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The XRR – An adaptable instrument for optically diverse environments

In July of 2019, Biospherical Instruments Inc (BSI) released the newest member of the Expandable Technology for Radiometric Applications (XTRA) class of high performance field instruments called the XTRA Reflectance Radiometer (XRR). The XRR is an economically priced AOP multiwavelength radiometer belonging to the instrument class that also includes the Compact Optical Profiling system (C-OPS), among other microradiometer-based instruments. Designed to replace the PRR-800-based BioPRO and PRR-2600 profilers, as well as the legacy PRR-600, the XRR uses BSI microradiometer detectors to provide unprecedented sampling speed and wide dynamic range. XRRs are available in two measurement geometries: XRL and XRE. The XRL, the most common configuration (Fig. 1), nominally features ten wavebands of downward irradiance (E_d) and ten wavebands of upwelling radiance (L_u). The XRE nominally uses ten wavebands of downward irradiance (E_d) and 10 wavebands of upward irradiance (E_u).

Figure 1. The XRL is small, lightweight, and easily hand deployed using a free-fall float collar (shown in red). The radiance end of the instrument can be seen at the bottom of the cylindrical housing.

Microradiometer detectors provide high-speed sampling at 17+ Hz (data-frames per second), and wavebands that can be selected from more than 30 available multicavity filters, with center wavelengths between 305 nm in the UV through 1640 nm in the SWIR. Ten decades of dynamic range ensure sufficient sensitivity for work in turbid waters or at larger solar zenith angles than legacy systems. Table 1 presents a sample of spectral combinations that might be useful for a variety of research activities using an XRR configured with 10 wavebands.

Ocean Color	Alg. Dev.	Pri. Prod.	UV Exp.	General Purpose
412	320	412	305	412
443	380	443	313	443
490	412	490	320	490
510	443	510	340	532
520	490	555	380	565
555	510	625	395	589
589	560	670	670	625
625	625	683	683	683
683	780	694	694	710
PAR	875	710	PAR	PAR

Table 1. *Sample waveband combinations for different scientific objectives. XRR microradiometers can be configured with a wide variety of optical filters to support a wide array of diverse activities.*

In Table 1, the Ocean Color column takes advantage of the wavelengths initially used for SeaWiFS data products. Algorithm Development emphasizes end members to detect colored materials. Primary Productivity includes wavelengths useful for fluorescence line height studies. UV Exposure focuses on UVB and UVA wavelengths. The General Purpose filter choices emphasize the distribution of central wavelengths over the solar spectrum.

BSI's XTRA-class instruments, such as the XRR, are based on microradiometer detectors (Booth et al. 2011). Each microradiometer contains its own complete control and acquisition system composed of a microprocessor, 24-bit analog-to-digital converter (ADC), voltage reference, temperature sensor, and electrometer front end. The electrometer is configured with three gains controlling the conversion of current to voltage. A collection of microradiometers, typically sampling different wavelengths, is aggregated into a microradiometer cluster, or instrument, where an electronics package ("aggregator") controls polling and acquisition of signals from each of the microradiometers. Aggregators issue simultaneous start commands to all microradiometers for near-synchronous sampling. The aggregator also contains power conditioning circuitry and data communications interfaces

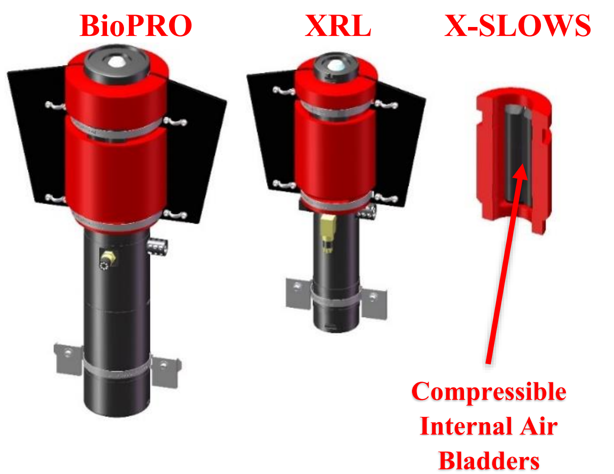

Figure 2. Equally-scaled models of legacy PRR-800 BioPRO (left) in contrast to the new XRL (center). X-SLOWS free-fall collars are all shown in red and with cutaway of the compressible internal air bladders (right) that allow the profiler to loiter near the surface (Hooker et al. 2018).

XRRs all use a 2.75” (7 cm) diameter cylindrical pressure housing. The housing includes all optics and support electronics, as well as water temperature, pressure/depth, and instrument X-Y tilt angle sensors. This package represents a significant decrease in instrument size and mass compared to legacy instruments – the PRR-800 is 33% longer than the XRL, and both the PRR-800 and PRR-2600 have a 45% greater diameter and weigh substantially more than the XRL (Table 2; Fig. 2).

Table 2. *Brief comparison of significant features of the XRL and legacy reflectance profilers.*

Instrument Specification	XRL	PRR-800	PRR-2600
	New 2019	Legacy	
Outside Diameter cm (inches)	7 (2.75)	10 (4)	10 (4)
Length cm (inches)	46 (18)	61 (24)	41 (16)
Weight kg (lb.)	2.1 (4.7)	4.8 (10.6)	3.6 (8)
Optical Waveband Count (Ed/Lu)	10 / 10*	19 / 19	8 / 8
Sampling Speed (Hz)	17+	12	12
Dynamic Range (decades)	10	10	10

**custom configurations are available*

X-SLOWS: The XTRA Surface Loitering Option for Water Samplers

A novel buoyancy control method has been pioneered by BSI called *hydrobaric control* using plastic air bladders located within the foam of the profiler float. The bladders slowly compress as the profiler descends, causing the profiler to descend more quickly with increased depth. Consequently, the profiler sinks slowly when surface effects are greatest and high vertical-resolution data are needed, and more quickly when vertical resolution is not as critical.

X-SLOWS adapts this approach to the XRR instruments, taking advantage of compressible air bladders to provide slow descent speeds near the surface of a profile, and increasing free-fall speeds with depth, allowing hand-held free-fall profiles to 200+ m in a reasonable length of time, but in a significantly smaller and lighter weight package than legacy instruments (Fig. 2; Fig. 3a).

***Figure 3**. **(a)** An XRL with E_d and L_u geometries sharing a single 46 cm long housing. The XRL or the XRE are typically deployed using a unique hydrobaric free-fall collar, known as X-SLOWS (shown in red). X-SLOWS can be optimized for slow descent rates for work in very shallow coastal waters, or faster descent rates for observations in the open ocean. **(b)** An XTRA-class microradiometer deck box supplies power and RS-485 telemetry to the XRR system, and USB communications to the data acquisition computer.*

An AC or battery-powered Microradiometer Deck Box (Fig. 3b) provides system power and serial telemetry to a Windows-based laptop computer or other PC. Biospherical Instruments software is provided, but other data acquisition software that supports similar systems, e.g. C-OPS, is available from third party sources. The deck box can supply power to the profiler and a surface reference sensor independently of AC power, or the system can be connected to its battery charger for continuous operations.

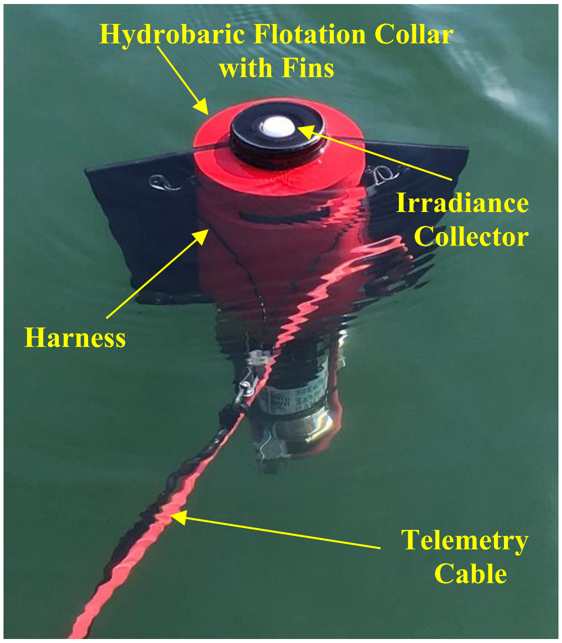

Figure 4. An XRL floats back to the surface after the initial entry into the water. The instrument is near-neutrally buoyant at this stage, and begins sinking very slowly as the internal air bladders compress due to increasing water pressure with depth.

X-SLOWS is ideal for experienced field scientists as well as for students. The single axis design allows for easy adjustment of instrument tilt and descent rate. Adjustable flotation affords near-surface descents of less than 3 cm s^{-1} (Fig. 4), to over 35 cm s^{-1} below 10 m. The ability to reduce descent rate and easily perform repeated near-surface profiles, in conjunction with a high data rate (17+ Hz), allows the XRR to collect usable data in optically complex field scenarios that could previously only be successfully sampled with C-OPS systems.

Solar Surface Reference Radiometer

A radiometrically similar solar reference radiometer is essential for meeting the goals of a variety of research activities, such as calculation of exact normalized water leaving radiance in support of satellite calibration and validation, remote sensing algorithm development, for new or evolving ecological data products, primary production in aquatic systems, and AOP/IOP closure research.

As an XTRA class instrument, the XRRs can use many of the same accessories as C-OPS. For instance, XRRs can use the same XAE surface solar reference as a C-OPS system, including the BioSHADE and BioGPS (Fig. 5). The XAE plugs directly into the microradiometer deck box, and the outgoing data stream is seamlessly integrated by the master aggregator for delivery to the acquisition computer over USB. The XAE is capable of being populated with between 8 and19 microradiometers, providing the most flexibility and highest spectral resolution of any of the XTRA class systems.

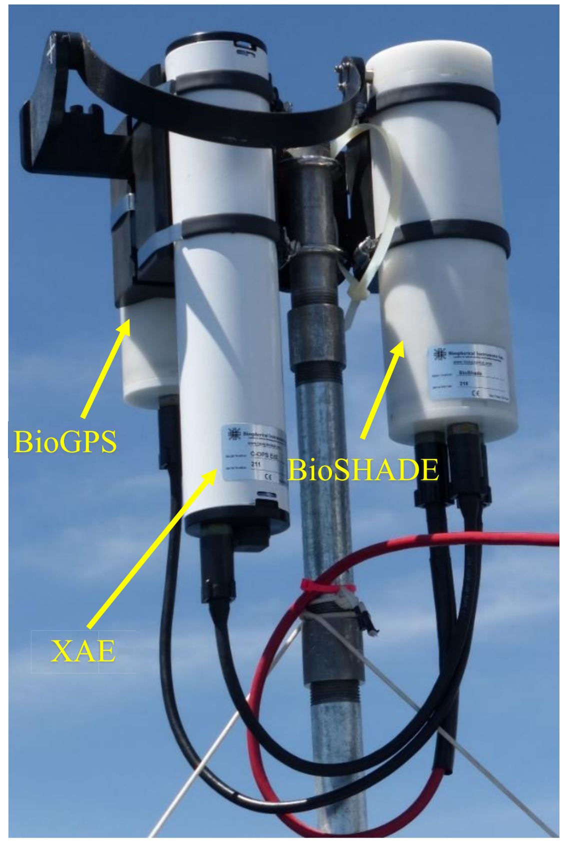

Figure 5. Available accessories for the XRR: the above-water XAE solar reference sensor measures incident global irradiance, Ed0 or E_s. Seen here are also a BioGPS which provides integrated recording of location and time, and a BioSHADE shadow band, which enables measurements of diffuse irradiance to support atmospheric correction algorithms.

References

Booth, C.R., J.H. Morrow, R.N. Lind, and S.B. Hooker, 2010: Development of the Microradiometer. *In:* Morrow, J.H., S.B. Hooker, C.R. Booth, G. Bernhard, R.N. Lind, and J.W. Brown, Advances in Measuring the Apparent Optical Properties (AOPs) of Optically Complex Waters. NASA Tech. Memo. 2010-215856, NASA Goddard Space Flight Center, Greenbelt, Maryland, 42-50.

Hooker, S.B., J.H. Morrow, T. Hirawake, and Maúre, E.R. 2018. The C-SLOWS Accessory for Legacy Profilers. In: Hooker, S.B. J.H. Morrow, R.N. Lind, C.R. Booth, J.W. Brown, K. Suzuki. T. Hirawake, and E.R. Maúre, 2018 Advances in Above- and In-Water Radiometry, Part 1, NASA Technical Memorandum 2018- In Press. P. 43-50.

Specifications

Microradiometer Specifications:

Detectors: Si (13 mm^2), InGaAs (7 mm^2).

ADC: 24-bit bipolar; 125 Hz nominal data rate.

Dynamic Range: 10 decades.

Linearity: Measured on all microradiometers over a signal current range of 1×10^{-12} to 1×10^{-5} A using a programmable light source. Typically, errors are < 1% compared to a reference system electrometer. Gain ratios are individually measured using a computer controlled optical source and programmed into each microradiometer.

Speed: ADC sample rate is typically set to 125 Hz, with averaging over the sampling period performed internally by the microradiometer.

Response Time: Exponential change with a time constant of less than 0.01 s. Time required for gain change is less than 0.1 s.

Electronic Sensitivity: ADC resolution is 0.5 µV with a current resolution of less than 10^{-15} A. The saturation current is 160 µA.

Noise: Si detector typically has 15-20 fA of noise when ADC is sampling at 125 Hz with the internal microradiometer averaging of 25 samples at a data rate of 5 Hz.

Optical Sensitivity: Sensitivity depends on the spectral region and irradiance or radiance geometries. It is expressed as Noise Equivalent Signals. Specifications at 5 Hz for radiance (µW cm^{-2} nm^{-1} sr^{-1}) and irradiance (µW cm^{-2} nm^{-1}) are as follows:

Channel	Radiance	Irradiance
320 nm	2.9×10^{-6}	9.0×10^{-5}
395 nm	5.0×10^{-6}	6.9×10^{-5}
490 nm	1.8×10^{-6}	2.3×10^{-5}
683 nm	9.9×10^{-7}	1.1×10^{-5}
780 nm	6.8×10^{-7}	8.0×10^{-6}

Note: Irradiance and radiance are both adjusted for immersion in water. Note also that both irradiance and radiance sensors may be pointed directly at the solar disk without saturating.

Dark Offsets: Dark offsets are measured and set at the time of calibration for each gain level. Offsets can also be automatically measured and applied in the field to accommodate different temperature regimes.

Microradiometer Power: ± 5 VDC at 4 mA total.

Optical Filters: 10 nm full width at half maximum multicavity ion-deposited interference filters optimized for maximum out-of-band blocking, minimum fluorescence, and long-term stability.

XRR Instrument Specifications:

Cluster Sizes: XRR microradiometers are assembled into collections of 10 wavebands for each end of the single housing. **XAE Surface Reference Instruments** have 8 to 19 available microradiometers under a single irradiance collector optimized for use in air. The following applies:

Diameter: 2.75 inches (7 cm).

Depth: 125 m depth rating standard (less than 1 cm resolution); 300 m versions are available.

Wavelength Selection: Standard wavelengths are selectable from more than 30 wavebands within 305-1640 nm.

Data Rate: User selectable 17+ Hz (data-frames per second); varies with the number of microradiometers attached to the system.

Communications Rate: submersible and surface reference instruments communicate with the deck box at 115,200 baud, using RS485. Deck box communicates with the acquisition computer over USB.

Power Requirements: XRR instrument with 20 wavebands (10 each end): 7.5 V at less than 110 mA.

XRL Radiance Field-of-view: 7.5° half-angle in air; 5.6° in water.

XRE Irradiance Cosine Error: ± 3% for zenith angles smaller than 60°; ± 5% for zenith angles 60-70°, and ± 10% for zenith angles from 70-80°.

Free-fall Speed: adjustable terminal velocity 3 to 35 cm s^{-1}; adjustable pitch and roll.

Ancillary Sensors: Water temperature, water pressure, and instrument tilt angles.

Available Accessories:

BioSHADE: Shadow band accessory for XAE surface irradiance reference sensor.

BioGPS: GPS accessory adds position and time to the data stream.

Custom cable lengths, cable reels, and shipping containers are also available. **Details upon request.**

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