Calibration and Validation Sensors for Next-Generation NASA Missions

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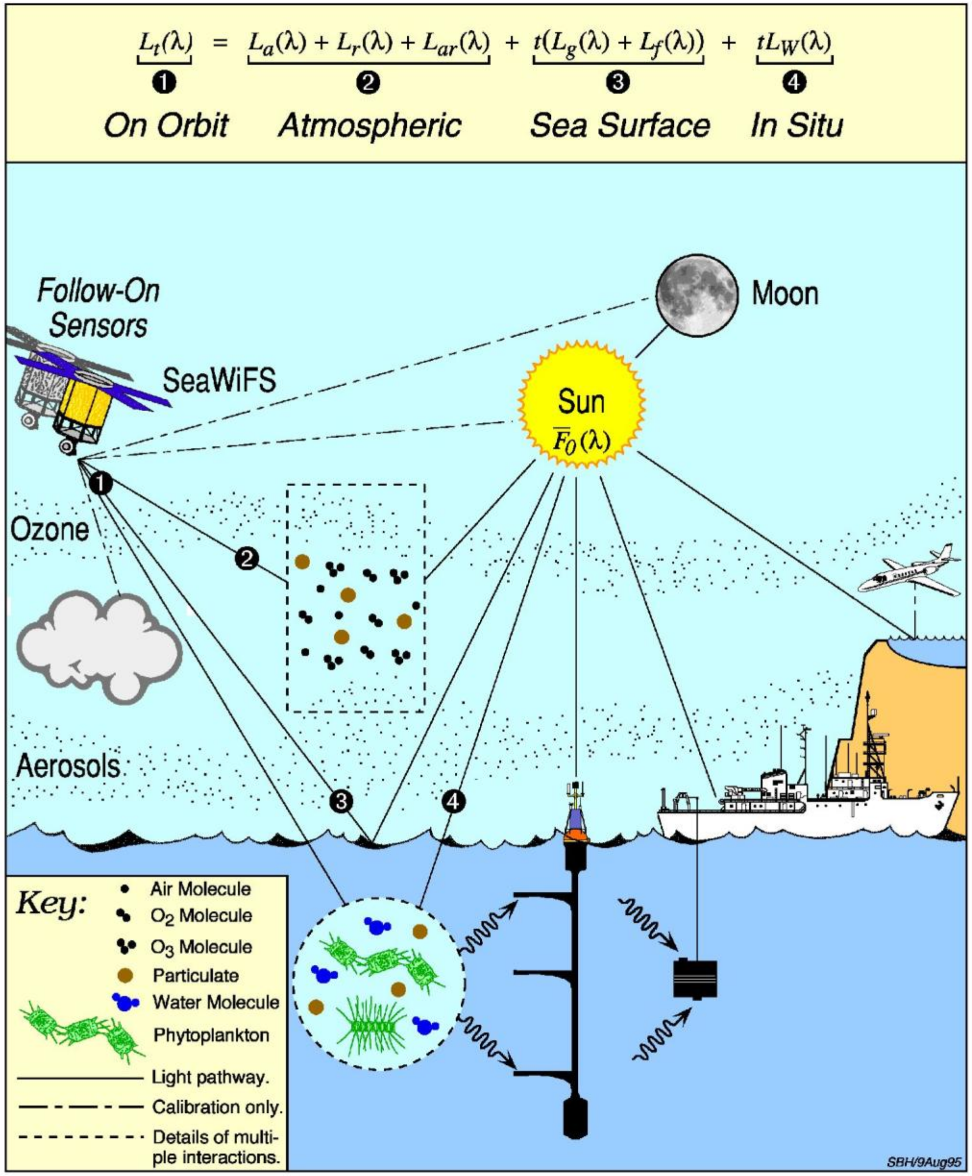
Calibration and Validation Paradigm for 20th Century (EOS) Ocean Color Satellites

The calibration and validation plan for SeaWiFS and its successors (MODIS) was based on an open-ocean, in-water, clear-sky perspective. A solitary vicarious calibration site in low concentration waters was established (MOBY) using custom hardware that could not be easily replicated or redeployed. Contemporaneous data collection from research vessels were used for algorithm validation. An airborne component was imagined, but did not ultimately contribute to either component. Most of the perspective was on the radiometry associated with the spaceborne and in-water data collection. To ensure the latter were of the requisite quality, the *Ocean Optics Protocols* were established and periodically revised (approximately on an annual basis).



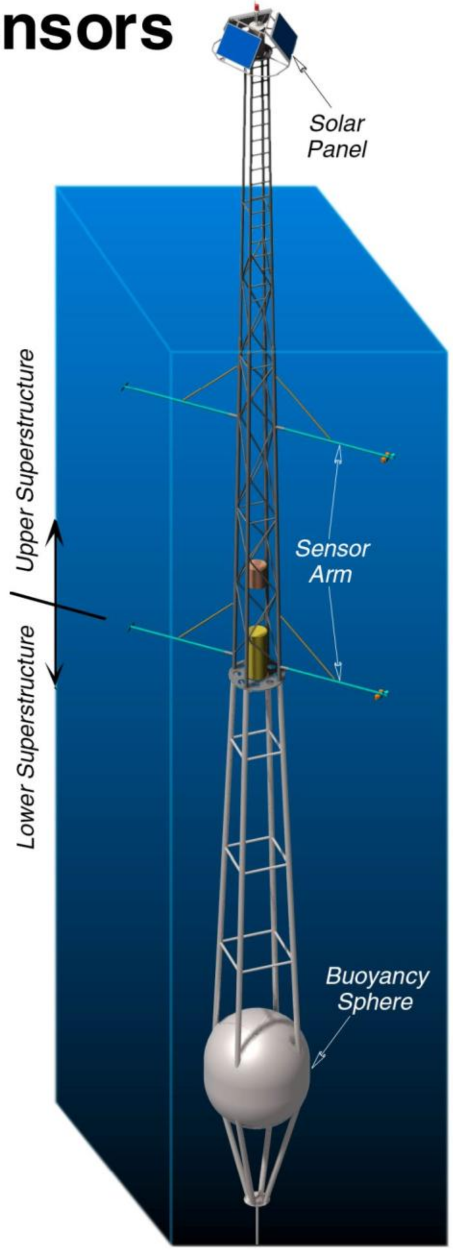
Calibration and Validation Activities Using Commercial Off-the-Shelf (COTS) Sensors

SeaWiFS vicarious calibration gains from three data sources.

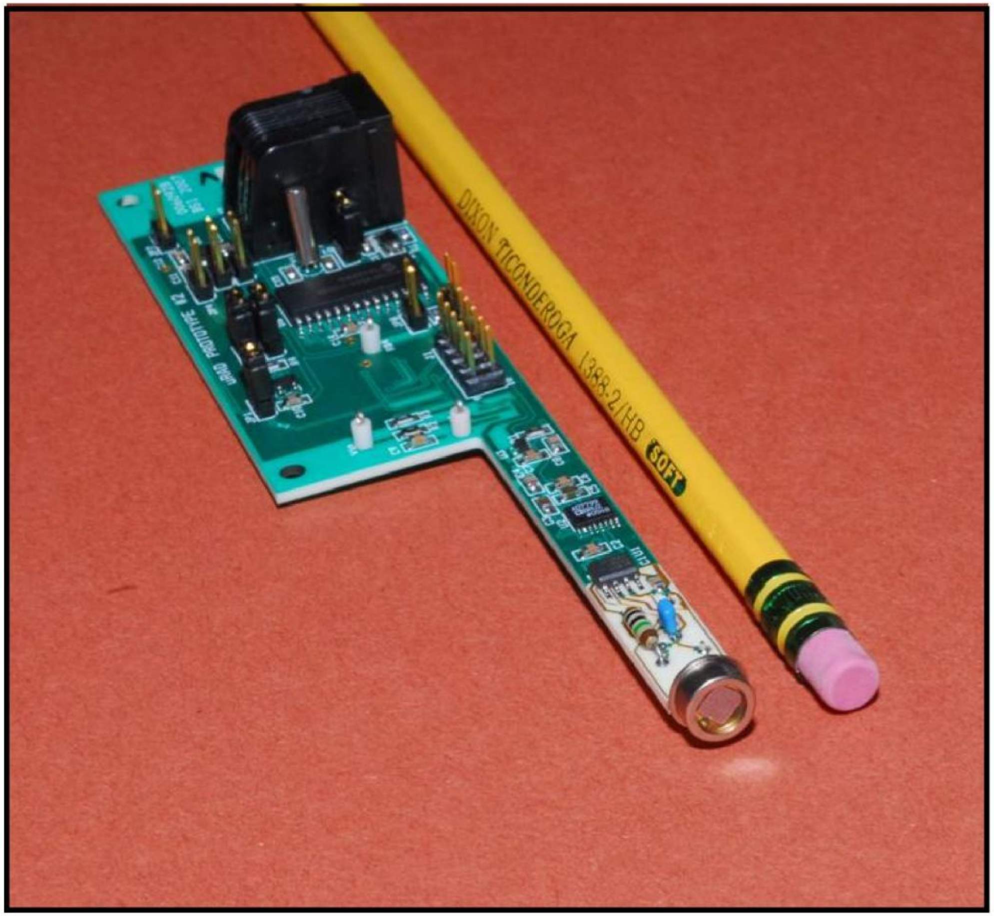
Source	*N*	*412*	*443*	*490*	*510*	*555*	*670*
MOBY	166	1.037	1.013	0.992	0.998	0.999	0.973
CV [%]		1.74	1.78	1.61	1.80	1.80	1.44
NOMAD	64	1.040	1.014	0.997	0.996	0.999	0.969
UPD [%]		0.13	0.01	0.25	-0.10	-0.02	-0.19
BOUSSOLE	46	1.040	1.013	0.996	1.002	1.001	0.967
UPD [%]		0.16	-0.01	0.22	0.17	0.07	-0.29

[Chl *a*] range relaxed for BOUSSOLE data from 0.2 to 0.25 mg m^{-3}.

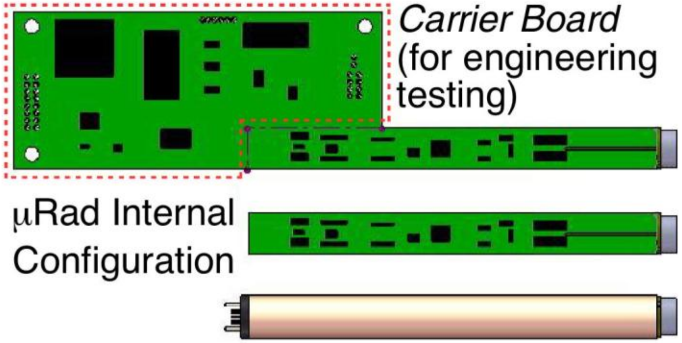
Bailey et al. (2008) used COTS AOP data to show vicarious calibration coefficients derived from both the NOMAD and BOUSSOLE data sets are quite comparable to the standard coefficients derived from MOBY. The agreement between the fixed wavelength COTS radiometers and hyperspectral MOBY results suggest that, *in the absence of hyperspectral radiance data dedicated to the purpose of vicarious calibration, low-cost, and easily deployed instrumentation can serve as source data for the vicarious calibration of ocean color missions*.



Miniaturization of AOP Sensors: *The Development of Machine-Made Microradiometer Detector Systems*



A prototype (hand-made) microradiometer (0.355 in by 3.75 in) with attached carrier board. The latter is needed, because the circuitry of the former is so small, engineering and test data are not easily accessed with standard instrument probes.



Carrier Board (for engineering testing)

μRad Internal Configuration

Completely Functional (networked) Instrument

A 19-channel sensor uses a 2.75 in outside diameter housing. The microradiometer specifications are:

- Machine made, except sleeving and adding fore optics (PRR-800 is mostly hand made),
- 3-gain amplifier with 9.5 decades of dynamic range (PRR-800 is 9),
- 3.5 mA per channel (5.5 mA for PRR-800), and
- 25 Hz data sampling rate for two 19-channel sensors (PRR-800 is 12 Hz).

Exploiting Advances in AOP Sensors for Optically-Complex Waters

The aggregator controls the 19 individual sensors as one sensor and can store the data

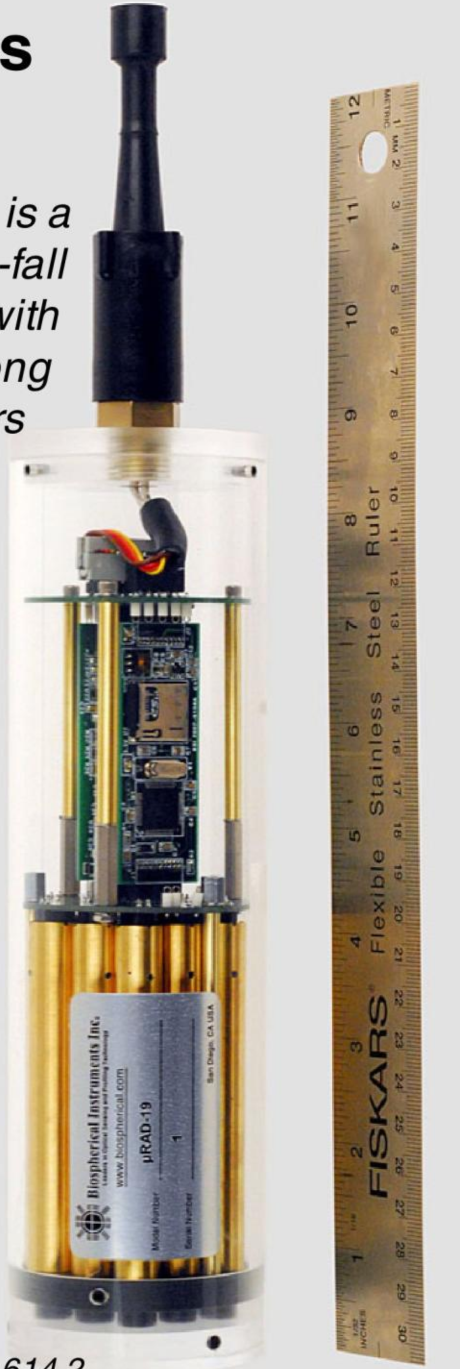
Each brass cylinder is an individual sensor

A 19-channel micro-radiometer fits in a 2.75 in (7.0 cm) cylinder—a 27% size reduction over present instruments

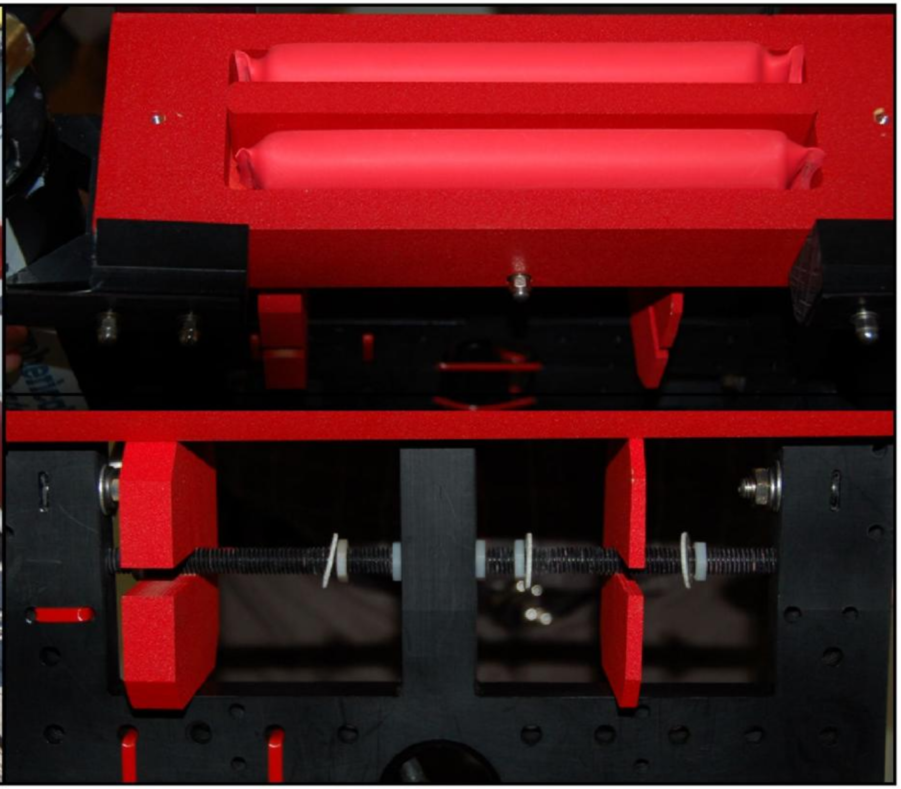
The ICs and the detector set the present size limit

A completely functional (networked) sensor with no fore optics

The goal is a new free-fall profiler with 15 cm long sensors



The Compact-Optical Profiling System (C-OPS):
A 19-Channel Microradiometer Free-Fall Profiler



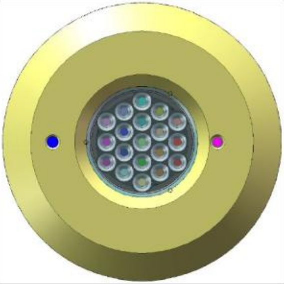
C-OPS uses 2.75 in sensors, and a kite-shaped backplane to improve the stability and vertical sampling resolution as follows: a) the radiometers can be tilted to counteract a pitch bias (e.g., from a current or the cable); b) a hydrobaric buoyancy system based on compressible bladders (top right) allows the profiler to loiter at the surface, slowly sink, and then accelerate to a tunable terminal velocity, *with 1 cm near-surface sampling resolution*; and c) insertible floats can be moved along the long backplane axis to ensure the roll angle is less than 2.5° (bottom right).

Four Classes of Microradiometer Sensors Emphasize Expandability and Quality

- STAR sensors are the smallest sensors available (1.5 in OD).
- Above- or in-water with up to 7 channels (305–1,670 nm).
- Fully functional with XTRA and EPIC radiometers and some EPIC devices (e.g., GPS).
- Small size significantly reduces self-shading effect.

- XTRA sensors are compact with wide spectral coverage (2.75 in OD).
- Above- or in-water with 8–19 channels (305–1,670 nm).
- Fully functional with STAR and *all* EPIC devices including pointing, systems, GPS, shadowband, and ancillary (meteorological) sensors.
- Small size reduces self-shading effect.

- OXR sensors are insulated and temperature stabilized (6.0 in OD).
- 8–18 fixed-wavelength channels (305–1,670 nm) plus a hyper-spectral spectrograph (245–785 nm or 310–1,100 nm).
- Designed for *laboratory use only* (calibration transfer).



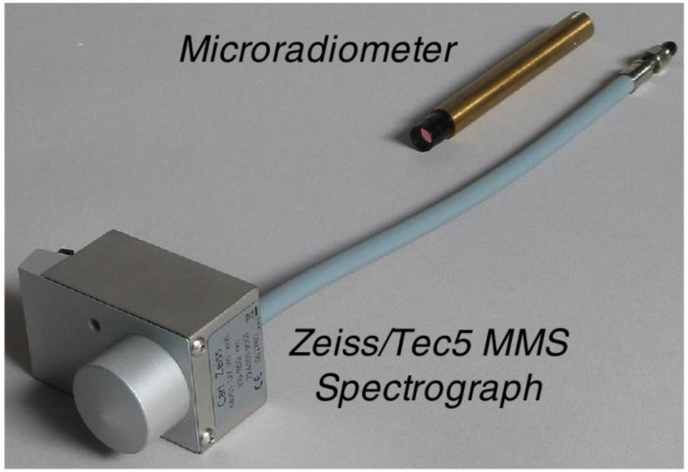
- EPIC sensors are insulated and temperature stabilized (6.0 in OD).
- Above water 8–19 fixed-wavelength channels (305–1,670 nm).
- Hyperspectral spectrograph (same as OXR) and video camera.
- 9-position filter wheel permits hyperspectral polarimetry, Sun viewing, plus improved dark currents and stray-light correction (cut-on filter).

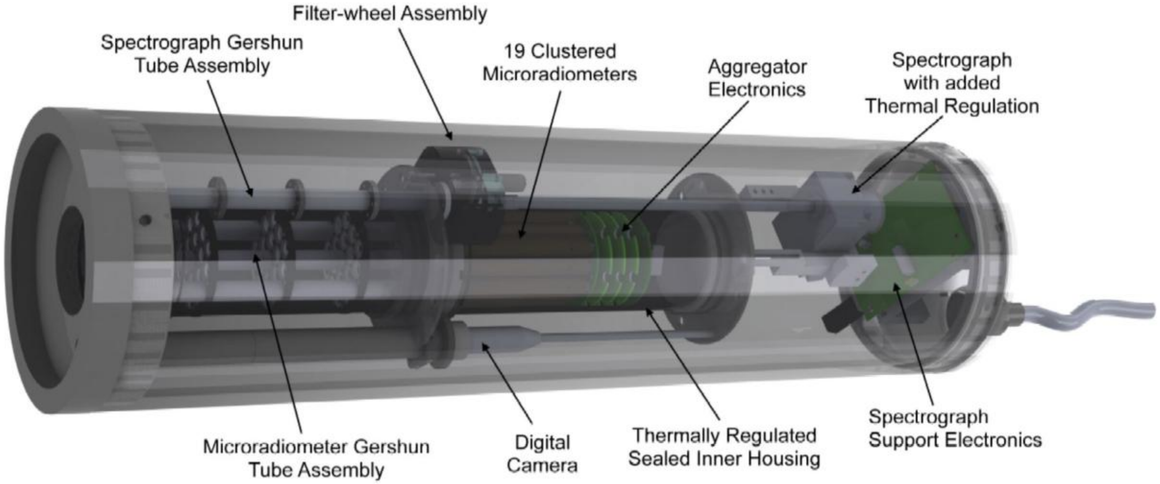
Calibration and Validation for the Next-Generation, Coupled Ocean-Atmosphere Ocean Color Satellite

The next generation of ocean color research emphasizes the coastal ocean and most likely requires simultaneous atmospheric measurements. The types of characterization problems for the spaceborne sensor which must be anticipated (e.g., polarization), are best addressed with an easily replicated system that can be set up at multiple sites in both hemispheres. The latter also permits rapid assessment of a sensor shortly after launch. The dynamic range of some of the problems is more easily fulfilled if calibration data can be acquired in waters more typically associated with validation, so bio-fouling must be minimized.

The Optical Sensors for Planetary Radiant Energy (OSPREy) concept is based on EPIC above-water sensors for vicarious calibration coupled with new XTRA sensors for in-water validation, all of which are commercially available.

OSPREy is Based on Hybrid (Enhanced) COTS Sensors for Atmospheric, Land, and Oceanic Data





OSPREy development phase to be completed in FY11 (no funded field campaigns):

- Hybrid sensors use 19 highly accurate microradiometers to maintain the calibration of a thermally regulated (hyperspectral) spectrograph (with different spectral ranges);
- A full 9.5 decades of dynamic range permits Sun, Moon, sky, and sea viewing;
- NIST SIRCUS traceability with the OXR, calibration maintenance with an FEL lamp library (21 lamps), and calibration monitoring with a portable source (PURLS);
- Filter-wheel provides polarimetry, dark currents, stray-light correction, and Sun data;
- Camera confirms target (Sun) tracking, no clouds, and no sea-surface debris; and
- Single irradiance diffuser covers 305—1,670 nm and shadowband ensures a maximum number of atmospheric data products (with Sun and sky radiance viewing).

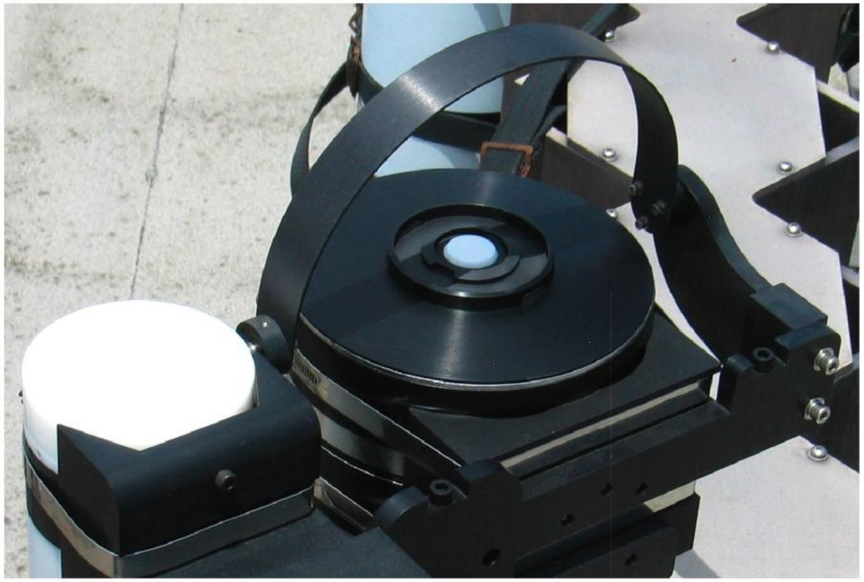
The PTU-D300: Military-Grade Pan-Tilt Unit from Flir Motion Control Systems (San Francisco, CA)

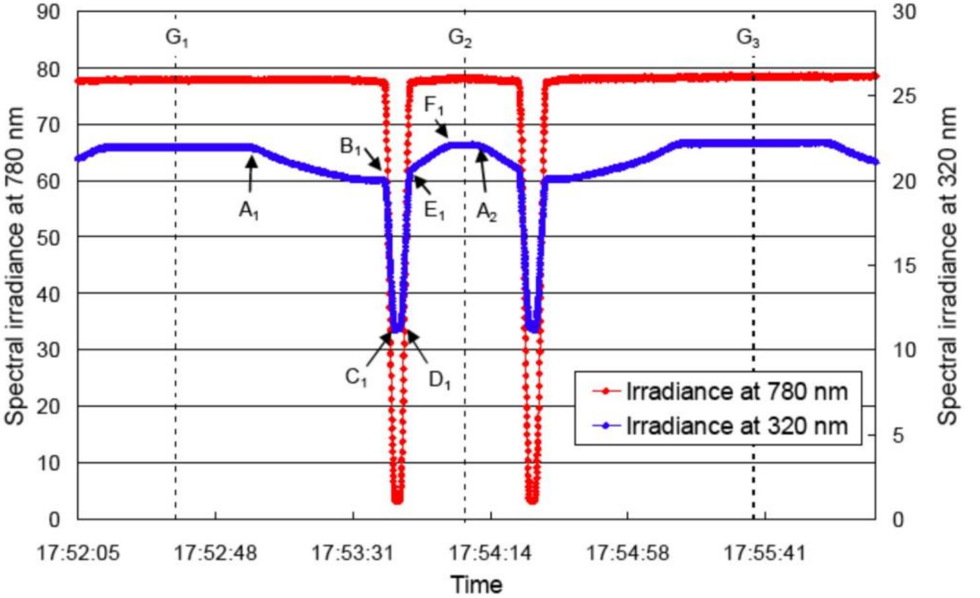
SPOTLITE Sniper Identification System

OSPREy Radiance Sensor Tracking the Sun

The PTU-D300 is a family of modular computer-controlled pan-tilt units designed for fast, accurate positioning of heavy payloads. It provides high torque for payloads up to 70 lbs while maintaining speed, precision, and a small form factor. It is designed for demanding applications requiring up to 100% duty cycles and long life in harsh all-weather environments (it meets the IP67 specifications for wind, rain, and fog). Signals can pass can through slip rings—which means, *no chance for cable hangs*. Testing at Biospherical confirmed its specifications meet OSPREy requirements in terms of tracking accuracy (*which is better than ±0.2°*), resolution, range of motion, speed, payload, power consumption, size, and weather resistance. In addition, its price (about $10K) is substantially lower than comparable systems.

OSPREy Shadowband Already Tested as Part of C-OPS Development (and Includes a GPS Unit)

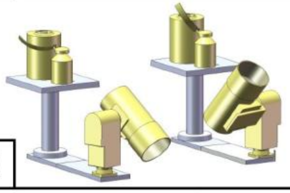
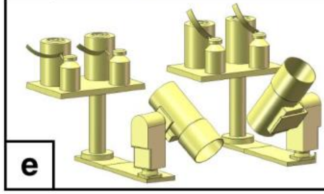




The shadowband instrument is an accessory for solar references that is used to measure the optical properties of the atmosphere. The device may be used with legacy radiometers where it is operated electronically as a separate system, or with microradiometer instruments (e.g., C-OPS) as a fully integrated system, operated over a single cable, and with movement synchronized with the radiometric sampling. Data products include global, direct, and diffuse irradiance, plus the construction of Langley plots. From these measurements, aerosol optical depth can be calculated.

The mounting and cabling configuration also permits the inclusion of a GPS unit, which is operated and controlled as a microradiometer instrument in the C-OPS architecture.

The OSPREy Instrumentation Architecture is Modular and Scalable

 **a**	***Starter System*** • 8 – 19 Channels • One radiance sensor (SeaPRISM analog) • Manual or fixed options	***Measurements, Data Products, and Mission Advantages*** • EPIC sensors expandable to 19 wavebands from 305 – 1,670 nm • Temperature stabilized, hyperspectral, video camera, and seven-position filter-wheel assembly (permits polarimetry) options • Direct solar, sky, sea, and lunar radiance measurements
 **b**	***Minimum System*** • Radiance and irradiance • Some redundancy (both measure the Sun) • Shadowband optional	***All of the Above, and in Addition:*** • Global irradiance plus diffuse component (using shadowband) • Direct-to-global irradiance ratio (used for cosine-error correction) • Improved data products and adds cloud optical depth • Enhanced quality assurance from two solar measurements
 **c**	***Spectral System*** • Two irradiance sensors with shadowbands • One radiance sensor • High accuracy	***All of the Above, and in Addition:*** • Two optimized cosine collectors for high irradiance accuracy (305 – 700 nm and 600 – 1,670 nm) • Up to 38 channels for irradiance or enhanced redundancy • Synchronous and asynchronous shadowband operation
 **d**	***Operational System*** • Up to 38 channels of radiance and irradiance • Synchronous and asynchronous data products	***All of Systems 1 and 2, and in Addition:*** • Redundancy minimizes risk (data loss from sensor malfunction) • Enhanced data products from synchronous sampling scenarios • Detection of thin cirrus clouds from asynchronous scenarios • Maximum fixed wavelength sampling can be optimized instead
 **e**	***Maximum System*** • Two complete triads • Maximum redundancy and spectral coverage • Maximum data quality	***All of the Above, and in Addition:*** • Maximum risk reduction (full instrument redundancy) • Maximum QA and QC (faulty channels can be quickly identified) • Maximum number and quality of data products • Maximum number of synchronous and asynchronous scenarios

OSPREy (EPIC) sensors are inherently scalable (microradiometers) and can be reconfigured to match evolving science objectives or mission resources.

Exploitation of the OSPREy Radiometers on a Very Stabile, Mobile Platform (JOIDES R/V *Resolution*)

The height of the derrick on the R/V *Resolution* is about 200 ft above the water with excellent viewing opportunities of the sea, sky, and Sun. The extraordinary stability of the ship during drilling operations—coupled with the fact that the ship traverses the world ocean—makes the mounting of an OSPREy system on the top of the derrick an intriguing possibility.

Application of Military Surveillance Equipment to Optical Sampling Problems: *The Telescoping Mast*

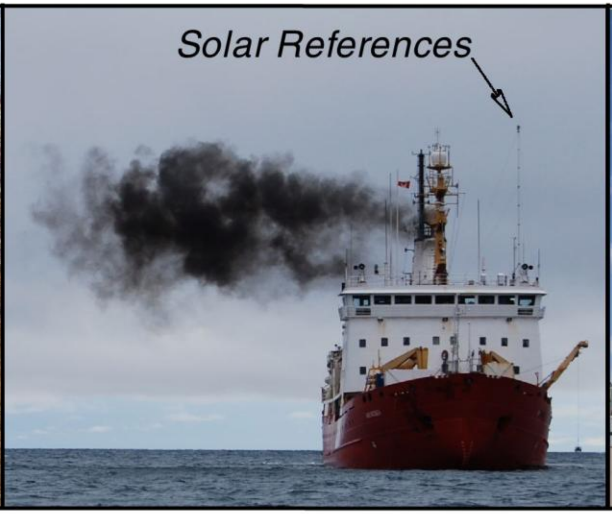


Photo Courtesy S. Ahmed

Working with Floatograph, Inc. (Silver Spring, Maryland), a manufacturer of telescoping masts used by the US Army to deploy surveillance equipment for terrestrial applications, a ship-based capability for raising and lowering solar references was created. When the mast is raised, the sensors are above the highest fixed point on the vessel, so superstructure shading or reflection perturbations are eliminated.

Past experience has shown stack exhaust is a recurring source of contaminants regardless of the height of the sensors. Depending on the size of the mast, when the mast is lowered, the sensors are either immediately accessible or are accessible after the mast is tilted into a cradle. This allows the sensors to be cleaned or serviced (if needed) without the need for specialized safety equipment. It also allows the sensors to be *safeguarded* during hazardous wind and sea states.