Calibration of NIST's OL455 using the VXR for support of the Field Instrument for Shadowing (FISH)
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The NIST OL455 is an uncalibrated integrating sphere source that is externally illuminated. An iris located between the lamp and the sphere is manually adjusted using a micrometer to control the radiance. An on-axis shutter enables ambient measurements with the lamp still operating. There is a central spider baffle to diffuse the on-axis lamp flux. No sphere housekeeping data are logged, but the front panel displays the output of the photopic-filtered monitor photodiode and the lamp current. The lamp current was locked at 5.505 A dc using the locking ring on the front panel. The OL455 microprocessor automatically slowly ramps the lamp current from off to on and vice versa in order to avoid shock to the bulb. The sphere is 30.5 cm diameter with a 7.62 cm diameter exit aperture. Past experience has found the short term stability to be adequate for studies of radiometer stability. This saves lamp hours on the MLML calibrated sources, the OL420 and OL425. However, it was desired to assign spectral radiance levels to the OL455 so that it could be used as a secondary calibration source. Parr and Johnson 2011 (J. Res. NIST, vol. 116, p. 751 – 760) showed the FWHM and out-of-band response in the six Visible Transfer Radiometer (VXR) channels is adequate to treat the results using a moment analysis, where to first order the VXR results are insensitive to the relative spectral shape of the source.

During HONO13 (aka NIST2012_02) this method was utilized. The NIST Portable Radiance (NPR) source was taken as the reference. The NPR was calibrated on FASCAL March 27 to 29, 2012. Prior to HONO13 (NIST2012_01, May 2 to 4, 2012)[1] and during HONO13 (May 18 and 20, 2012) the VXR measured the NPR a total of nine times. On May 26 during HONO13, the VXR measured the OL455 at four settings of the iris micrometer: 10.0, 9.0, 5.0, and 1.0. Level 10.0 feels "fully past" the open position (resistance to turning the dial decreases) and the radiance is the same as the value at Level 9.0.

The radiances at the VXR wavelengths were found from the ratio of the NPR/OL455 net signals and the NPR radiances from FASCAL interpolated to the VXR wavelengths using Matlab's piecewise cubic interpolation – this method is designed to avoid the wiggles common to cubic spline. Table 1 gives the NPR radiances, and Table 2 gives the VXR/NPR assigned radiances of the four OL455 levels.

Table 1. NPR radiances from the average of the VXR measurements at NIST prior to and during HONO13.

VXR Wavelength	L(λ) uW/cm2/sr/nm
411.64	9.0369
440.97	14.899

[1] All dates and times are GMT.

548.22	48.760
661.10	91.330
775.17	123.48
869.54	135.96

Table 2. Spectral radiance of the OL455 at the four levels determined from the VXR/NPR signal ratios and the NPR (FASCAL) spectral radiances. Note the Level 1.0 is similar to the MLML OL420.

VXR Wavelength	L(λ) uW/cm2/sr/nm			
	10	9	5	1
411.64	2.3325	2.3322	0.99545	0.015595
440.97	4.1736	4.1736	1.7863	0.028229
548.22	15.605	15.604	6.7172	0.10667
661.10	30.997	30.996	13.368	0.21288
775.17	43.390	43.390	18.655	0.29909
869.54	49.799	49.796	21.382	0.34364

The spectral shape of the OL455 does not change much with micrometer setting. Level 9, 5, and 1 are 1.000, 0.429, and 0.00682, respectively, times the OL455 spectral radiance at Level 10, averaged over the six VXR wavelengths. The variability about these ratios is shown in Fig. 1. Level 9 is pretty much identical to 10, and Level 5 shows a spectral dependence of +/-0.5% while Level 1 varies a total of 3 %.

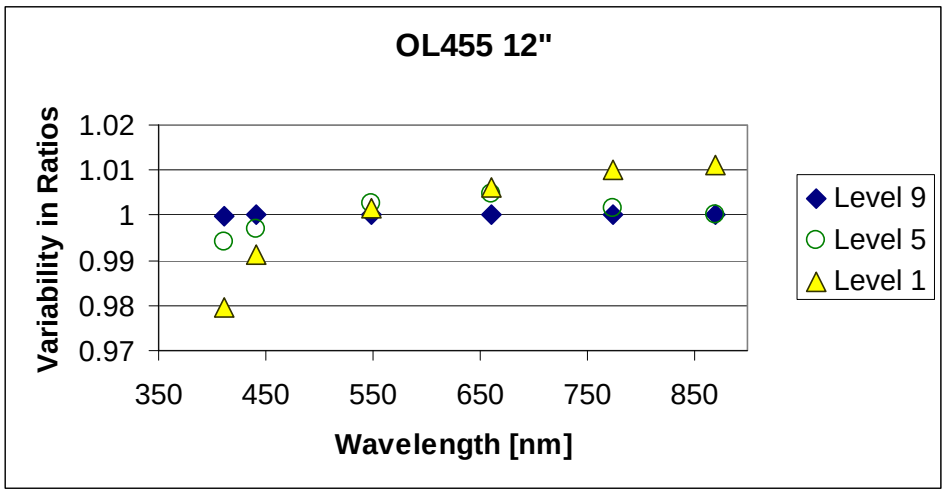

Figure 1. Dependence on OL455 spectral shape with micrometer setting.

When the NPR is used as the reference, not the OL455 Level 10, the spectral dependence of the radiance ratio is much more pronounced. Levels 10, 9, 5, and 1 are 0.319, 0.319, 0.137, and 0.00218, respectively, times the NPR spectral radiance, averaged over the six VXR wavelengths. Figure 2 shows the results. The spectral variability in the OL455 to NPR radiance ratios varies from 0.80 to 1.15, a 35 % change.

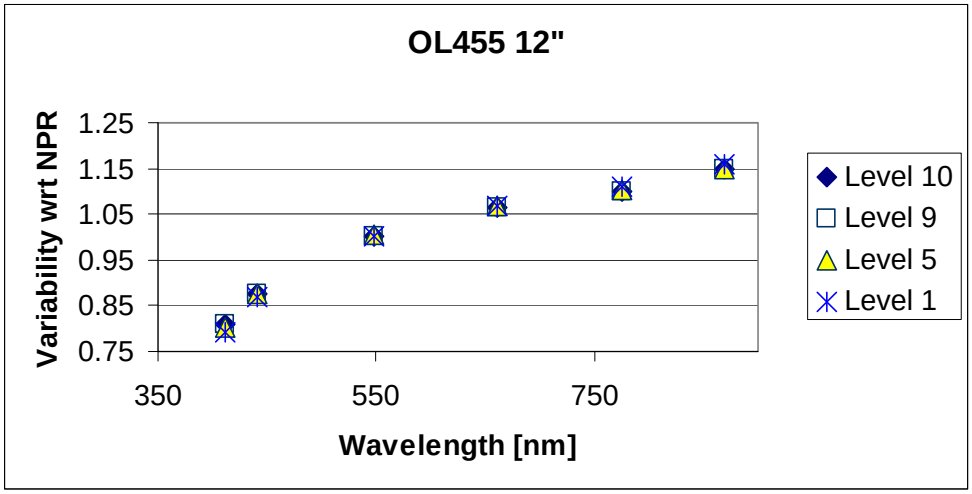

Figure 2. OL455 spectral shape for all four levels vs. NPR.

The spectral radiance of the OL455 was determined from the VXR and NPR data using two different techniques. In the first method, the data in Fig. 2 were fit to a third order polynomial from 330 nm to 960 nm for all 24 results (four levels, six channels). Next the NPR spectral radiances were interpolated onto the desired instrument wavelength grid. Then the OL455 spectral radiance for a particular level was found by multiplying the NPR spectral radiance by the average OL455 to NPR ratio for that level and the polynomial function evaluated at that wavelength. In the second method, the six VXR derived spectral radiances for each level were fit to a blackbody spectral distribution using a single temperature.

The results are given in Figs. 3 and 4, and are compared in Fig. 5.

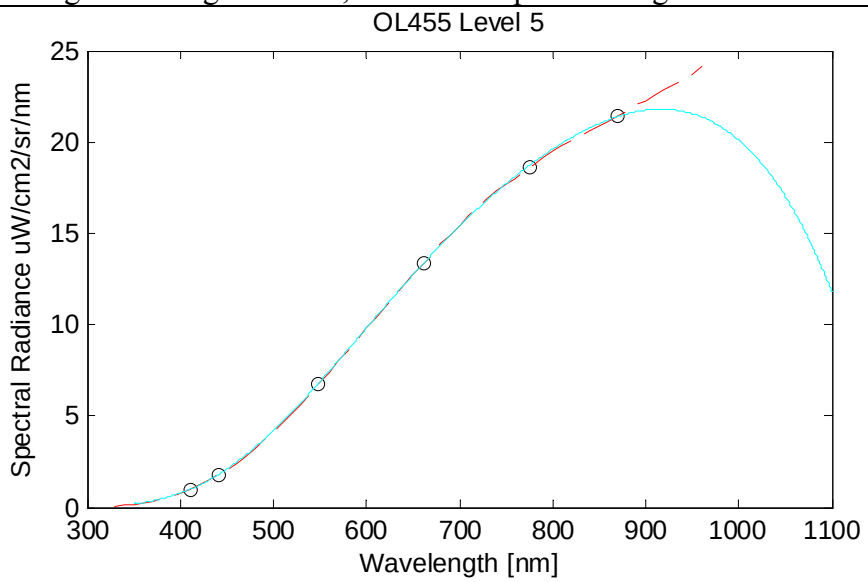

Figure 3. Spectral radiance of the OL455 Level 5 determined at discrete and continuous wavelength values using the VXR/NPR results (circles) and spectral scaling to the NPR radiances (dashed line) or direct blackbody fit to the VXR values (solid line).

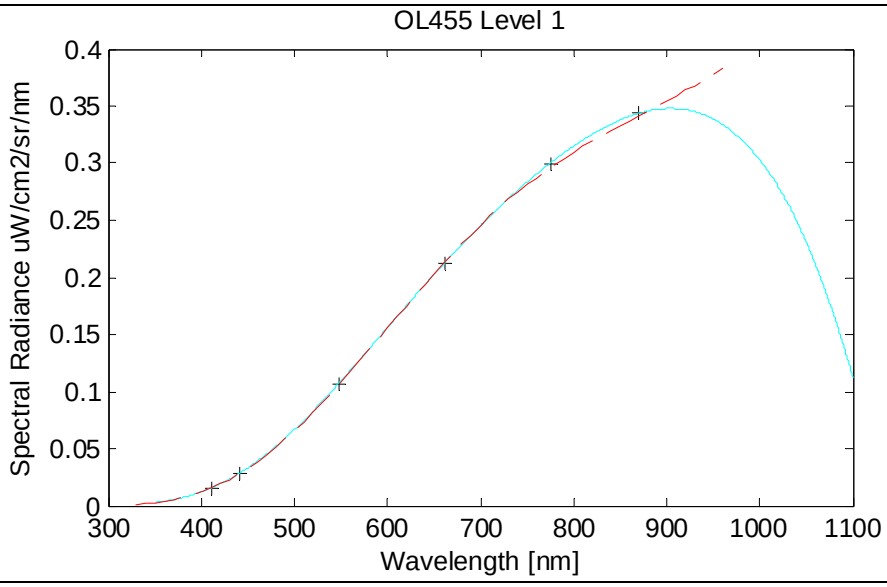

Figure 4. Spectral radiance of the OL455 Level 1 determined at discrete and continuous wavelength values using the VXR/NPR results (circles) and spectral scaling to the NPR radiances (dashed line) or direct blackbody fit to the VXR values (solid line).

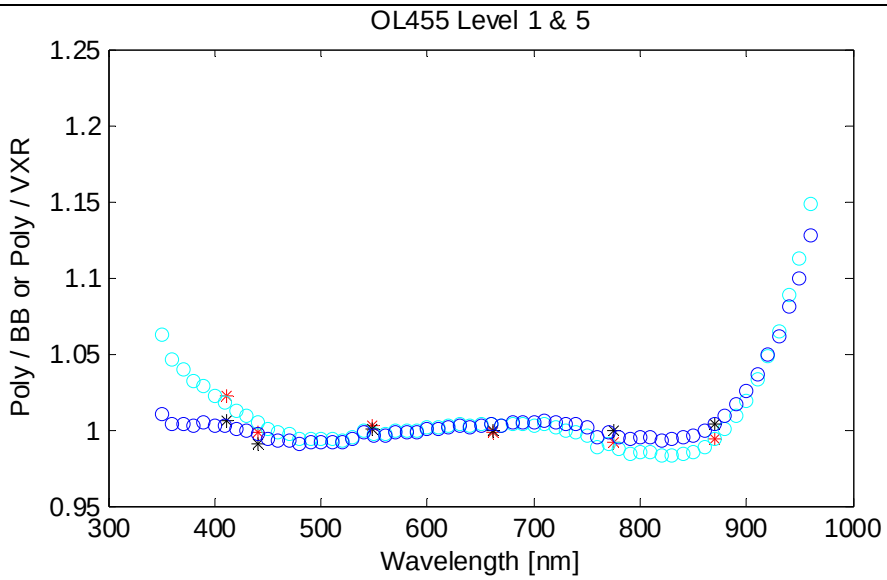

Figure 5. The ratios of the OL455 spectral radiances determined using the spectral scaling polynomial to the blackbody based method from 350 nm to 960 nm (open circles) and the polynomial to the VXR results (stars): Level 5 (blue circles, black stars); Level 1 (cyan circles, red stars).

Between 400 nm and 900 nm the two methods agree for Level 5 to +/- 1 %, and for Level 1 to within +/- 2 %, but outside this range the disagreement is 5 % or greater. This is not unexpected given this corresponds to extrapolation beyond the VXR values. Improvement in the extrapolation regions requires additional constraints. Also note that the polynomial scaling for Level 1 is disparate in the blue; this is expected given the

method assumes both levels scale the same with respect to NPR, but Fig. 1 indicates this is not true.

The uncertainty budget for these OL455 spectral radiance values is given Table 3. The VXR responsivities are known to drift, especially in the first two channels. The VXR drift component was estimated to be the possible amount of drift between May and September. Level 5 is 11 % to 15 % dimmer than the NPR, and Level 1 is 0.17 % to 0.25 % dimmer than the NPR. The VXR linearity was measured in 1996 when the instrument was built, and we assume it has not degraded in its performance since that time. The exit aperture of the NPR is 10.16 cm in diameter, and the exit aperture of the OL455 is 7.62 cm in diameter. The VXR has a size-of-source (SSE) effect that is monitored by acquiring background signal with the lens cap on, and with the lens cap off, but viewing an on-axis central obscuration (disk) that is 7.62 cm in diameter and placed at the sphere source aperture. This disk is slightly oversized from the target area of the VXR at the sphere aperture plane. The difference between the two background values for the NPR is taken as the SSE uncertainty. The measurement uncertainty for the NPR signal is the experimental standard deviation normalized by the square root of the number of measurements (9 sets were averaged). For the OL455, only one measurement was made and we report the experimental standard deviation. All measurements were made with the VXR mounted on a tripod and using a tape measure to set the distance and perpendicularity to the sphere aperture, a level to set the pitch and yaw, and the on-axis VXR sighting channel to align to the target on the center of the sphere's cover apertures. The uncertainty of 0.3 % is based on experience of repeated alignments using this methodology. Experience has shown that spheres such as the OL455, which is coated with barium sulfate, do not exhibit stable reflectance over time, especially in the blue and ultraviolet. We assign an uncertainty for OL455 drift between May and September 2012 based on this experience. The uncertainty related to estimating the spectral radiance from 350 nm to 960 nm was found by using the discrepancies noted above and a uniform probability distribution.

Table 3. Standard uncertainties (k = 1) at the VXR channels for the OL455 Level 1 and 5 spectral radiances for Oahu 13 (September 2012) based on the HONO 13 (May 26, 2012) VXR NPR to OL455 comparison.

VXR Channel	1	2	3	4	5	6
Wavelength	411.64	440.97	548.22	661.10	775.17	869.54
Component						
VXR drift	0.33	0.09	0.05	0.00	0.05	0.07
VXR linearity	0.1	0.1	0.1	0.1	0.1	0.1
VXR SSE	0.09	0.03	0.03	0.02	0.05	0.19
NPR signal	0.05	0.07	0.05	0.04	0.05	0.05
OL455 signal Level 1	0.082	0.031	0.009	0.007	0.004	0.007
OL455 signal Level 5	0.003	0.003	0.003	0.002	0.002	0.001
Align NPR	0.3	0.3	0.3	0.3	0.3	0.3
Align OL455	0.3	0.3	0.3	0.3	0.3	0.3
NPR Radiance	0.54	0.48	0.40	0.35	0.34	0.26
OL455 Drift	0.5	0.4	0.3	0.2	0.1	0.1

L(λ), Level 1	0.29	0.29	0.29	0.29	0.29	0.29
L(λ), Level 5	0.58	0.58	0.58	0.58	0.58	0.58
Combined Standard Unc. (k = 1), Level 1	0.97	0.83	0.73	0.66	0.64	0.63
Combined Standard Unc. (k = 1), Level 5	1.09	0.97	0.88	0.83	0.81	0.80