MOBY Normalized Water-Leaving Radiance Time-series Uncertainty Reduction for Improved Multi-platform Satellite Sensor Vicarious Calibration (OS33A-01)

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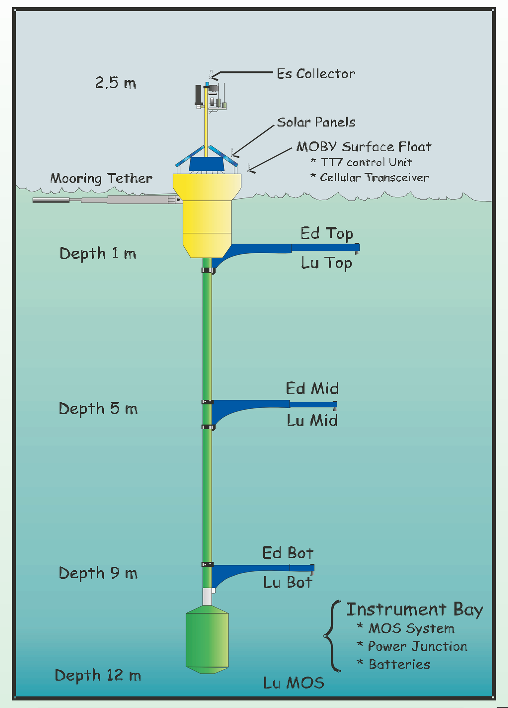
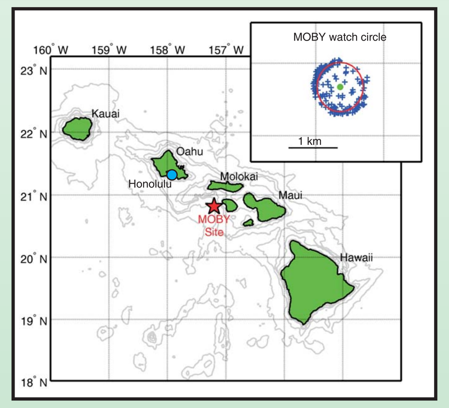
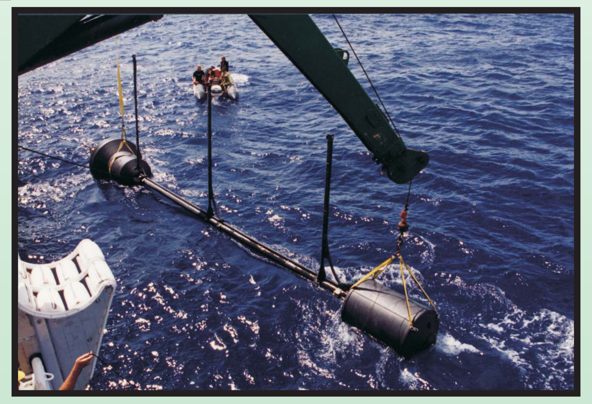
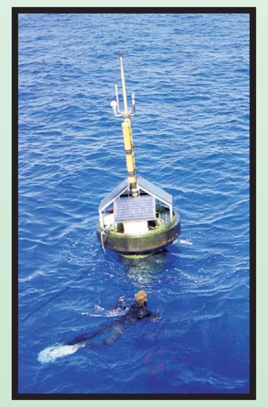


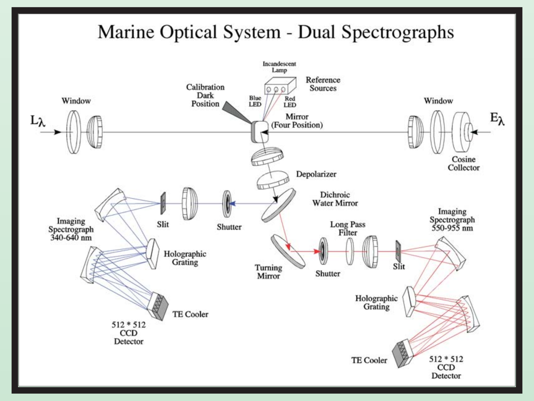
Abstract

The Marine Optical Buoy (MOBY), a radiometric buoy stationed in the waters off Lanai, Hawaii, is the primary ocean observatory for vicarious calibration of satellite ocean color sensors. Since late 1996, MOBY has been the primary basis for the on-orbit vicarious calibrations of the USA Sea-viewing Wide Field-of-view Sensor (SeaWiFS), the Japanese Ocean Color and Temperature Sensor (OCTS), the French Polarization Detection Environmental Radiometer (POLDER), the USA Moderate Resolution Imaging Spectrometers (MODIS, Terra and Aqua), the Japanese Global Imager (GLI), and the European Medium Resolution Imaging Spectrometer (MERIS). The MOBY vicarious calibration of these sensors supports the international effort to develop a global, multi-year time series of consistently calibrated ocean color data products. A longstanding goal of the Ocean Color Science Teams is to determine satellite-derived normalized water-leaving radiance (L_{WN}) with a combined standard uncertainty of 5%. A critical component of this approach is to reduce uncertainties in MOBY *in situ* L_{WN} data. As has been the case since the first MOBY deployment, these improvements are achieved incrementally and from a variety of system aspects. We will discuss these efforts and present results relating to the radiometric calibration, instrument stability during deployments, sensitivity to temperature, stray light corrections, data acquisition protocols, and instrument self shading.



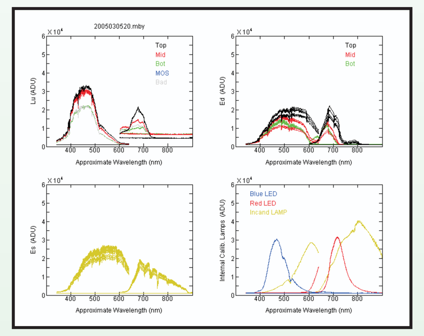






MOBY Data Collection

MOBY uses a high-resolution hyperspectral instrument known as the Marine Optical System (MOS) to detect radiation over the spectral range from 350 nm to 955 nm. In MOBY, MOS is fiber-optically connected to radiance and irradiance ports on the three MOBY arms (denoted Top, Mid, and Bot) that are located at depths of approximately 1.5 m, 5 m, and 9 m, as well as a surface irradiance port. Data acquisition is autonomous and designed to overlap with the overpass of the sun-synchronous satellites, resulting in daily acquisitions at 20h, 22h, and 23h (GMT), corresponding to SeaWiFS, MODIS-Terra and MODIS-Aqua, respectively. In this presentation, we describe the processing of the MOBY data sets, including what is collected, analysis and quality control, and dissemination and archiving.



Optical Buoy

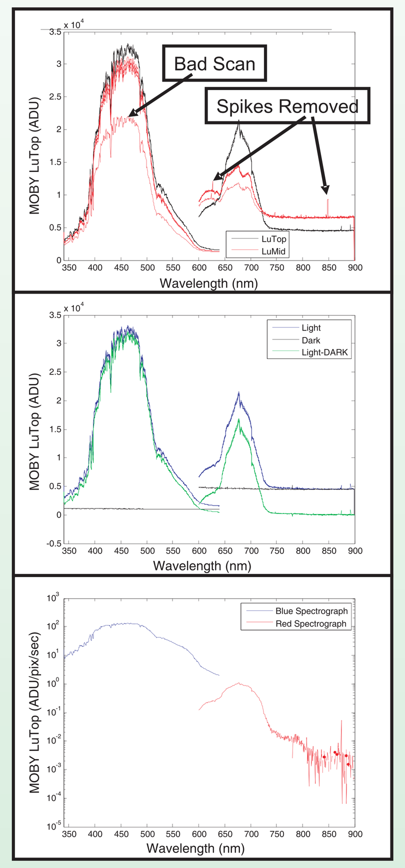
- E_s, L_u(at four depths), E_d(at three depths)
- CCD parameters (integration time, bin factor, temperature)
- Temperatures and power
- Attitude (x, y tilt; pressure at top arm; compass heading)
- Time (onboard, GPS)
- Internal LED and incandescent references

MOS in temperature controlled bath

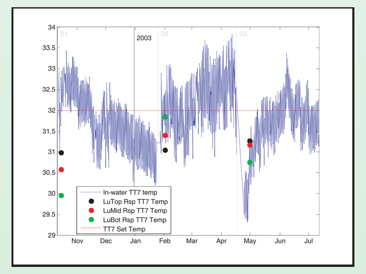
MOBY Data Processing

The optical measurements (e.g., E_s and L_u) by MOBY are sequential. A complete data set for L_u at each depth includes multiple scans of L_u, bracketed by dark scans; this L_u measurement is bracketed in turn by a set of E_s scans (which are also bracketed by dark scans).

Pre-processing of the entire data set includes the incorporation of time stamps for the ancillary data, if necessary, rejection of anomalous radiometric scans, and removal of "spikes" in the radiometric data. Multiple scans are averaged, the data are normalized for integration time and bin factor (a sub-sampling along the slit direction in the CCD spectrographs), and the net counts are determined using the associated dark scans.



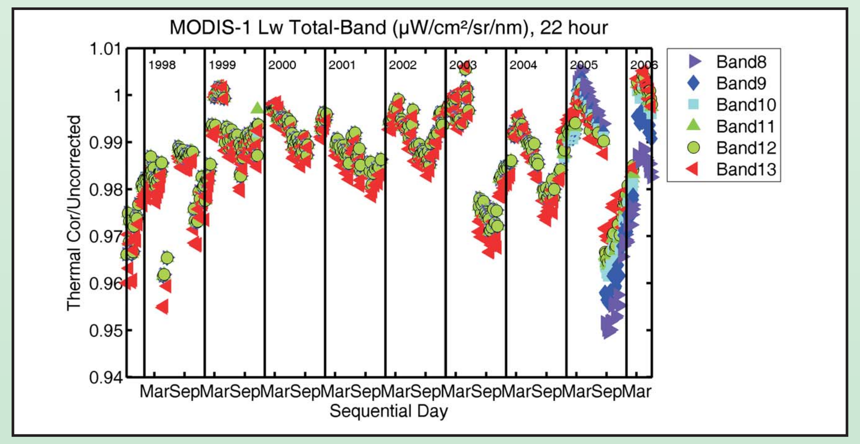
MOBY processing steps



In-water and system response temperatures (ref. is 32°C)

Thermal Correction

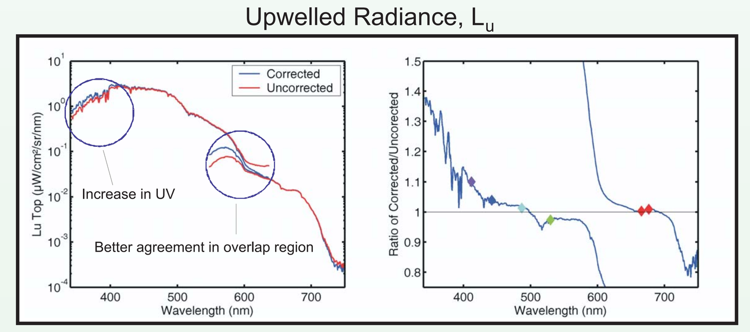
Although the MOS CCDs are temperature-controlled, the temperatures of the optical components in the spectrographs, the electronics, the MOBY fiber optics, and other system components are subject to environmental conditions. Because the ambient temperature and degree of thermal equilibrium depends on the measurement purpose (calibration vs. in-water radiometry) and type of deployment (MOBY vs. MOS), the radiometric responsivities of MOS instrument in MOBY was studied as a function of temperature. In December 2002, a temperature controlled bath was constructed and a set of measurements were acquired on the MOS instrument. Results show that for the blue spectrograph there is a thermal sensitivity on the order of 0.5% ADU/pix/sec per degree Celsius.



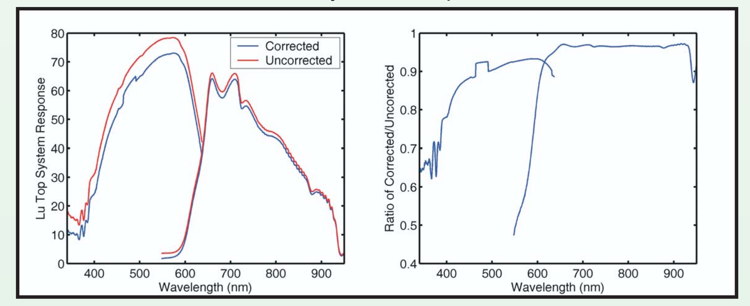
Stray Light Correction

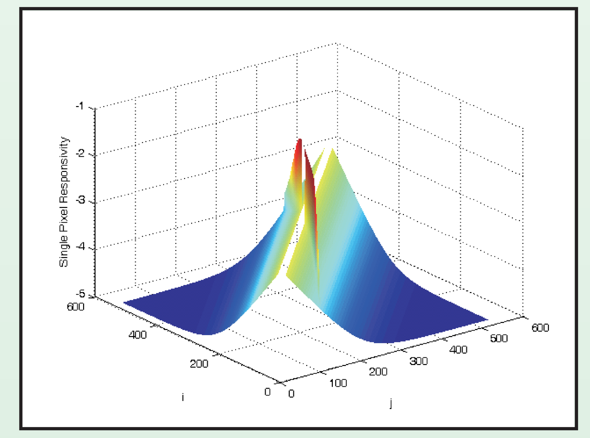
Radiometric sensors do not have an ideal spectral selectivity. That is, the response at a wavelength of interest to flux at other wavelengths ("out-of-band") is small but finite. For MOS, the out-of-band response is largely determined by the scattering properties of the grating and inter-reflections of flux diffracted at higher orders. We refer to the effect as "stray light". It is a significant issue in ocean color research because the calibration sources are red-rich compared to the measured sources for L_u and E_d. To correct for stray light, the function that describes the sensitivity to flux at wavelengths other than the desired wavelength must be determined for the MOS. This requires a tunable, monochromatic source with the correct geometric parameters. In 2001, a portable version of Spectral Irradiance and Radiance Calibration using Uniform Sources was developed by National Institute of Standards and Technology (NIST) and deployed to the MOBY operations site in Honolulu for the buoy characterizations. A stray light correction model was developed by NIST. The stray light correction algorithm iterates to a solution based on laser characterizations at the MOBY facility. The magnitude of this correction depends on wavelength and the relative spectral shape of the source being measured.

Upwelled Radiance, L_u

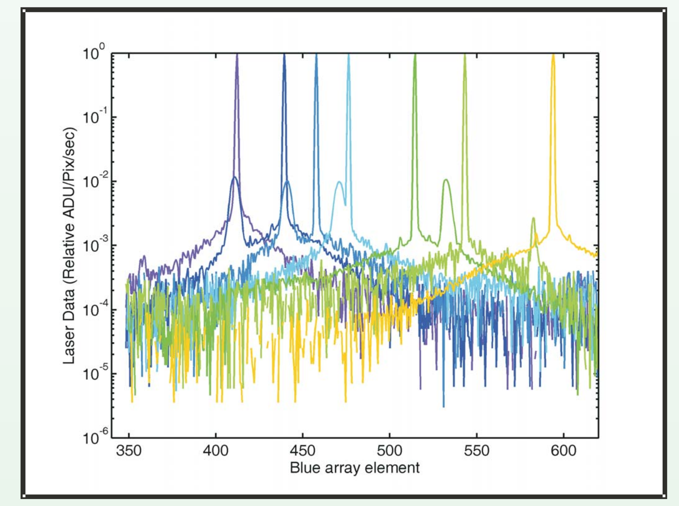


MOBY System Response

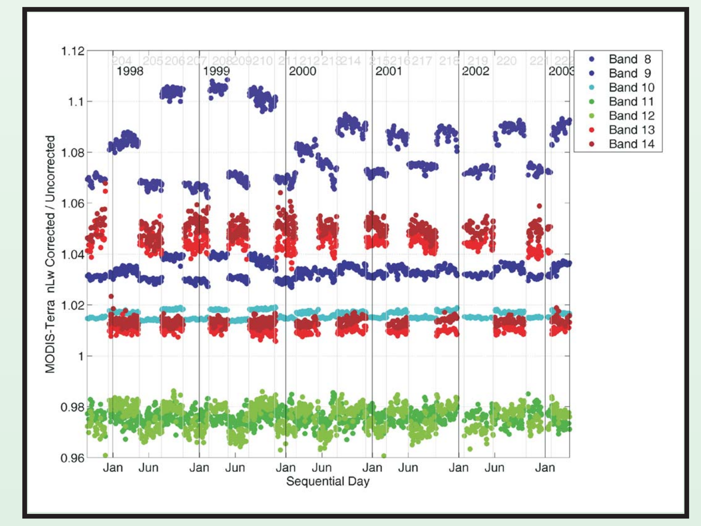




Single Pixel Responsivity correction matrix

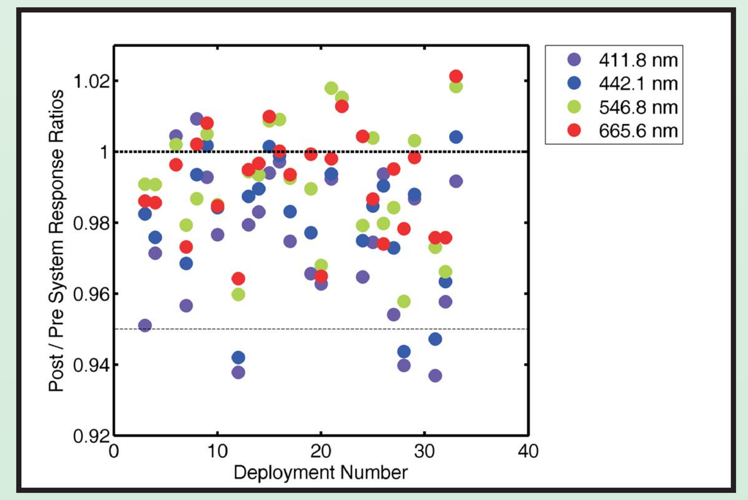


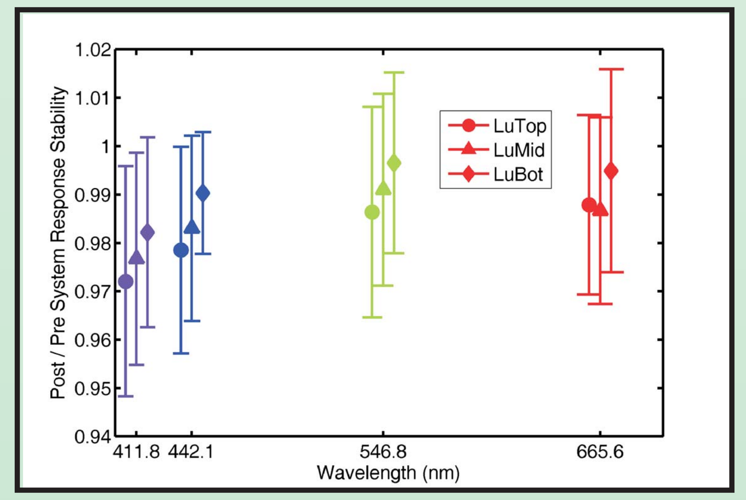
Laser data used for stray light correction

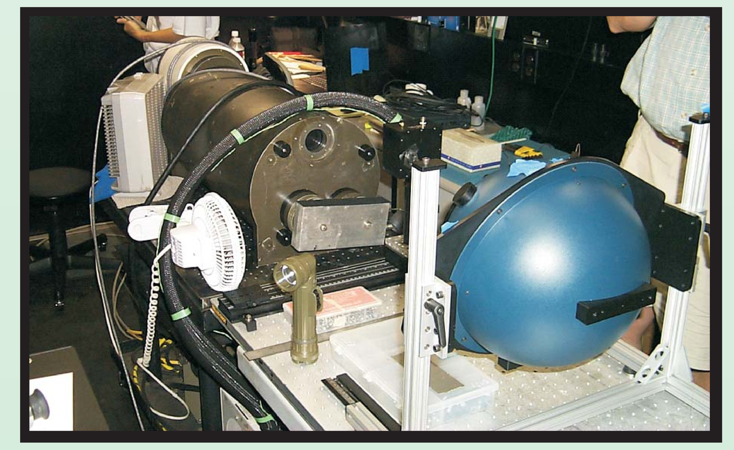


Stray light correction ratios for MODIS Bands

Calibration







The unique role of MOBY as a primary, long term, daily reference for vicarious calibration of satellite ocean color sensors requires radiometric measurements of the highest possible quality. The estimated combined standard uncertainty of MOBY radiance measurements is between 4% and 8%. This estimate is based on uncertainties of MOBY calibrations at less than 3%, changes in pre- and post-deployment calibrations ranging from 1% to 6%, radiometric stability tests during deployments using internal reference sources that show changes less than 1%, and diver-deployed external reference lamp responses that are stable within less than 3% (the estimated uncertainty of the method).

The Need for a Vicarious Calibration

-A longstanding goal of ocean color satellite Science Teams is to determine satellite-derived L_{WN} with a combined standard uncertainty of 5%.

-Because water-leaving radiance contributes only 10% (at most) of the radiance measured by a satellite sensor above the atmosphere, a 5% uncertainty in L_{WN} implies a 0.5% uncertainty in the above-atmosphere radiance measurements.

-This level of uncertainty can only be addressed by using "vicarious-calibration" approaches.

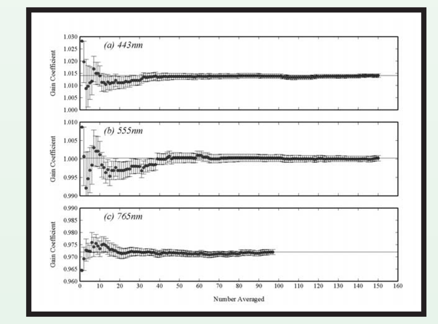
-In practice, this means that the satellite radiance responsivity is adjusted to minimize the squared differences between an ensemble of satellite and in situ L_{WN} data pairs.

-The end result of this approach is to implicitly absorb unquantified, but systematic, errors in the atmospheric correction, incident solar flux, and satellite sensor calibration into a single correction factor to produce consistency with the *in situ* data.

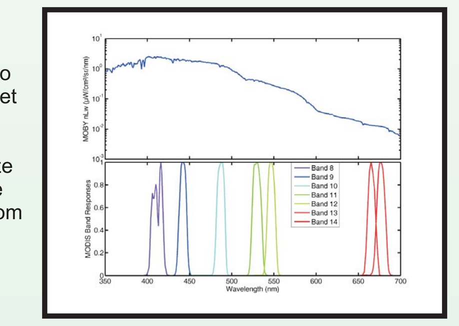
MOBY's role in vicarious calibration

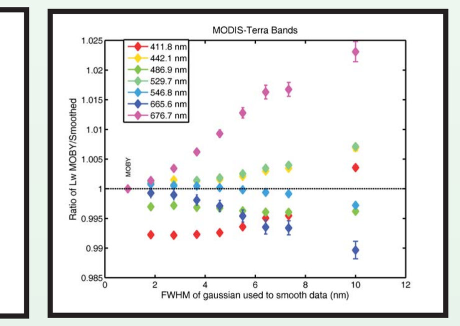
An interdisciplinary team of scientists and engineers has been assembled who collaborated to develop, produce and maintain a high quality system. The team has payed rigorous attention to characterizing and calibrating MOBY to reduce the uncertainty and biases within the system. The site provides the required oligotrophic waters which minimizes horizontal variability around the site.

MOBY's optical design, even though it is 15 years old, still remains state of the art. MOBY's high spectral resolution has provided for accurate convolution of each satellites relative spectral response, which eliminates the spectral bias. A multi-spectral approach introduces systematic biases into the calibration process.



Mean vicarious gains, derived for SeaWiFS bands at 443, 555, and 765 nm based on calibration samples spanning the mission lifetime from September 1997 to March 2006. Individual gains from the mission-long set of calibration match-ups were randomly sampled, growing the sample set one case at a time and averaging to show the effect of increasing sample size on mean vicarious gains. Vertical error bars show the standard error on the mean at each sample size. (From "Sensor-Independent Approach to the Vicarious Calibration of Satellite Ocean Color Radiometry" by Bryan Franz, Sean Bailey, P. Werdell, and Charles McClain. Applied Optics(2007)

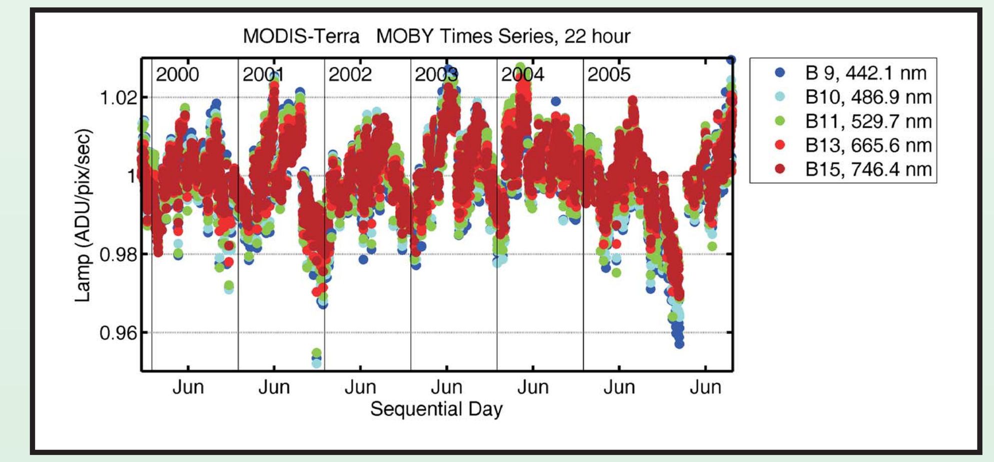




One source of uncertainty comes from the transfers of NIST standards to vendors which were then transferred to MOBY's primary calibration systems. Midway through MOBY's deployment life, NIST became the primary source of the calibration standards.

MOBY's system stability is monitored with on board calibration lamps and utilizes periodic diver lamps for total system calibration status. Time histories of reference lamp responses for each deployment period show the MOS spectrograph responses to be stable at the 1% level.

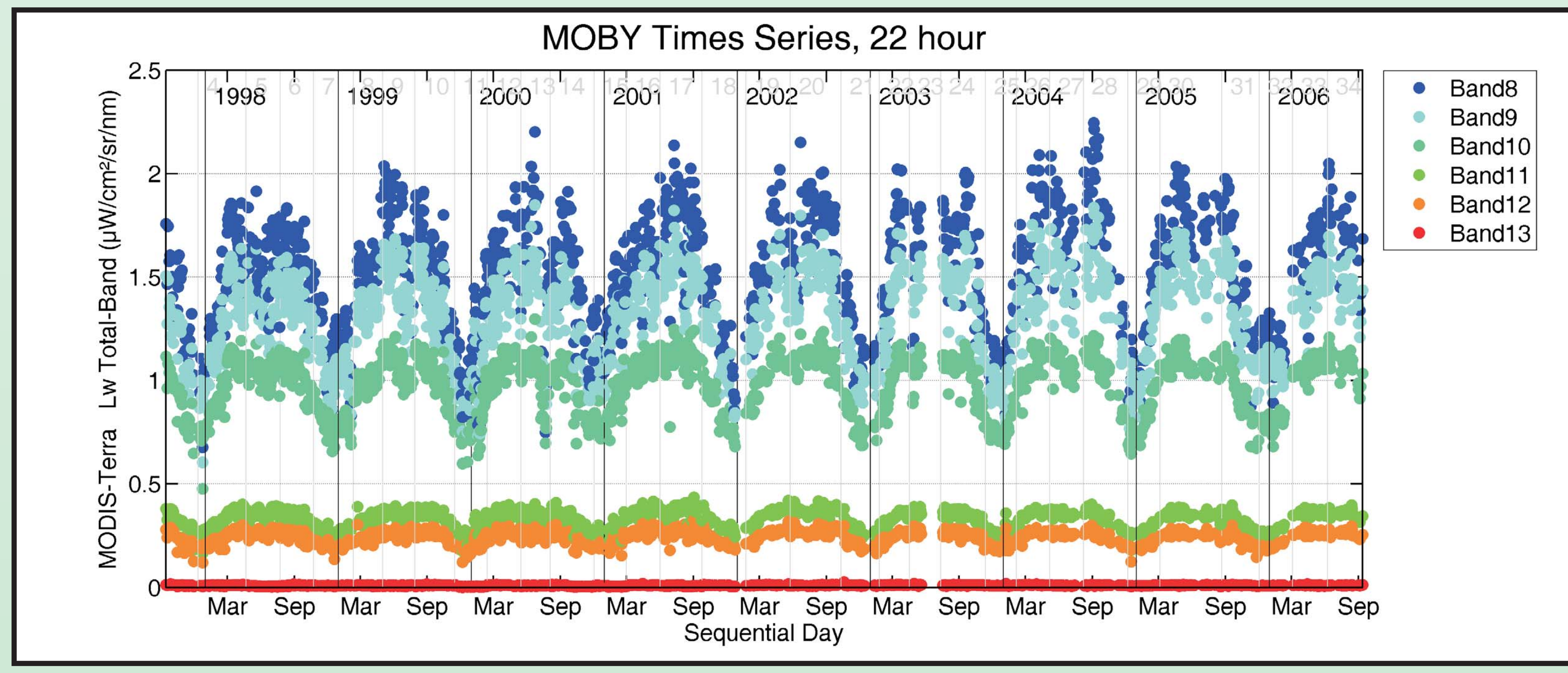
Ancillary environmental measurement of wind speed, temperature, relative humidity, and PAR are observed for environmental effects on the MOBY data set.



For the interval from July 1997 to February 2007, 8,347 measurements have been made. Approximately 50% of those are high quality data available for satellite match-ups.

MOBY has provided the only decade-long marine optical time series which is directly traceable to NIST.

The MOBY Product: Water-leaving Radiance Time-Series



Nine Year Time-Series 7/20/97 to Present
NIST Radiometric Scale & Collaboration
Verification of System Performance
Stray Light and Thermal Characterizations
Sensor Spectral Band Matching

Ocean Color Sensors Supported:

US - SeaWiFS	Europe - MERIS
US - MODIS (Terra and Aqua)	Japan - OCTS, GLI
US - MISR (Terra)	French - POLDER

1. Moss Landing Marine Laboratory, 8272 Moss Landing Road, Moss Landing, CA 95039, United States
2. National Institute of Standards and Technology, Optical Technology Division 100 Bureau Drive Stop 8443, Gaithersburg, MD 20899-8442, United States
3. Marine Optical Consulting, 842 Mill Creek Rd, Arnold, MD 21012, United States
(Dennis Clark's (Marine Optical Consulting, Arnold, MD) SDL affiliation is part of the Joint NIST/Utah State University Program in Optical Sensor Calibration)
4. DOC/NOAA/NESDIS/STAR, 5200 Auth Road, Camp Springs, MD 20746-4304, United States
5. Perot Systems Corporation, 5200 Auth Road, Camp Springs, MD 20746-4304, United States
6. University of Miami Physics Department, Atmospheric and Ocean Optics Group 1320 Camposano Dr, Coral Gables, FL 33124-0530, United States

Sponsors: NIST, NASA GSFC - MODIS Science Team and NOAA/NESDIS.