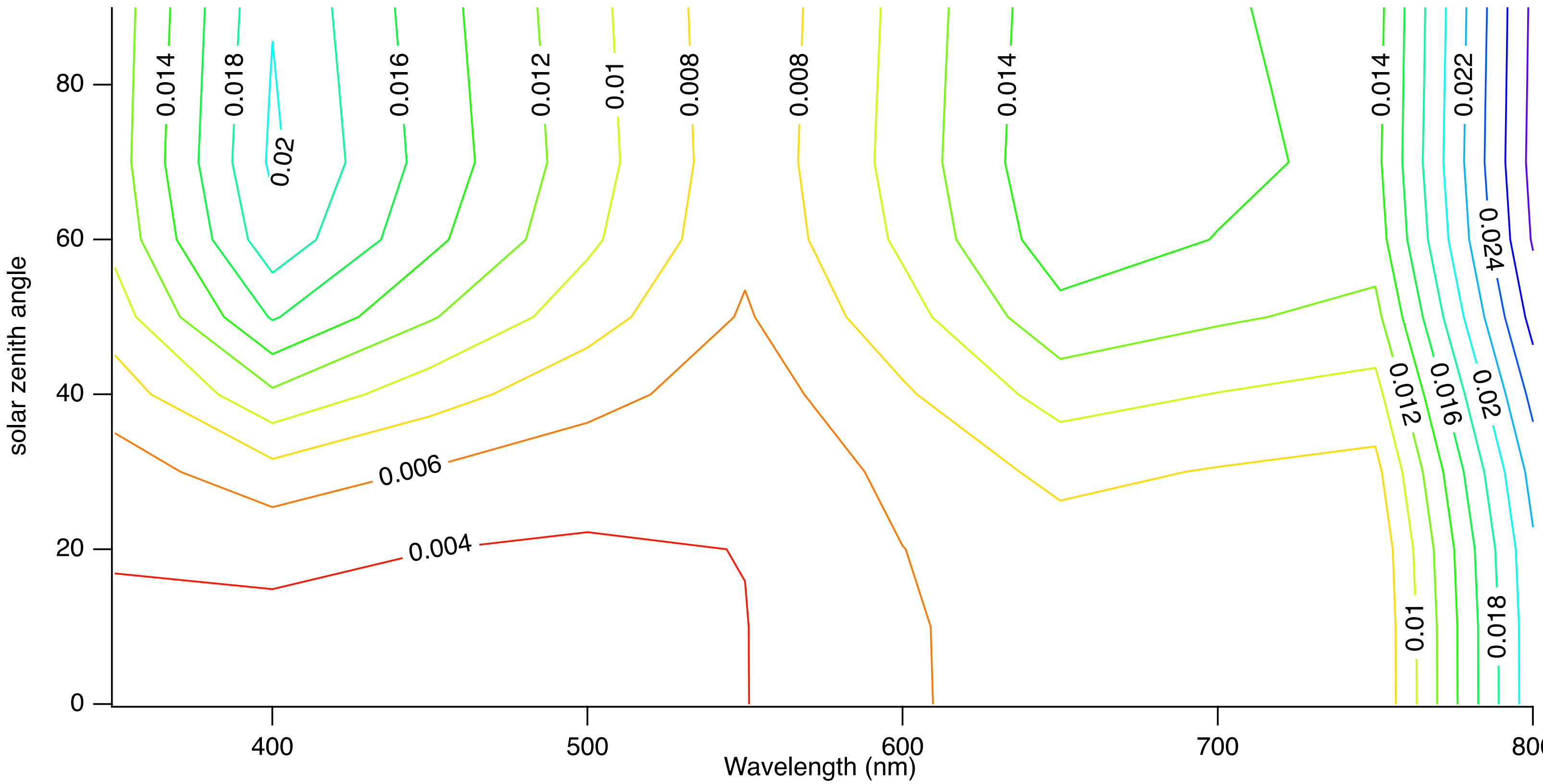
E) KL depth error due to tilt, basically equal to tilt *0.2%

F) KL error due to polarization differences in arms: top middle: <0.2%, top-bottom <1%, mid bottom < 1%. Table from model for this uncertainty.

G) Transmittance factor 0.1% due to index of refraction variations. Note there is currently a - 2% to +2% bias because constant 0.543 is used.

H) depth uncertainty: 4% of depth times wave height (enters through exp(KL*z)

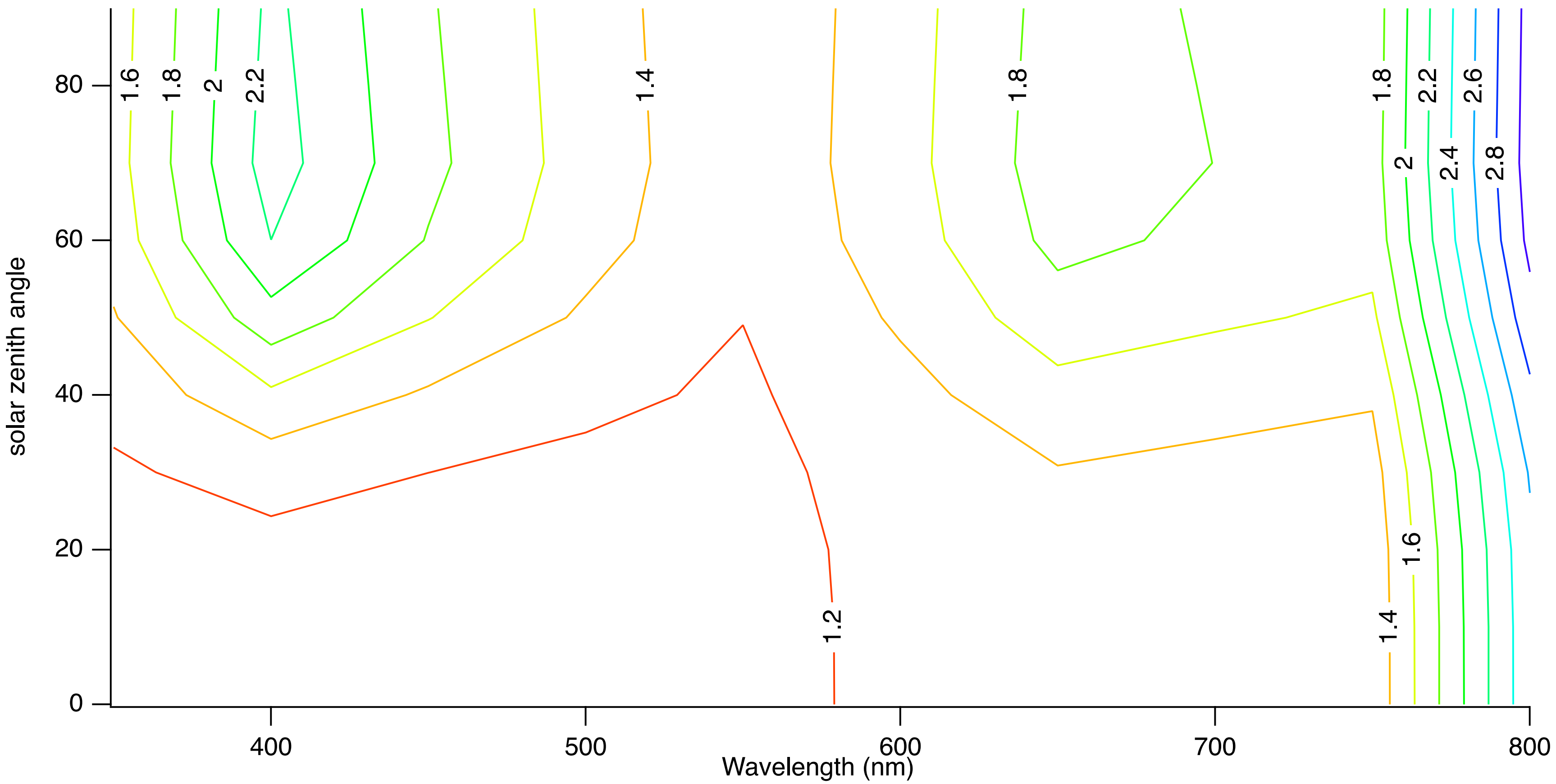
Example calculations.



Lw, Environmental uncertainty, tilt=1 deg, waveheight =0.5m, Lu from top arm, KL from top-mid arm

Uncertainty ranges from <0.4% to 1.4%, due to environmental factors, in this relatively benign example.

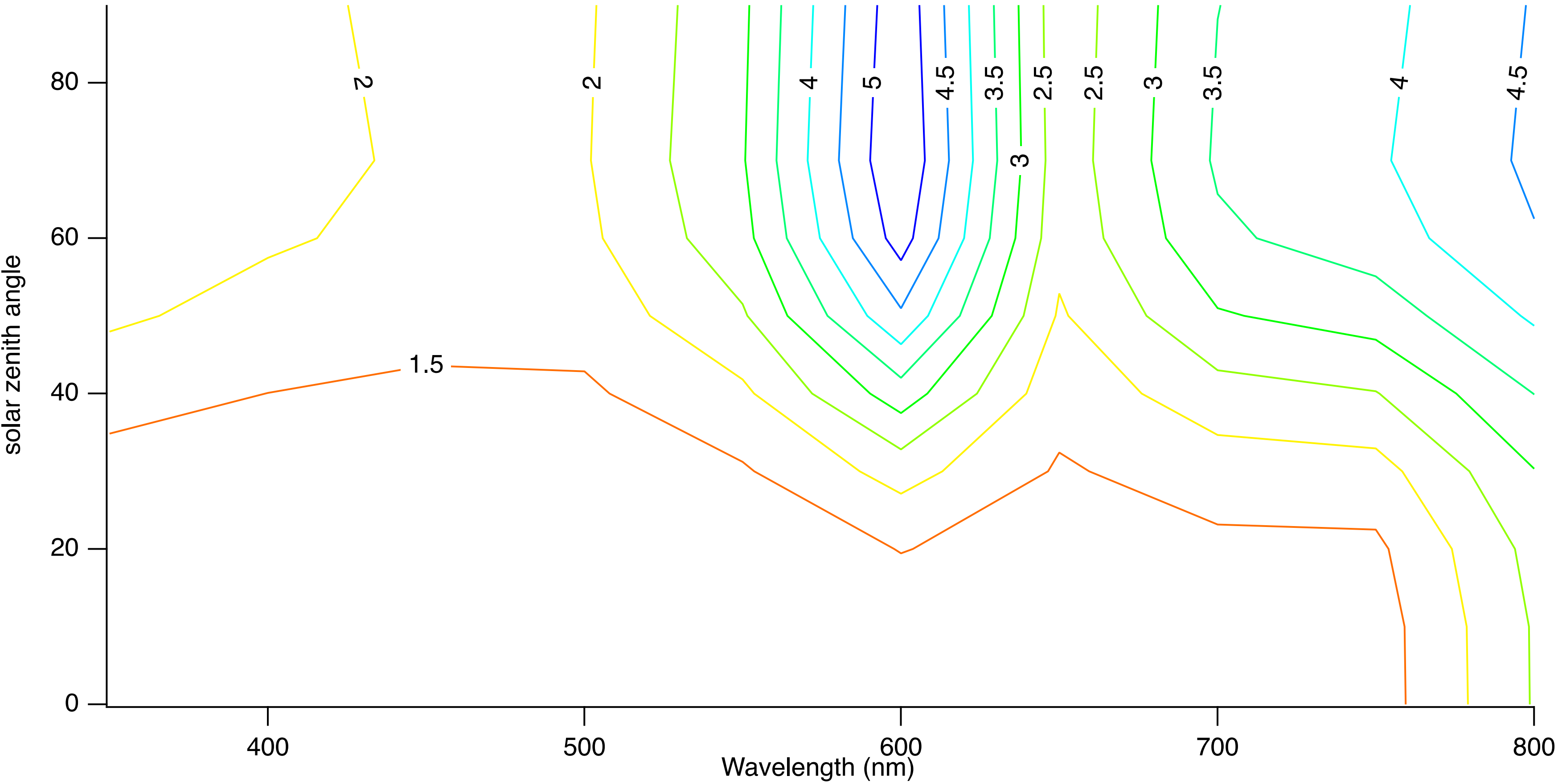
Example calculations.



Lw, % Environmental uncertainty, tilt=2 deg, waveheight =0.5m, Lu from top arm, KL from top-mid arm

When tilt is increased to 2 deg, uncertainty increases by about double (for 350-700 nm, <40 deg solar zenith angle

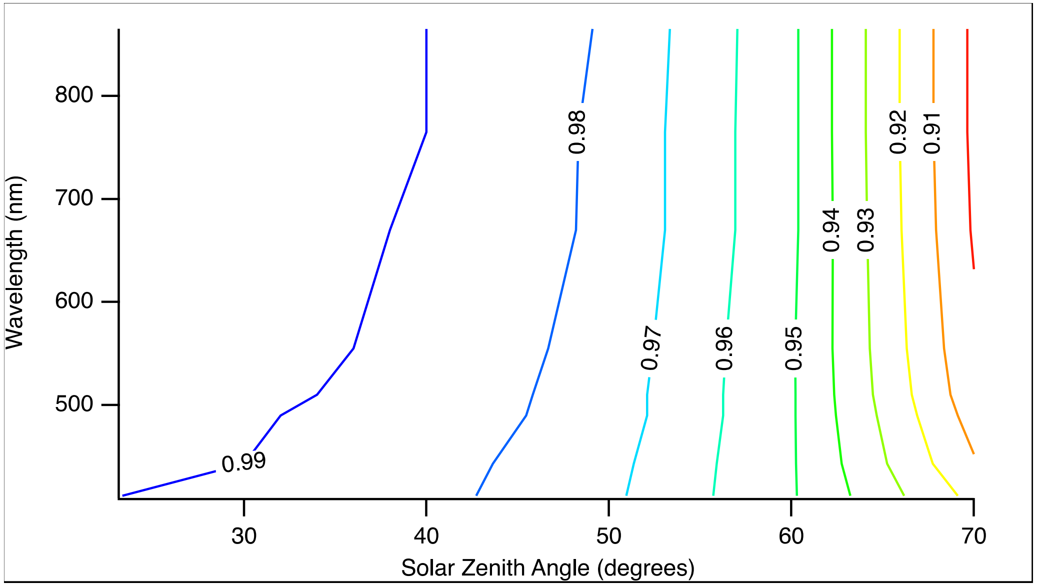
Example calculations.

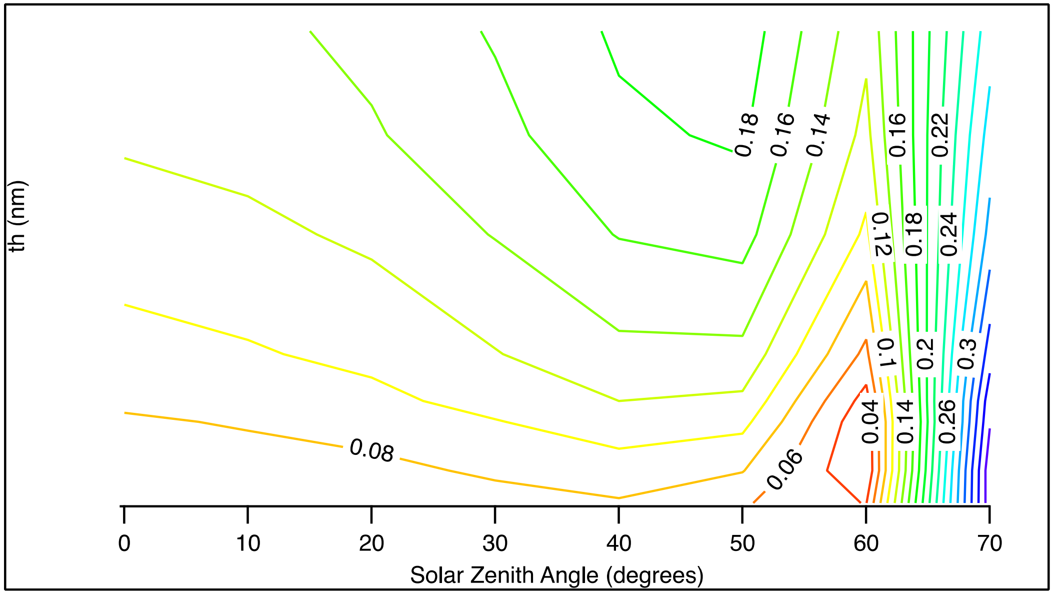


Lw, % Environmental uncertainty, tilt=2 deg, waveheight =0.5m, Lu from top arm, KL from top-bot arm

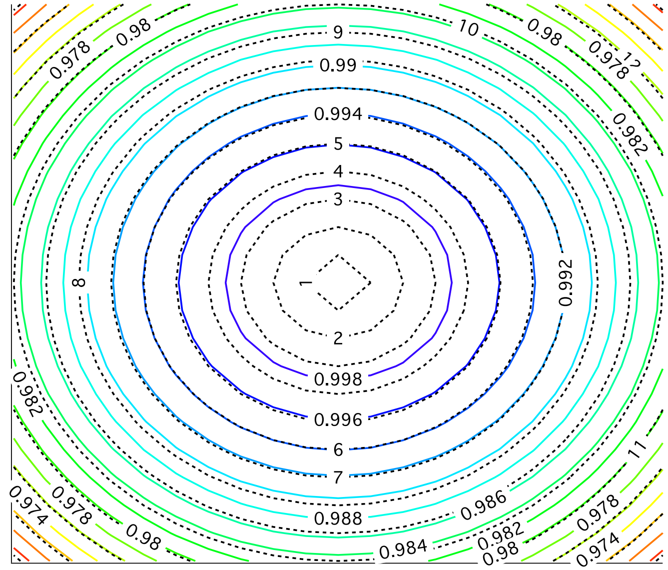
Uncertainty also increases (mainly due to polarization) when using top bottom rather than top middle.

For Es (needed for nLw) there is a complication because the cosine collector is not perfect. The top graph shows the needed correction (measured Es is biased low), while the bottom graph is the % uncertainty in this correction. For the most part, with this correction the uncertainties are less than 0.2%.

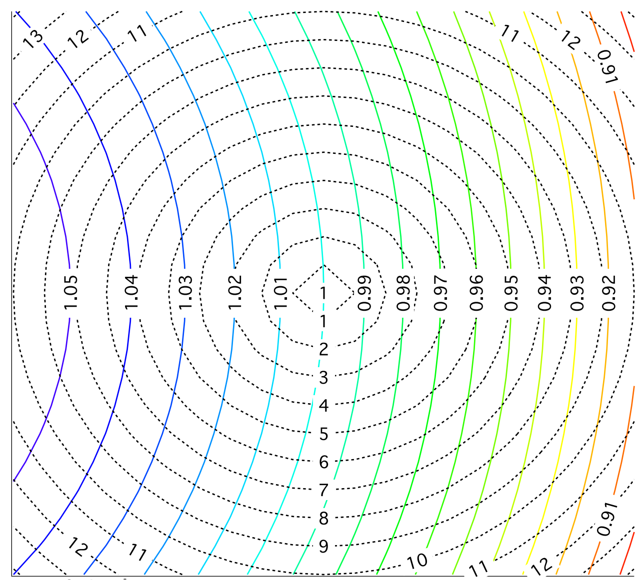




But if you add in tilt, it gets complicated. The top shows (as concentric rings in degrees) the effect with solar zenith angle =0. Up to 2 deg of tilt has a uncertainty of <0.2%.



However if the solar zenith angle is 20 deg it goes up to 1.5%.... The larger the solar zenith angle, the larger the error, even when the buoy has tilt <1 deg.

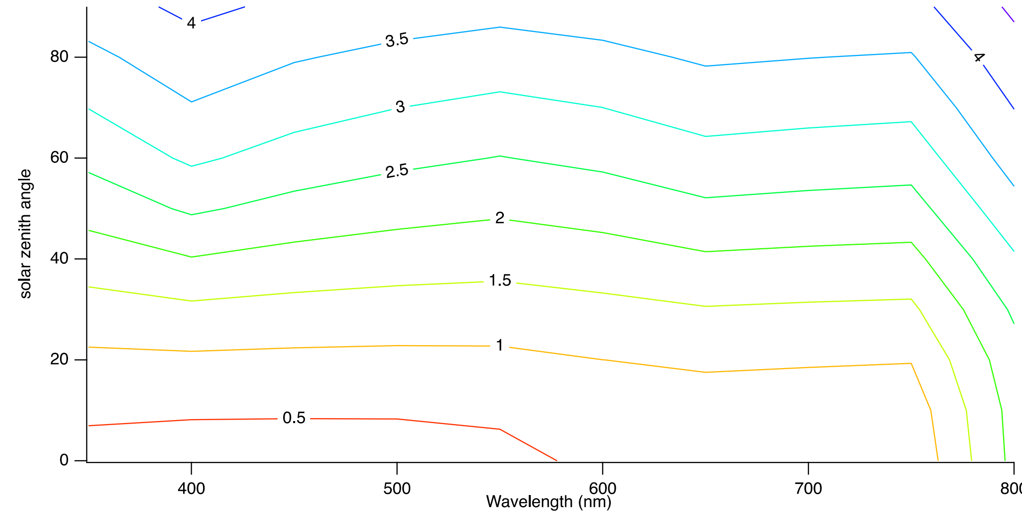


In general the uncertainty can be represented as:
Uncertainty =+-(solar zenith angle/10)*tilt angle*0.4%.

So adding tilt and seeing uncertainty in nLw we see:

Top graph is uncertainty for 1 deg tilt on nLw.

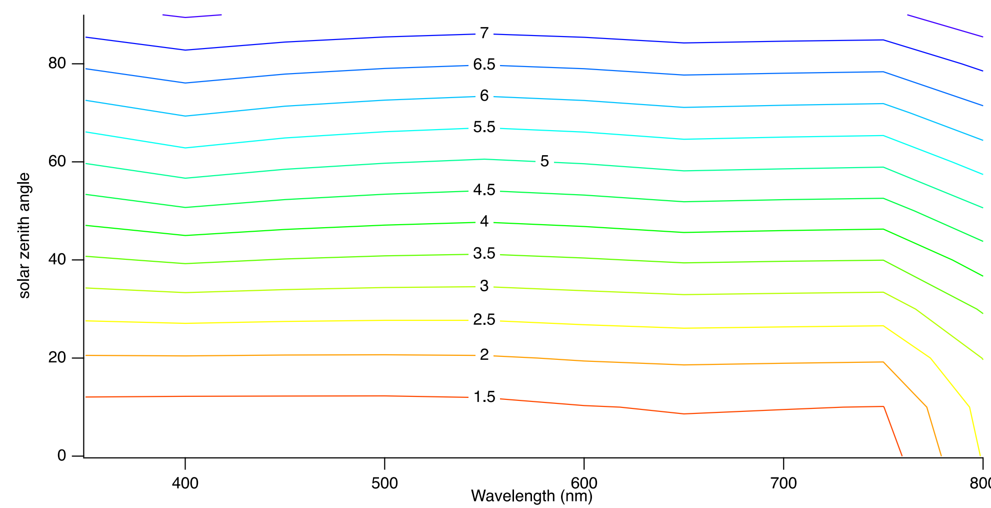
ALL UNCERTAINTIES ARE %



nLw, Environmental uncertainty, tilt=1 deg, waveheight =0.5m, Lu from top arm, KL from top-mid arm

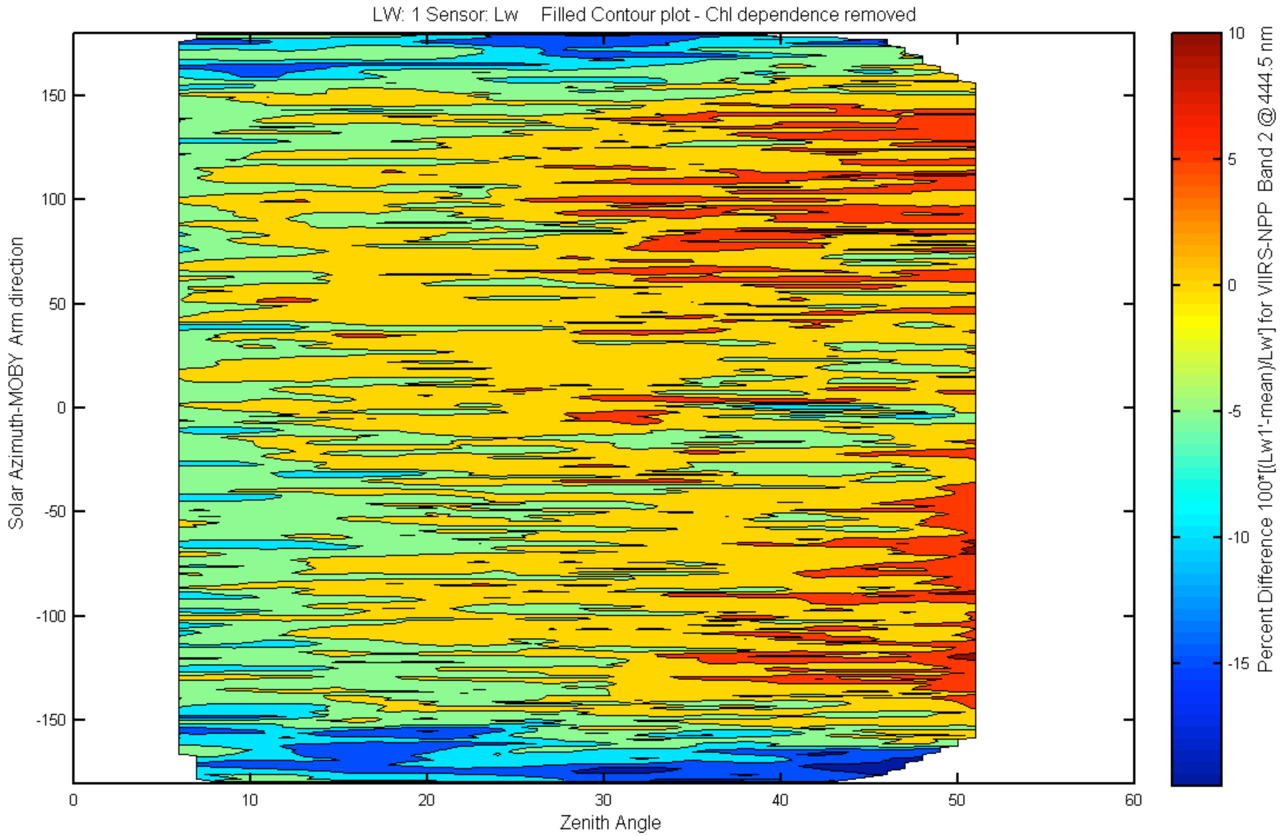
Bottom graph is same situation with 2 deg tilt

Bottom line is, even without adding radiometric uncertainty of another measurement, nLw uncertainty is much bigger than Lw.



nLw, Environmental uncertainty, tilt=2 deg, waveheight =0.5m, Lu from top arm, KL from top-mid arm

What I have not talked about is shadowing. With MOBY, in this clear water, shadowing is very azimuthally dependent. Evidence is in this graph, where we have tried to remove all seasonal trends, and plot the historical data vs. solar zenith angle and azimuth. As can be seen, the region of negative numbers is confined to very small azimuthal region around 180 deg azimuth…otherwise shadowing is not seen. So if these regions are avoided, shadowing is avoided.



Conclusions

- Daily QA is important
- Environmental uncertainty depends on wavelength, solar zenith angle, other environmental factors
- There should be a spectral uncertainty estimate with each data set (we are moving towards this).

Talk 3, Extended Abstract

MOBY: Quality Assurance and Quality Control (QA/QC) and environmental uncertainties in the final MOBY product

FRM4SOC Workshop, Feb 21 – 23, 2017, Frascati, Italy

K. Voss, C. Johnson, M. Yarbrough, S. Flora, M. Feinholz, D. Peters, T. Houlihan, S. Mundell, S. Yarbrough, A. Gleason

This talk provided an overview of the QA/QC process for MOBY along with an estimate of the environmental uncertainties in the final MOBY product.

1) QA/QC

Before any data is posted on the NOAA Coastwatch site for the MOBY project, it has been processed and undergoes a QA/QC process. This process consists of several steps. The first is to look at corresponding GOES imagery for visual identification of the cloud state (cloud free or cloudy). Looking at the variation in the downwelling irradiance (Es) measurements during the sequence also helps to identify the state of the sky during measurement. Other checks including looking at the diffuse upwelling radiance measurements, KL, derived from the various arm pairs for consistency at wavelengths below 550 nm. Theoretically, with homogeneous water in the upper 9 m, they should be almost exactly the same. These steps typically define whether the data will be good, questionable, or bad.

Other steps done in the processing is to remove, by hand, anomalous data spikes in the spectral scan, and possibly out-of-family individual scans, if obviously problematic. For longer term, the data in the spectral region where the blue and red pictograph overlap is examined and the derived data are compared with the historical time series of measurements, as we now have a 20-year time series.

2) Environmental uncertainty

Sources of environmental uncertainty, the uncertainty coming from factors other than the radiometric calibration, can be found in each of the measured quantities. Light field fluctuations affect both the upwelling radiance measurements, Lu, and KL. Polarization sensitivity (if it exists) can affect both Lu and KL. Buoy tilt during measurement can cause errors in Lu or KL because of variations in the radiance distribution in the upwelling light field, along with changing the measurement depth because of the arms. Index of refraction of seawater variations can affect the immersion factor and the transmission through the air sea surface. Waves can affect the effective measurement depth. We looked at many of these factors and modeled the effect to get an estimate of the uncertainty they introduce into the final Lw product. We detailed one of these, light field fluctuations, but could only list the current estimates for the other factors, based on our current models.

To give an example of these uncertainties, we looked at light field fluctuations in detail. MOBY reduces these through extended integration times for Lu, typically 30-60 seconds. The literature is not extensive on the coefficient of variation (COV) for the upwelling radiance light field. Stramska and Dickey (1998) published some results where they saw a peak in a broad power spectrum at 0.4 Hz and a COV, with 6 Hz sampling time, of 4.5%-13% as for wavelengths from 412 nm to 650 nm. This variation reflects the change in incident light field from the blue, where skylight is a large proportion, to red, where the direct beam is more important.

We also had the results of an experiment in which bursts of 20 measurements of the upwelling radiance were measured. Each measurement had a 4 s integration time, and there was a 7 s gap between measurement bursts. The measured COV in these measurement bursts corresponded well to the data of Stramska and Dickey when the COV was adjusted for the longer integration time and 20 measurements. In this case the COV dropped to approximately 1% for the blue and 2% for the red wavelengths. In the case of operational MOBY measurements, with 60 s integration times and averaging 5 samples, the effect of fluctuations is expected to cause an effect between 0.1% and 0.2% from 412 nm to 650 nm. Looking at the COV between the 5 samples of individual MOBY acquisitions confirms this.

One other source of uncertainty is buoy tilt, but it is important to mention that because of the design of MOBY and it's mooring, the tilt is usually small. 75% of the time MOBY has a tilt less than 1.5 degrees, while 90% of the time it is less than 2.5 degrees. So in general, tilt is not a large problem but should be taken into account.

Because of time and space limitations we cannot detail all of the factors, we are currently writing an extended paper on this, but to summarize our current thinking on these factors:

Immersion uncertainty	0.05%	Driven by index of refraction variations
Fluctuations	0.1 – 0.2 % blue to red	Based on experimental results
Tilt	No correction for tilt< 2 deg: 0.2% BRDF uncertainty. Greater than 2 degrees, corrected result 1% uncertainty	Based on modeling and previous validation work

Polarization	None after August 2016, Before this it depends on wavelength and solar zenith angle	Based on measurements of polarization sensitivity and models.
KL depth error due to tilt	Uncertainty equal to tilt (in degrees) times 0.2%	Based on modeling
KL error due to polarization differences of arms	None after august 2016. Previous top-mid:0.2%. Mid-bottom and top-bottom <1%. Model results provide table	Based on polarization sensitivity and model results.
Air-sea transmittance factor	0.1% due to index of refraction variations, but currently a small bias because of using a constant value of 0.543	Results based on theory and measurements of the salinity at the site.
Depth uncertainty in propagation to the surface	Uncertainty is .4%, but wavelength dependent	Based on modeling

An example of combining all of these factors for the case of 2 deg tilt, shows an uncertainty that varies with wavelength and solar zenith angle

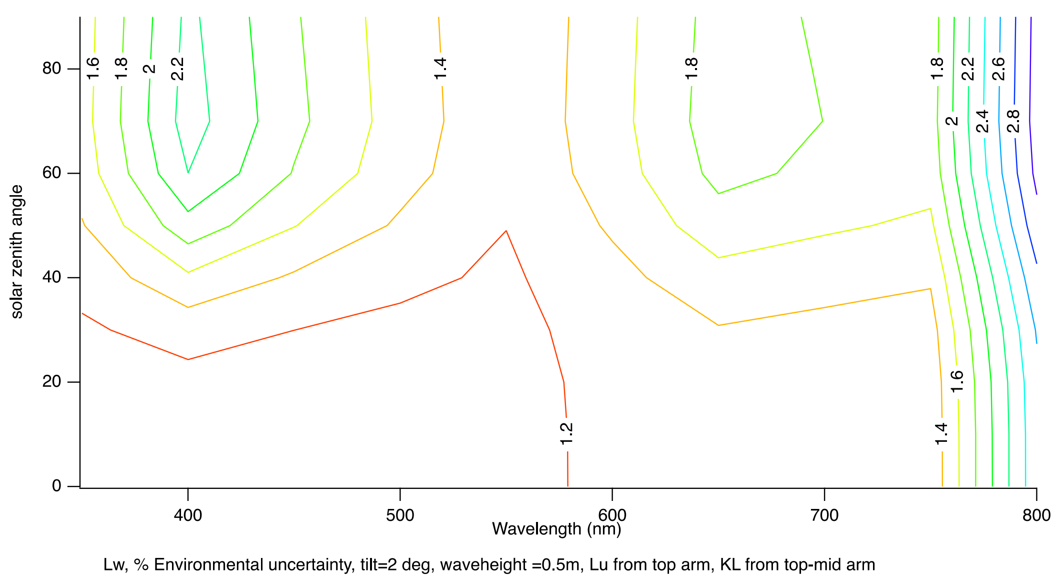


Figure 1) Shows % uncertainty as a function of wavelength and solar zenith angle. Note that the normal reported measurement range for MOBY is currently from 380 nm -700 nm, and solar zenith angles at the measurement time rarely exceed 55 degrees.

When Lwn is the desired quantity, additional factors come into play due to the Es measurement and its associated uncertainties. Because the Es cosine collector is not perfect, a correction must be made that has uncertainties associated with it. Even small tilts can cause problems with Es at larger solar zenith angles. The Es uncertainties increase the uncertainty in Lwn relative to Lw, as shown in the figure below, which is the same case as shown above, but for Lwn.

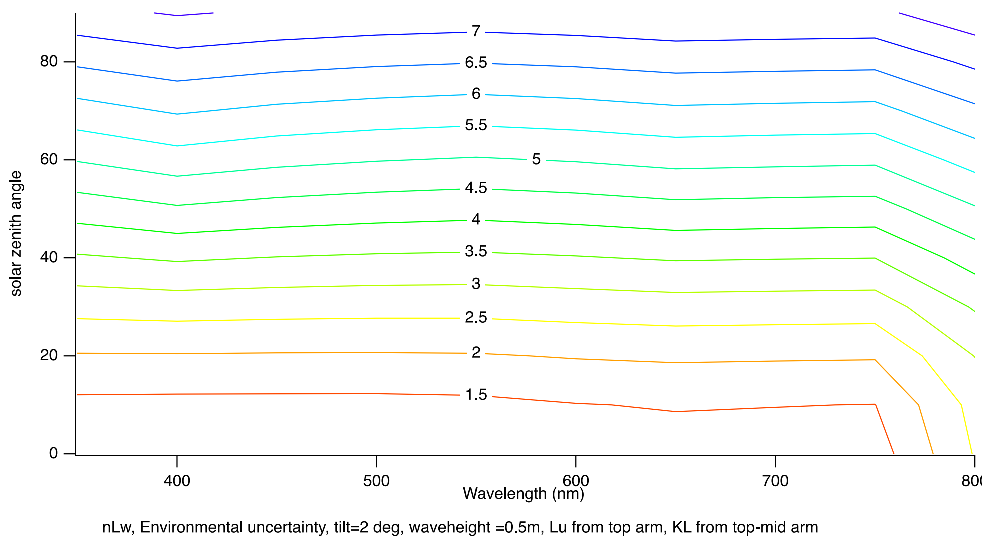


Figure 1) Shows % uncertainty as a function of wavelength and solar zenith angle. Note that the normal reported measurement range for MOBY is currently from 380 nm -700 nm, and solar zenith angles at the measurement time rarely exceed 55 degrees. Still because Lwn includes Es, Lwn has increased uncertainty relative to Lw.

In this work, we have not quantified the error due to shadowing. We are still working on this factor, but the time series indicates that shadowing causes a large problem when the arm is within 30 degrees of being pointed directly away from the sun. It also seems to cause a problem on the order of a few percent when the solar zenith angle is less than 10 degrees, but for other geometries shadowing is not significant.

3) Conclusions

Daily QA is important, and requires someone with extended experience consistently looking at the data.

Environmental uncertainty depends on wavelength, solar zenith angle and other environmental factors.

A spectral estimate of the uncertainty should be provided with each data set.

MOBY: time series, lessons learned and status of MOBY-Refresh/MOBY-Net

Kenneth Voss, University of Miami

B. Carol Johnson, National Institute of Standards and Technology

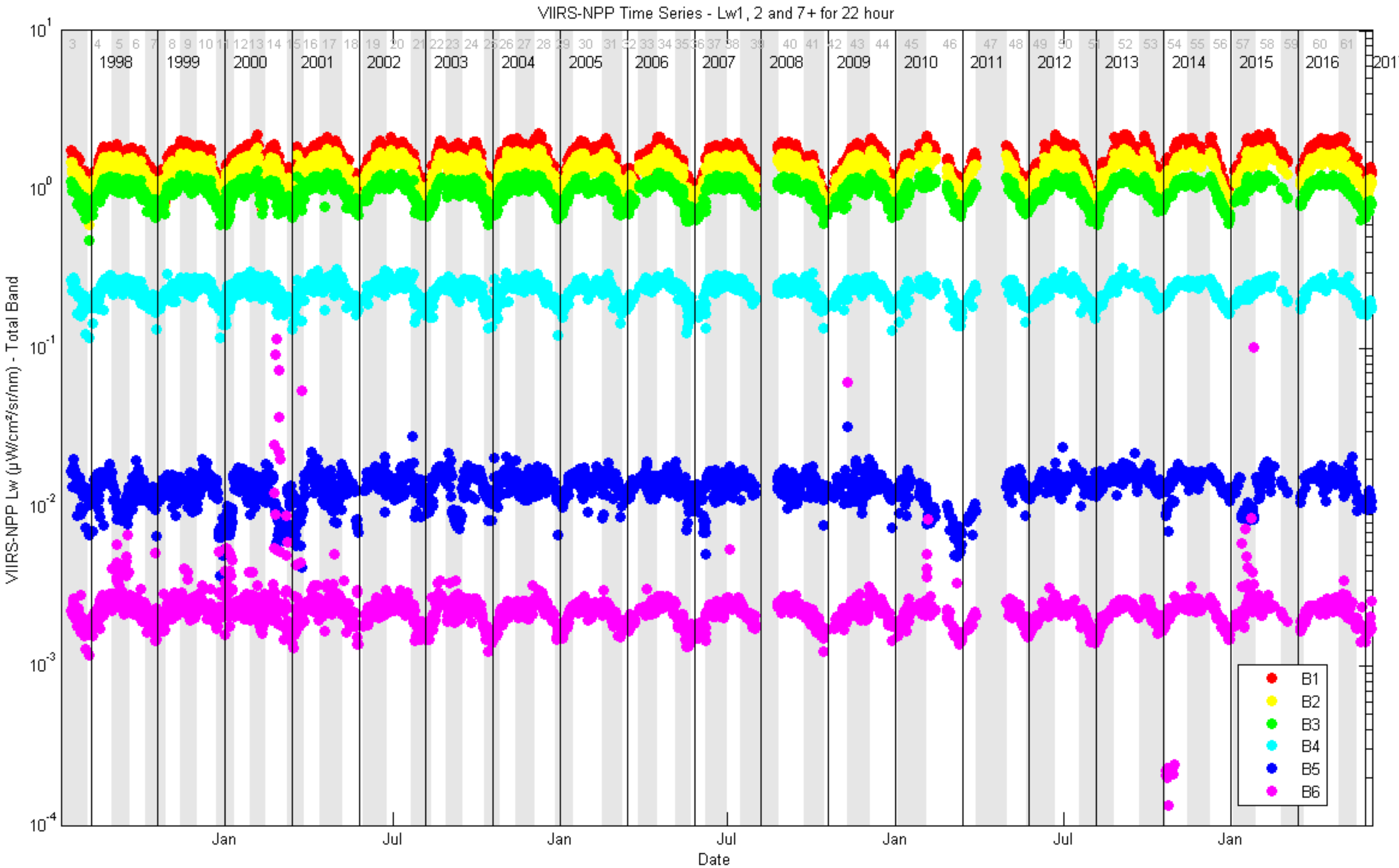
and the MOBY Team (Mark Yarbrough, Stephanie Flora, Michael Feinholz, Terry Houlihan, Darryl Peters, Moss Landing Marine Lab) and Art Gleason, University of Miami

MOBY and MOBY-Refresh are supported by NOAA's Joint Polar Satellite System (JPSS, MOBY-Net by NASA OBB program.
Past support from NOAA (STAR/Dennis Clark and Research and Operations Program) and NASA (Earth Observing System Program, SeaWiFS Project, and the Ocean Biology and Biogeochemistry Program.

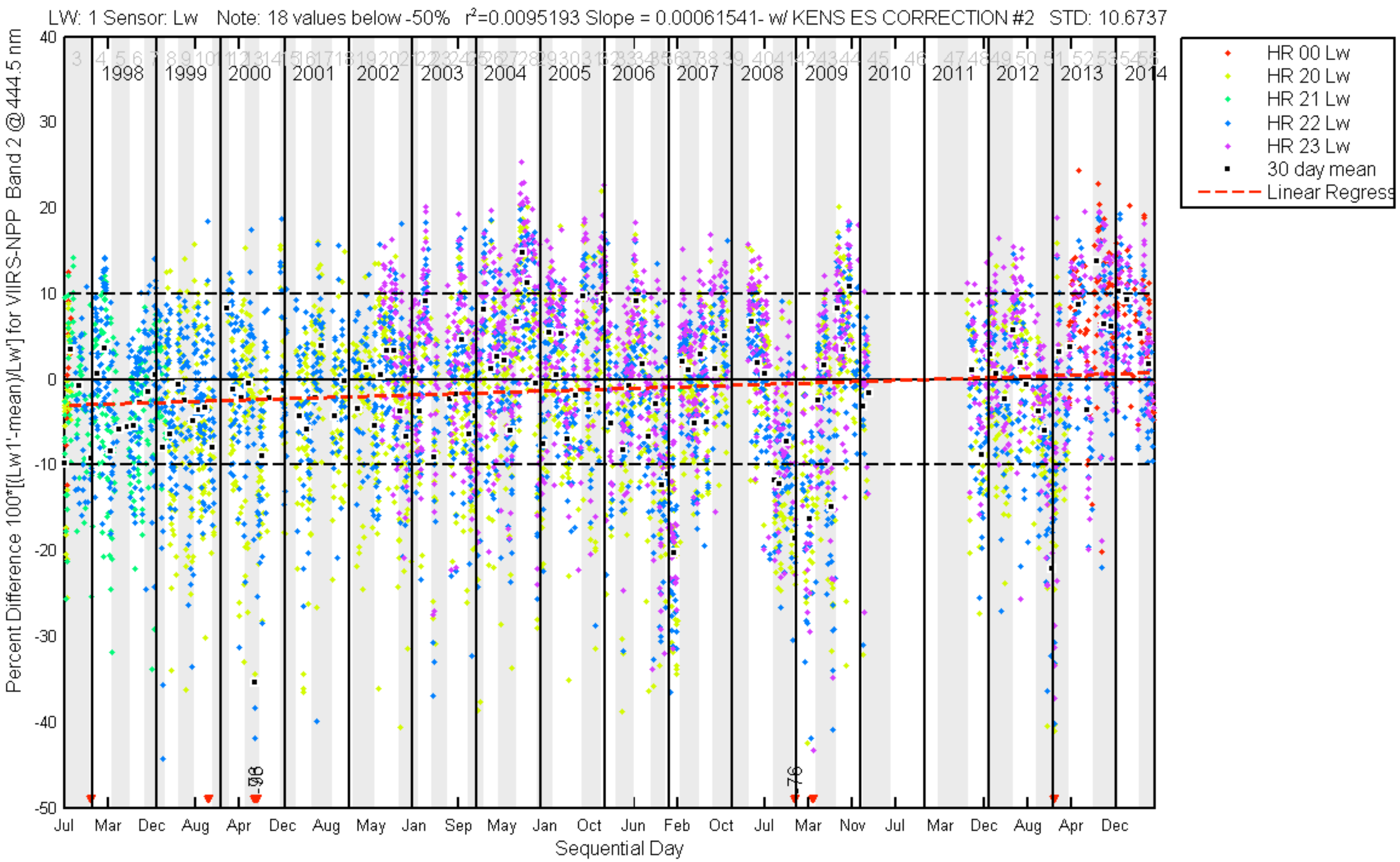
1. Time Series
2. Lessons Learned
3. Status of MOBY-Refresh/MOBY-Net

Time series

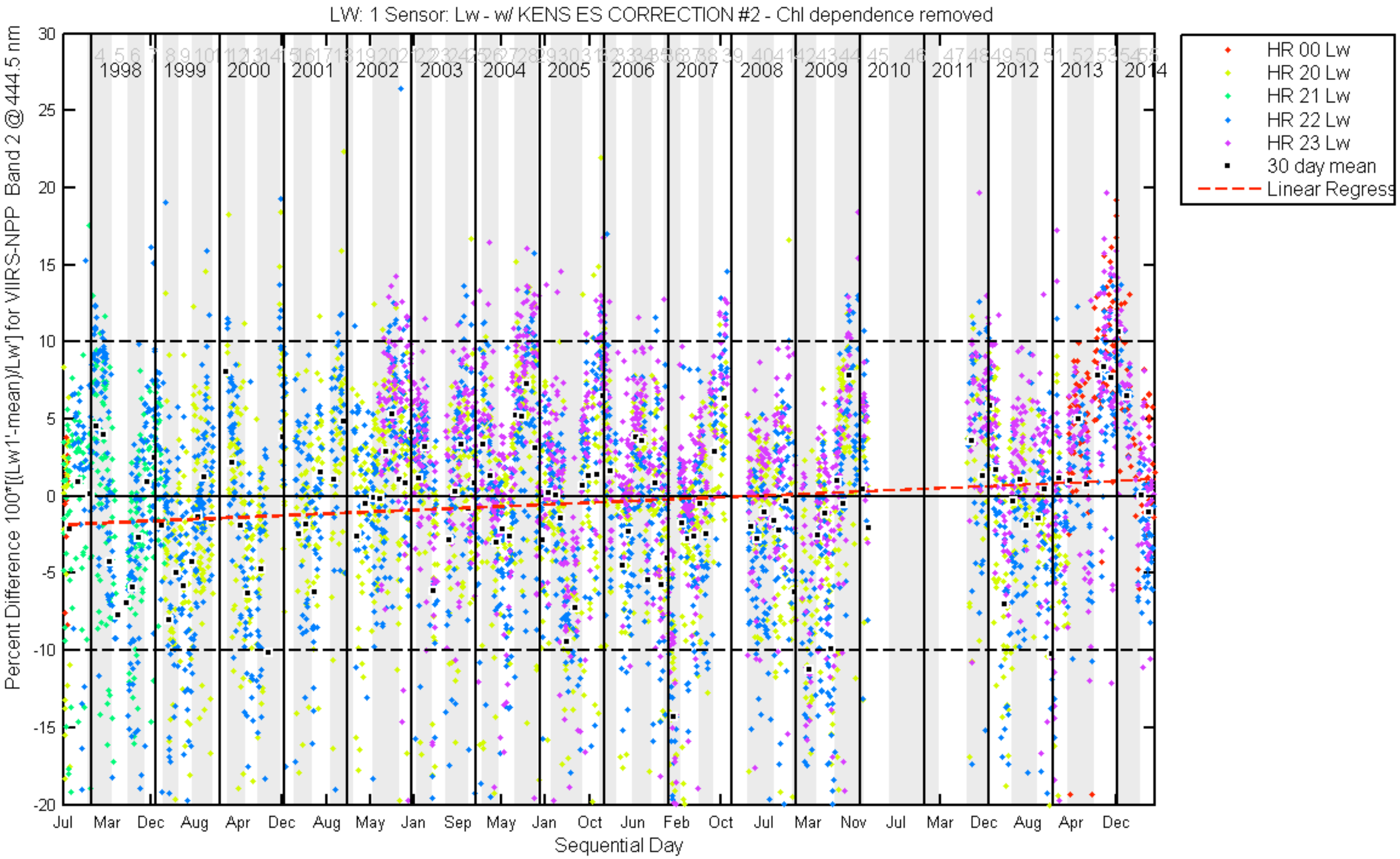
20 year time series at this point at site in Hawaii.



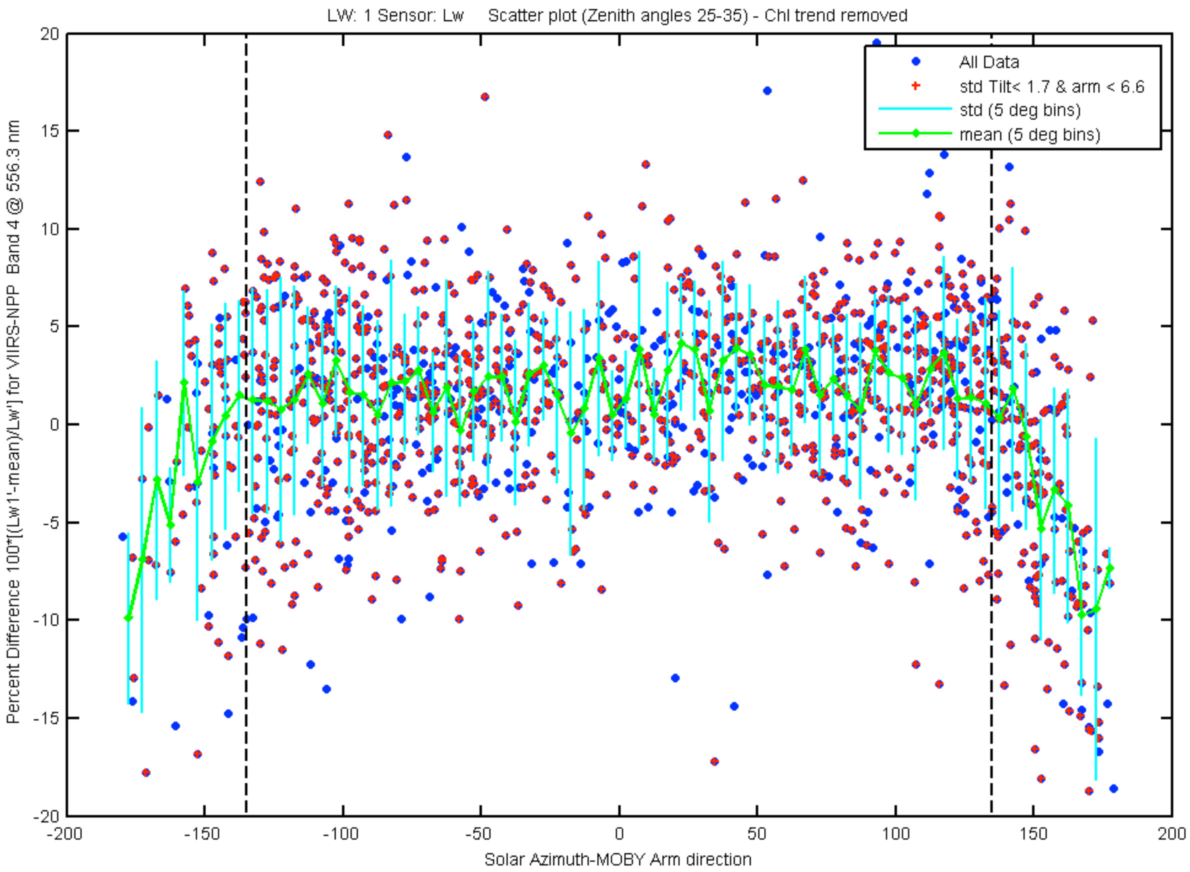
Can look for trends, Lw (444 nm) after seasonal and daily Es has been taken out. Very small 5% trend over 20 years, mostly driven by data acquisition time.



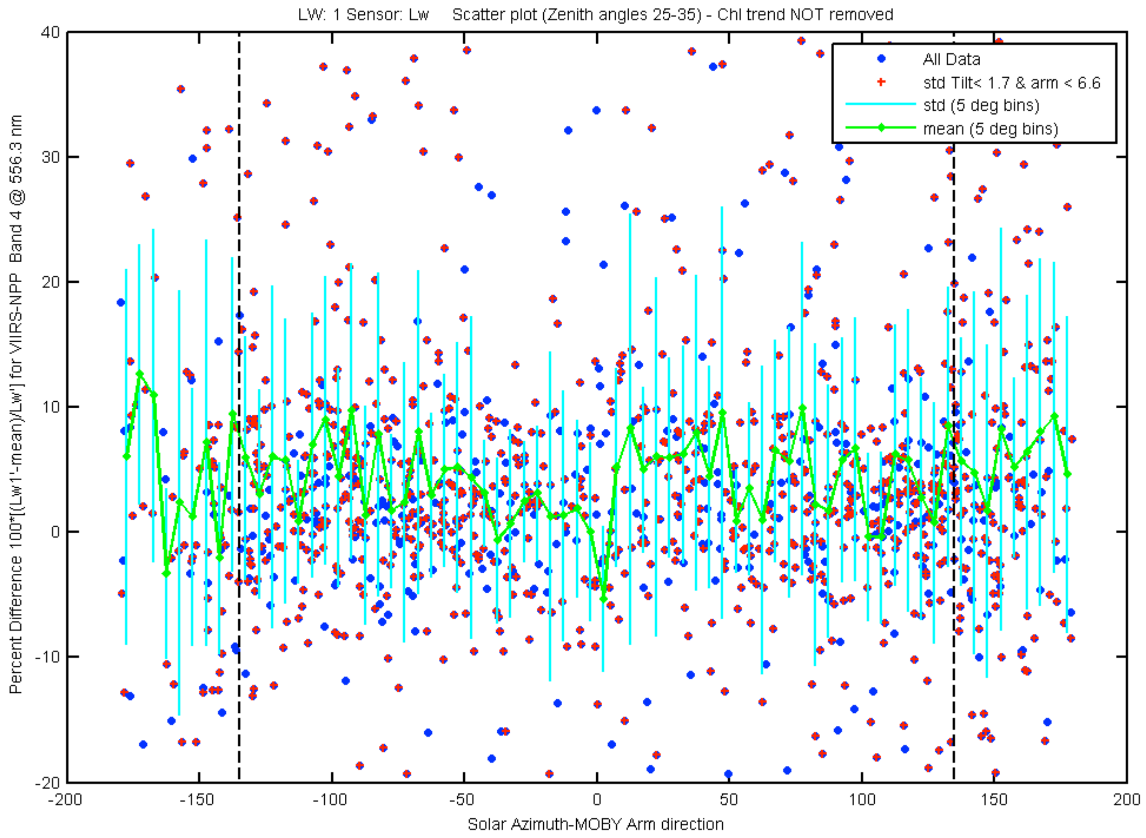
Take out chlorophyll (Chl) variation (normalize to Chl), compresses this even farther, with trend now 2.5% or so



Also look for problems, such as shadowing



Simple shadow correction, note edges, but scatter seems to have increased



Lessons we all know (but are difficult to deal with):

Long term funding is required, but difficult to maintain, long term relationships have to be maintained with agencies, and sometimes these change.

There is always some time/budget constraints…know the critical bottlenecks and major sources of uncertainty, concentrate on these first.

Lessons that have worked with MOBY (somewhat)

MOST IMPORTANT: CONSISTANCY OF PEOPLE, REQUIRES TEAM WORK AND INDIVIDUAL EXPERTISE!!

Redundancy is important, both in radiometry and physical structure.

The cost is driven not by the equipment but by the characterization, calibration and maintainance.

Being in a “constant” environment is very useful for QA/QC.

Follow and inspect every aspect of the data daily. From raw counts through processed data

Make sure to have contingency funding for emergencies..they will happen (buoys drifting off, new regulations, boat strikes).

To get a long time series, anticipate and plan for system replacements. We had extra parts to start with, but it has been a 10+ year process to get Refresh going.

Try to make sure stakeholders/users are getting what they need.

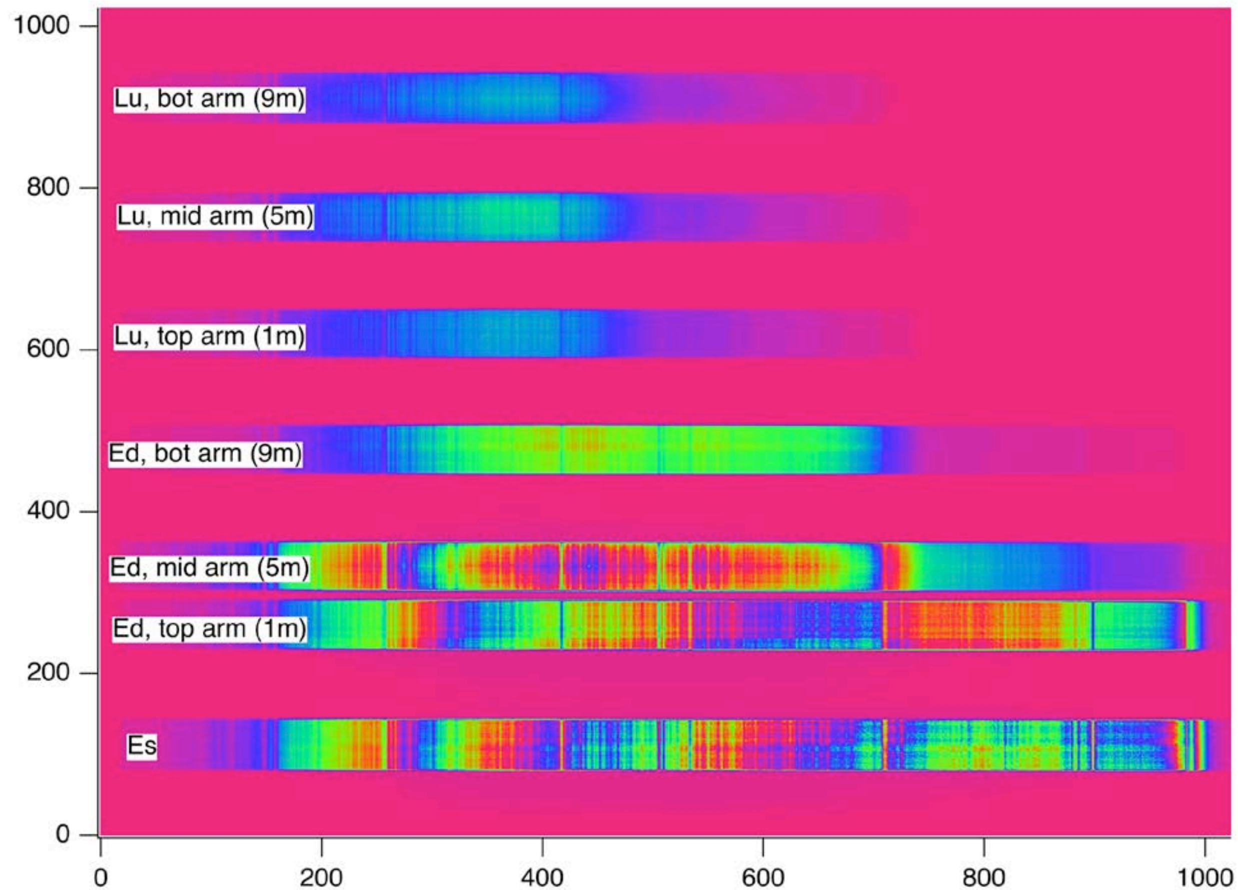
Start with a flexible but very capable data system.

Have a way to document everything on a website for easy access.

Have an automated system to generate and post graphs of all parameters daily

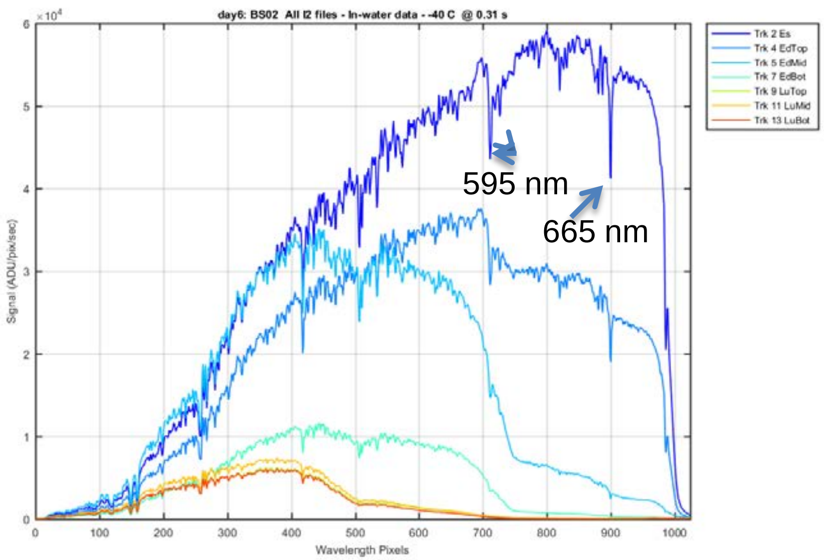
The Blue spectrometer from the new optical system is being operated on MOBY during deployments:

Preliminary results show that the new optical system does the simultaneous measurements, as we anticipated, but it is very optically "fast", so must be slowed down (good problem to have).

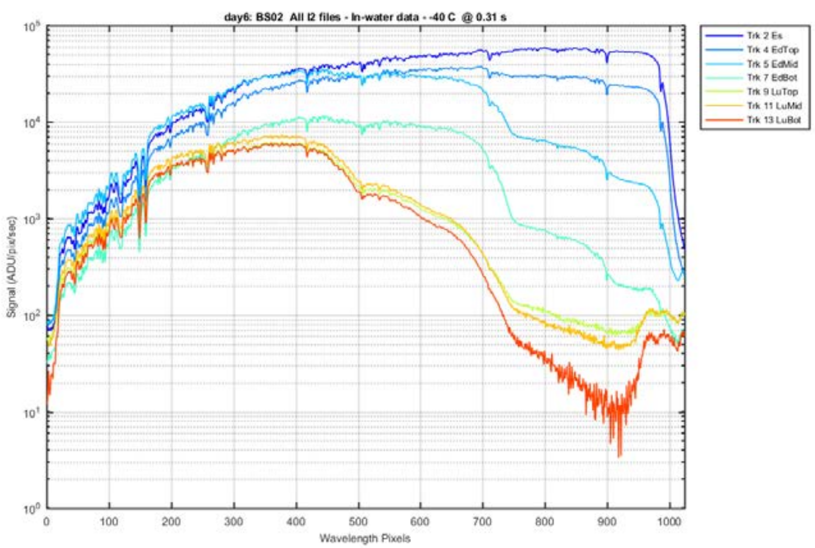


Wavelength from 340-700 nm

Another view

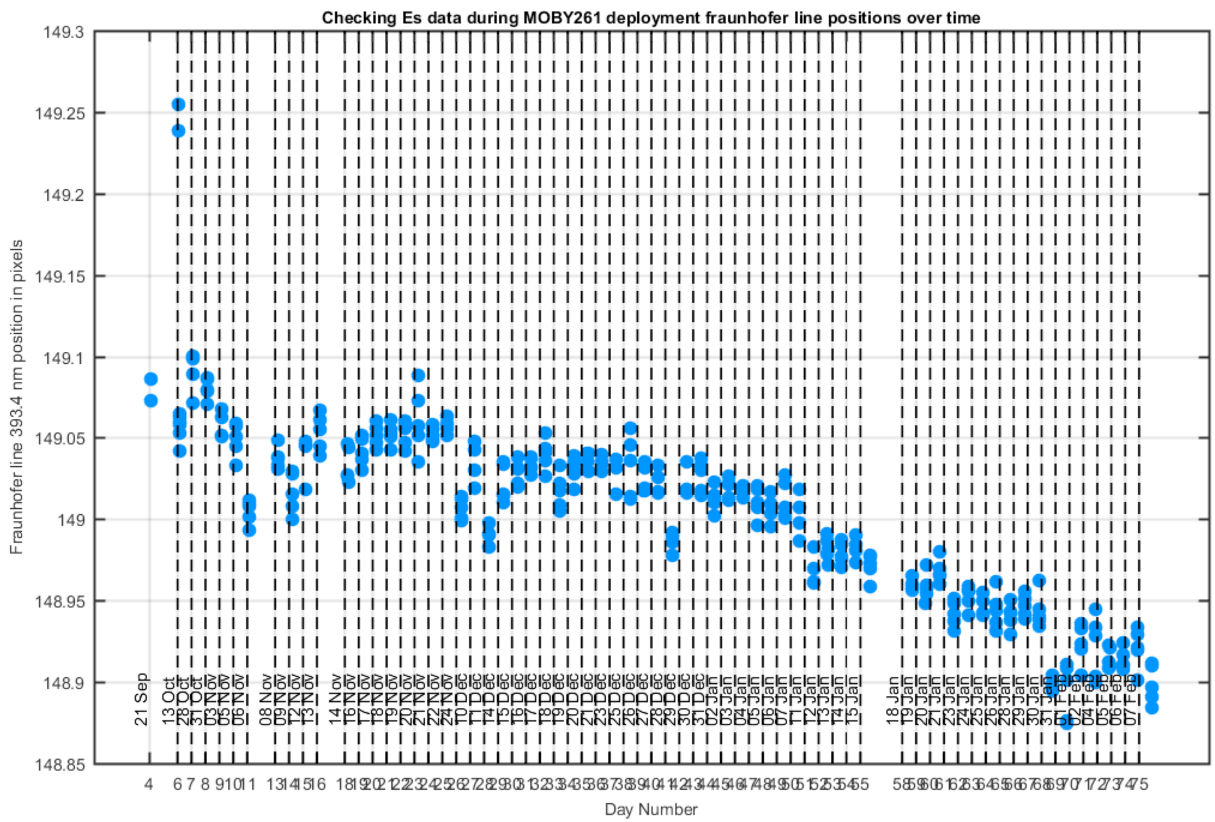


Each track on previous graph is shown here versus wavelength. Wavelength calibration is linear but starts at approximately 340 nm, and ends at 700 nm. Fraunhofer lines are very evident in the Es spectra, note the spectral resolution.

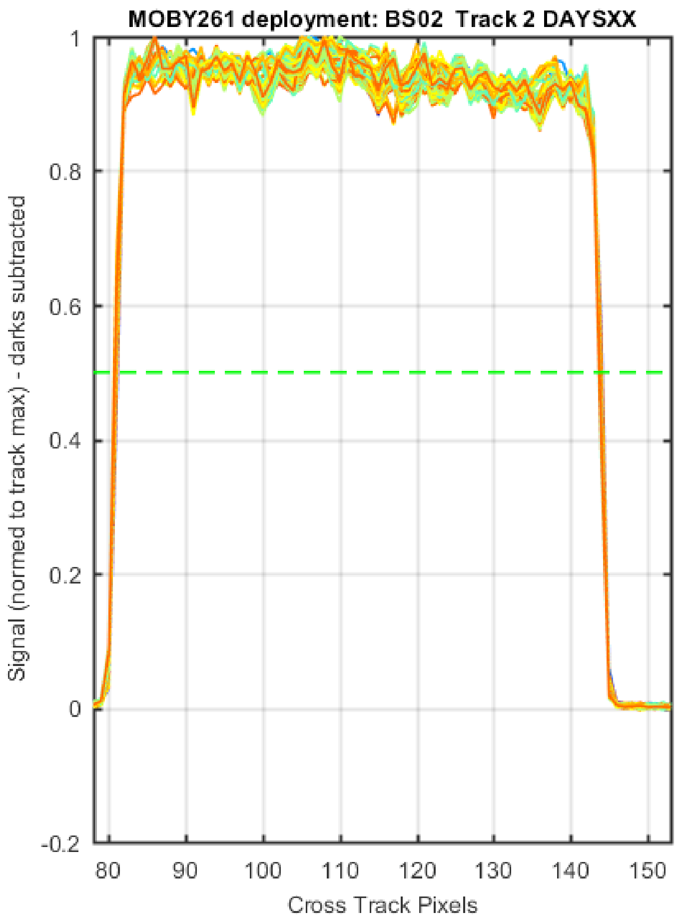


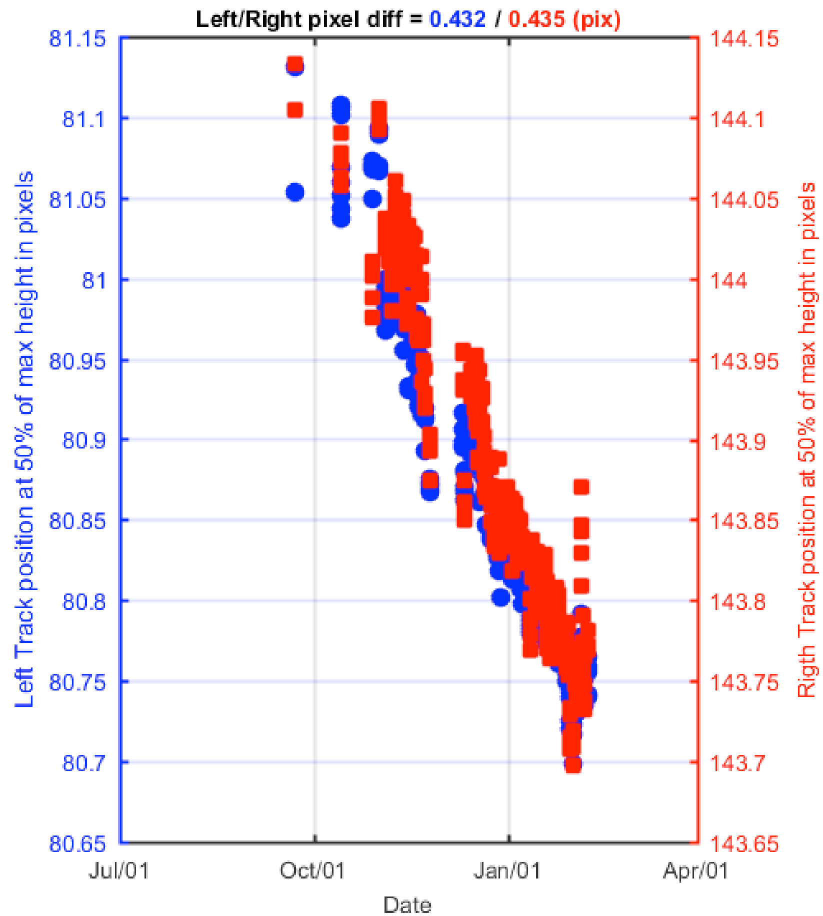
Same graph, but in log-linear scaling The system is very "fast", probably too fast. These images were taken at 8AM HST, sun angle was approximately 60 degrees, and still the integration time was only 0.3s. In general (particularly for the upwelling channels) an integration time of 30-60 seconds would be better. There are internal iris's which can be adjusted for balance and gain, but for stability reasons this must be done manually.

System has been very stable in both spectral registration (Less than 0.1 nm shift over 4 month deployment, as registered with Fraunhofer lines).

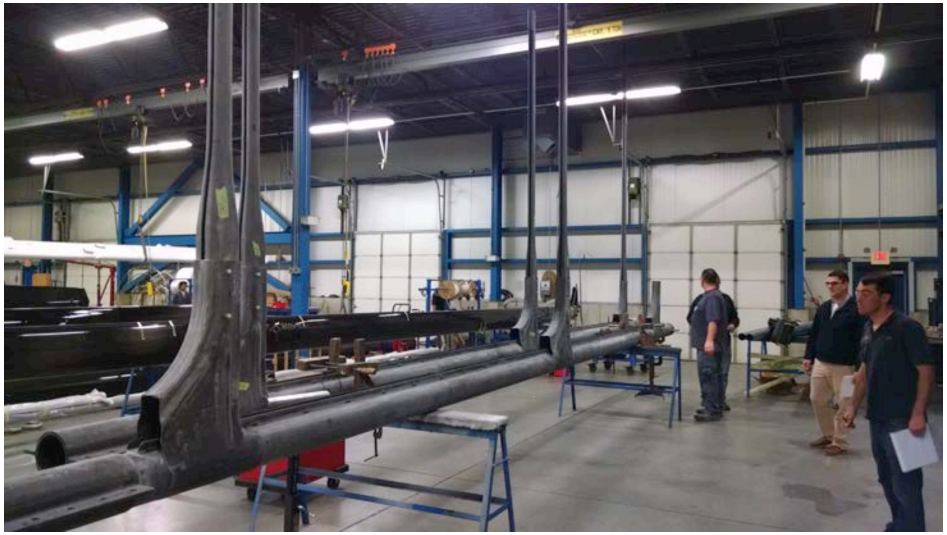


And stable in the track dimension (less than 0.5 pixel shift over 4 months):





For MOBY-Net, structure has been designed and built:

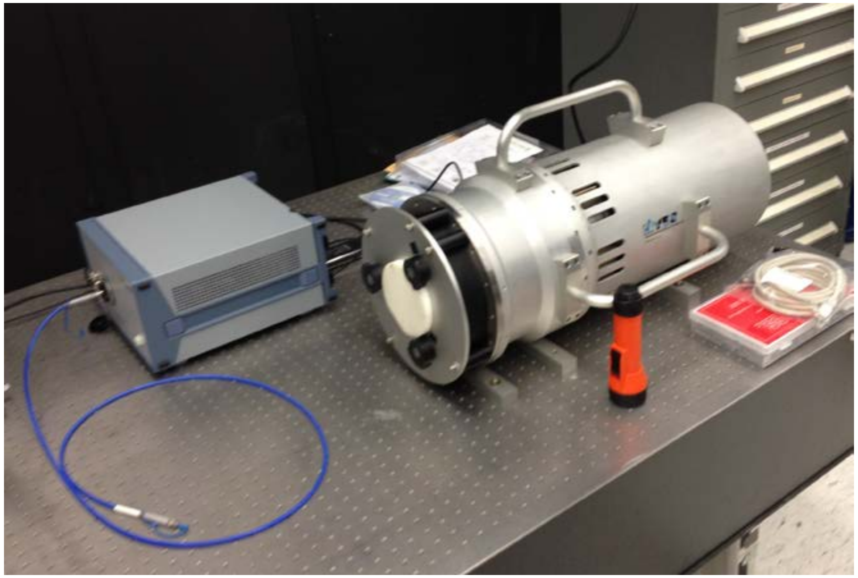


Above, main Spar with arms fitted in place.

To right: close up of end of spar with irradiance and radiance collectors fitted.

The other piece of MOBY-Net is the stability source and source monitor

The Stability System consists of a source stability system, the Satellite Quality Monitor (SQM)† with SIMBIOS* heritage and a CAS‡ fiber-optic coupled spectral radiometer. Both are commercial systems.



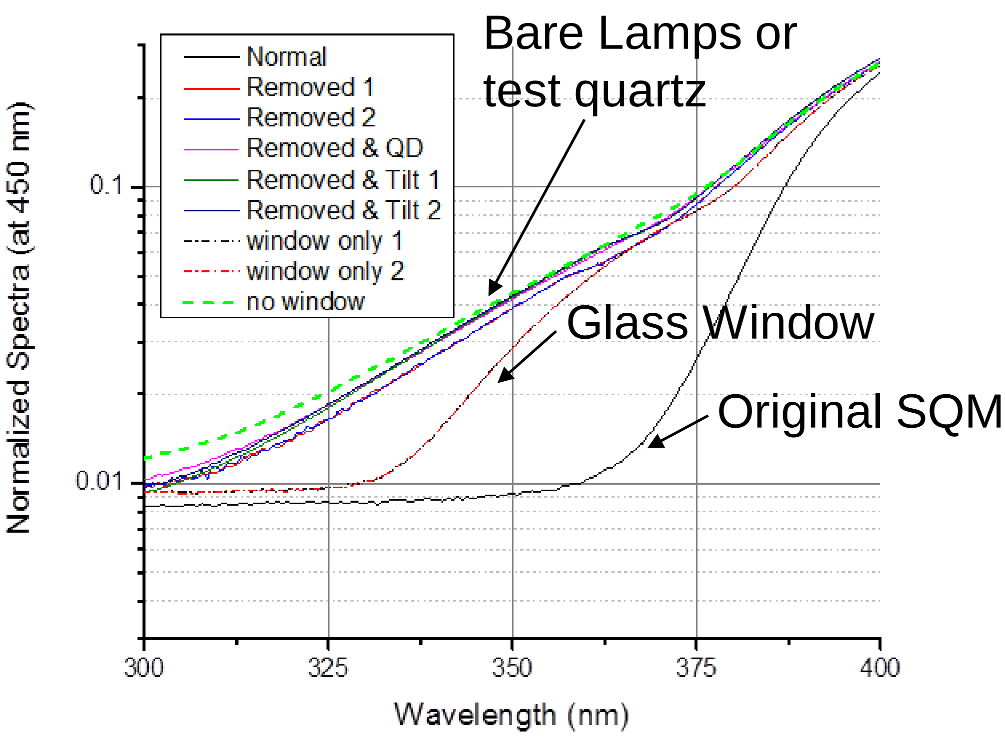
†Yankee Environmental Systems, Inc.

*Sensor Intercalibration and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS)

‡Instrument Systems, Inc.

Modifications of SQM

There was little ultraviolet in the SQM as delivered, because the window was glass and the diffuser was acrylic. MOBY-NET goes down to 350nm to support PACE*. We solved this issue by replacing these with fused silica components.

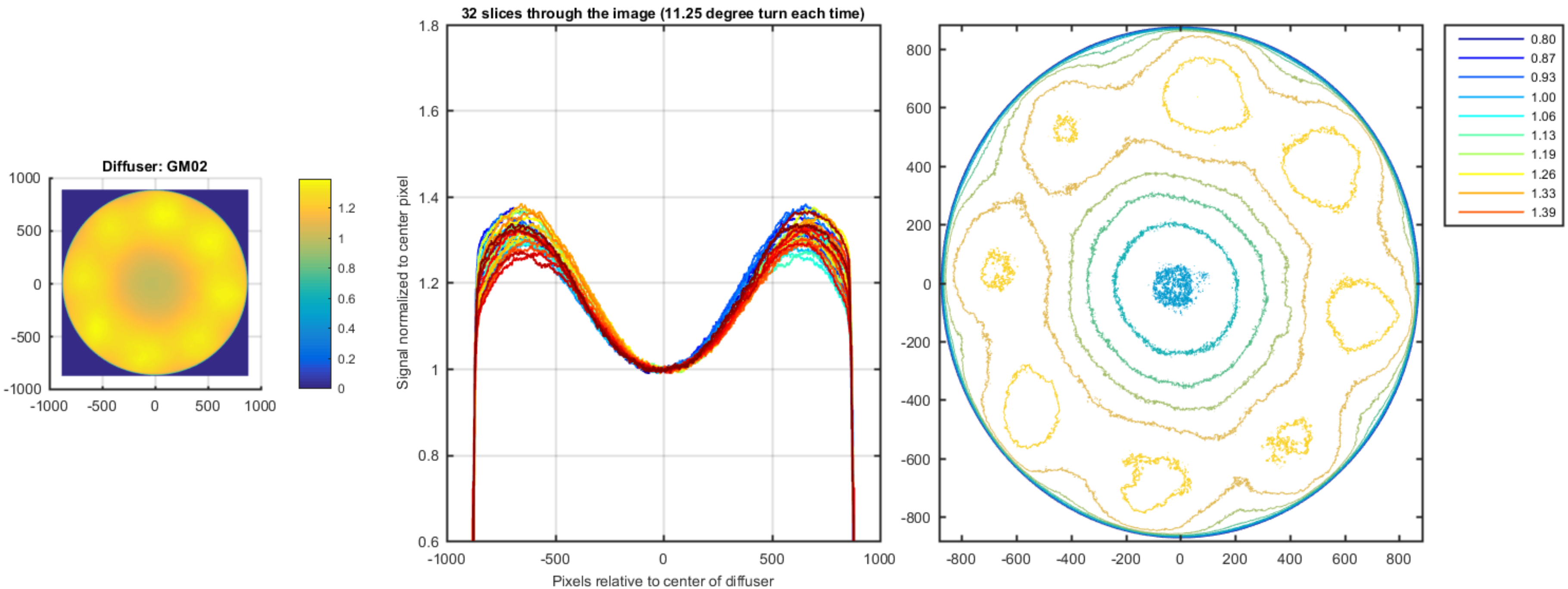


Measurements of the SQM using a NIST UV CAS (200nm to 875nm) – spectra normalized to 450nm.

Conclude: quartz (fused silica) diffuser and window will not degrade the inherent spectral shape (lamps & Al chamber)

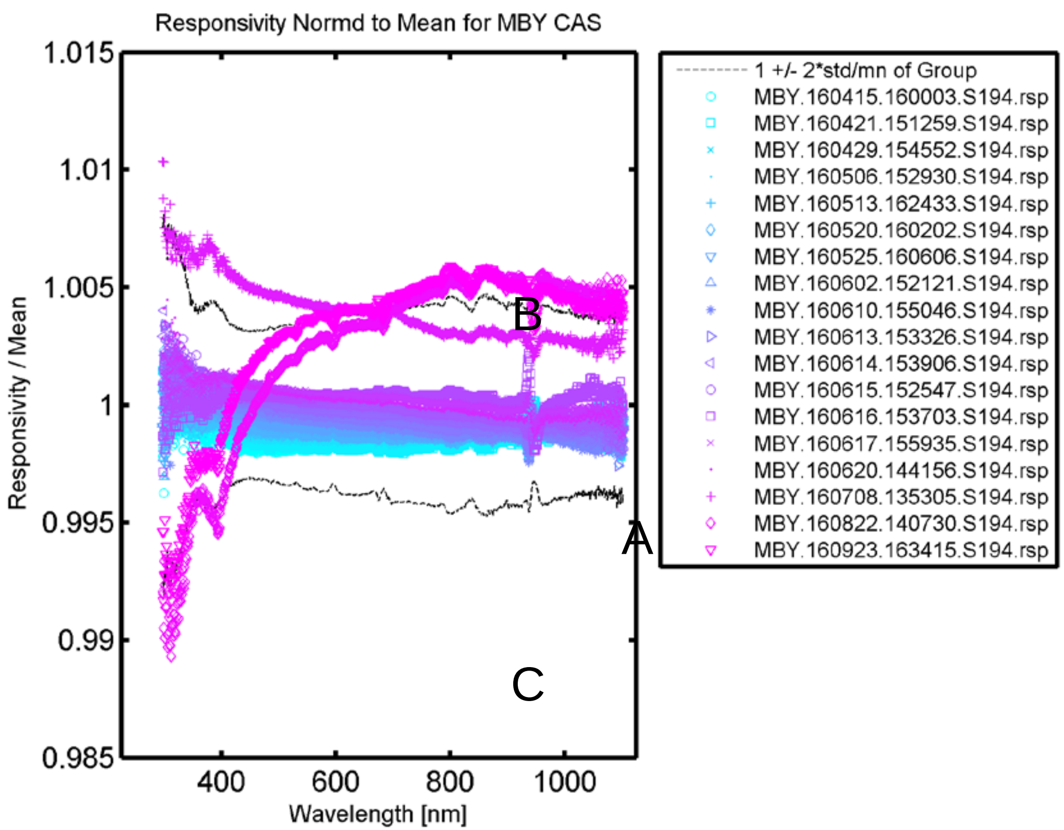
*Plankton, Aerosol, Cloud, ocean Ecosystem

We made four quartz diffusers by different surface treatments of optical polished fused silica. The two-sided bead-blasted was the best. It is not as uniform as the original plastic diffuser, but the Lu head of the device under test will only see the central region, and will always be at the same distance and azimuthal orientation.



Images acquired with a single lens reflex digital camera using the manufacturer’s software to process the raw images

CAS Repeatability w/ moving



"B" measuring at NIST, transporting the CAS to other laboratories at NIST, and returning to the first site

"C" is the same, but the optical fiber was removed it was shipped to/from Honolulu for use at MOBY.

Conclusions

Having a time series in a stable site allows many continuity tests….since this site is specifically for the purpose of Vicarious Calibration this is cruicial.

It is important to have a stable team (and funding) involved with the site with a long term history of working with the instrument and looking at the data.

MOBY-Refresh and MOBY-Net are moving ahead. The goal is a yearlong cross-over between the new/old optical system, completed in 2018.

Talk 4, Extended Abstract

MOBY: time series, lessons learned and status of MOBY-Refresh and MOBY-Net

FRM4SOC Workshop, Feb 21 – 23, 2017, Frascati, Italy

K. Voss, C. Johnson, M. Yarbrough, S. Flora, M. Feinholz, D. Peters, T. Houlihan, S. Mundell, S. Yarbrough

This talk provided an overview of the 20 year MOBY time series, some of the lessons we have learned and think are important, and the current status of MOBY-Refresh and MOBY-Net.

1) MOBY time series

At this time we are only a few months short of having a 20-year operational time series with MOBY. With this long time series we can look at the stability of the data set and other issues. When seasonal and daily variations in Es are normalized out, a very small, 5%, trend over the 20 years seems to be evident. However over these 20 years, we have been modifying our data acquisition times to account for different satellite mission requirements. Most of this trend is due to our taking measurements earlier in the day during the first part of the time series, and not being able to normalize totally for Es daily variations. The real trend is much smaller than 5% over the measurement period. We will be working on determining the true measurement trend during the summer, when the 20-year time series has been completed.

2) Lessons learned

There are several obvious lessons, such as long term funding is hard, but required and takes effort to sustain. For the MOBY project we have found that consistency of people, each with individual expertise on some aspect of the project has worked well. Being in a nearly constant environment allows careful QA/QC to be maintained. The original cost of the equipment is quickly dwarfed by the costs of maintenance, calibration, and characterization, so you might as well start with really good equipment. Finally we think it is critical that the data be inspected daily, if you are going to do an operational SVC site, to allow rapid response if there is an issue. This means following each step of the data processing, from raw data to finished data at all times.

Other timely lessons are that contingency funding must be available for emergencies; if the time series is long enough plans to upgrade equipment must be made. For MOBY it was a 10-year process to secure the funding for MOBY-Refresh. Finally, since it is an expensive operation, make sure the users are getting what they require.

One other aspect which helps with the quality control is being able to automatically update graphs, and having a web page that documents everything.

3) Progress on MOBY-Refresh and MOBY-Net

Currently we have installed the blue spectrograph from MOBY-Refresh and MOBY-Net on the MOBY buoy, and are acquiring images with the spectrograph during one of the MOBY acquisitions times each day.

Figure 1) picture of new blue spectrometer installed on the MOBY buoy.

An example image from this acquisition is shown below

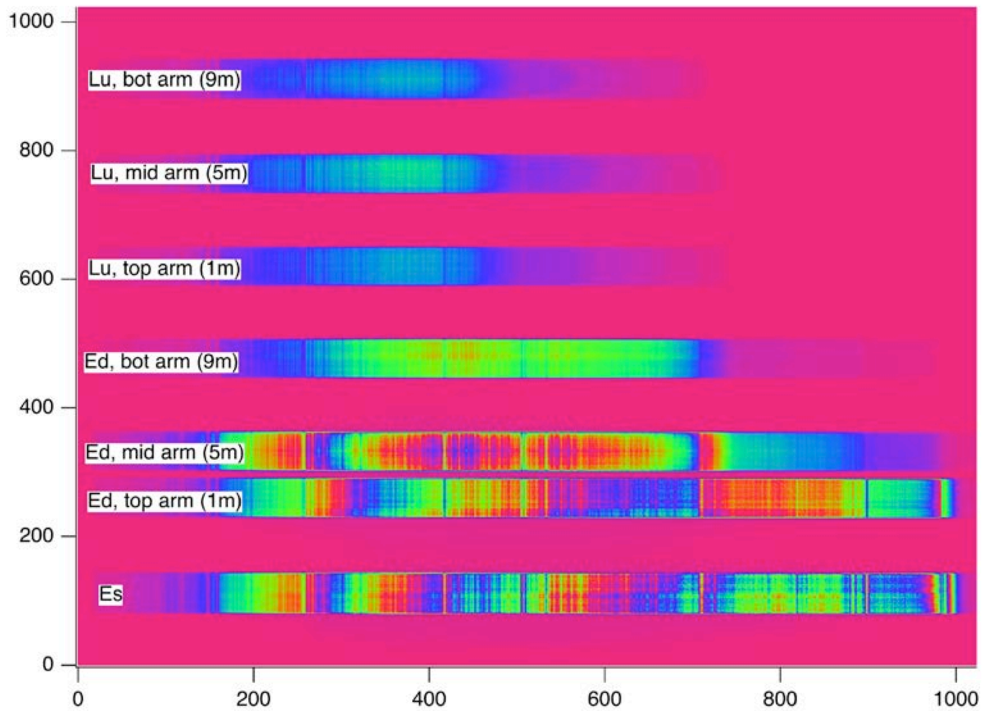


Figure 2) sample image of different environmental light field measurements, all obtained simultaneously. The x-axis is a relative wavelength scale, starting at 340 nm on the left and going to 700 nm on the right.

We have been monitoring the stability of the system over the deployment and it is working well, with less than a 0.1 nm shift over the deployment period, and less than ½ a pixel shift in track location over the deployment.

The new carbon structures for MOBY Net have been built, and we are waiting for the final stage of construction of the buoy structure.

The other part of MOBY-Net is the stability source and monitor. We are currently using a Satellite Quality Monitor (SQM) from Yankee Environmental Scientific as a stability source. We have extensively modified the software associated with the system to allow careful tracking of all the instrument parameters. An acrylic diffuser was in the original instrument, but we found that the throughput at 350 nm with this diffuser was much too small. Through tests we found that we could replace this diffuser with a quartz window that had been sand blasted on both sides, and this would both be diffuse enough, and allow for almost no spectral losses at 350 nm.

We selected a CAS spectrometer for the stability monitor device because NIST had several of them and experience with using them. We are in the middle of a long term stability study with this spectrometer. In addition we are testing its stability after transport in various ways.

4) Conclusions

Having a time series in a stable site allows many continuity tests, and since the MOBY site is specifically for System Vicarious Calibration (SVC) this is important.

Having a stable team, and relatively stable funding has been critical for the success of the MOBY team.

MOBY-Refresh and MOBY-Net are moving forward. The goal is a yearlong crossover time series between the new and old optical system completed in 2018.