Hawkeye Radiometric Calibration – The Simple Technique

Alan Holmes

10/11/2017

The radiometric calibration of the instrument is a more complicated subject that might first appear. It is not just a simple matter of pointing the instrument at an integrating sphere and noting the reading. I will outline the steps here:

The Simple Technique

First of all, use measured monochromator data for each band to determine the center wavelength for each band, as well as the spectral bandwidth. The most important parameter as regards radiometric calibration is the center wavelength.

Secondly, we use the instrument to view the sphere. The instrument is mounted close enough to the exit aperture such that each band is fully illuminated. Data is taken at one light level, and dark subtracted. The actual data out of the instrument has 1818 pixels per line, where I call the first pixel "Pixel 1" (not zero). Using the center 21 pixels (908 to 928) as the reference value, tabulate the dark subtracted sphere count values, and then correct these values for linearity to find the value that would have been measured had the instrument been linear at high light levels. Use the equation presented in my report, "Hawkeye Linearity with Light Level – 081117".

Thirdly, we look at the nominal exposure time that was used to collect the sphere data and, using the methodology summarized in my report "HawkeyeExposureTimeLinearity-080917", we calculate what the actual exposure time was for that band.

Fourth, we correct the calculated counts per millisecond to a temperature of 35 degrees C. The units tend to run warm so we chose 35C as closer to our room temperature average. Use the data presented in my report "Temp Effect Summary – 081417".

Fifth, we use this value, in conjunction with the sphere radiance, to calculate the counts per millisecond per Rad Unit (a rad unit is 1 watt per meter squared per steradian per micron). This is the on-axis calibration value of the instrument.

Sixth, the filter data shows a shift to shorter wavelengths for off-axis points. We use this data to produce a generic equation for wavelength as a function of angle. The wavelength shift follows a quadratic equation.

Seventh, for each band we calculate the sphere calibration shift that would result just from the wavelength shift for the sphere.

Eighth, we use the dark subtracted flat field data for each band, corrected by the sphere calibration shift, to calculate a relative radiometric calibration for each pixel. This relative data for each pixel, multiplied by the on-axis calibration value, is the final calibration of the instrument.

The More Accurate Technique

The simple technique works well for bands 1 to 4, to 1% accuracy. However, bands 5 to 8 have the problem of the exposure time non-linearity correction. It turns out the flat field response pattern is completely different between the direct path and the leakage path, and the leakage path is much more irregular. This means the best flat field is a function of exposure time, and cannot be calculated without knowledge of the exposure time. We can use the sphere data collected with different exposure times to solve two equations in two unknowns to derive a flat field file for each path, and then merge them to a combined flat field for the exposure used in the instrument. I will expand on this in a later report. First let me work through an example for the simple technique.

Wavelength Shifts: Band center wavelength and passband widths are shown in Table One below for both units. This was measured using a monochromator at the instrument level, with the monochromator scanned a 0.5 nm increments, and a calibrated photodiode for a reference. A LOT of numbers are used to derive each value below!

Table One: Band Center Wavelengths and Passbands

Unit One Filter Summary:								Wavelength
	Nominal	Center Wavelengths (nm)			PassBand Widths (nm			shift with
Band	Wavelength	Pixel 918	40	1796	Pixel 918	40	1796	Pixel
1	412	411.91	409.05	409.07	18.38	19.52	15.68	0.9931
2	443	446.97	445.06	444.03	21.85	19.02	19.95	0.9946
3	490	487.06	485.32	484.64	18.50	19.27	18.29	0.9957
4	510	510.97	507.83	507.84	18.99	19.80	19.49	0.9939
5	555	555.56	551.20	551.29	20.39	19.06	19.00	0.9922
6	670	670.85	667.02	666.98	19.88	20.26	19.24	0.9943
7	751	751.19	746.54	747.39	16.19	17.00	15.33	0.9944
8	865	863.85	859.93	860.32	34.75	35.02	34.16	0.9957
							Average:	0.9942

Unit Two Passband Summary:								Wavelength
	Nominal	Center Wavelengths (nm)			PassBand Widths (nm			shift with
Band	Wavelength	Pixel 918	40	1796	Pixel 918	40	1796	Pixel
1	412	412.97	409.66	409.80	16.51	19.02	15.48	0.9922
2	443	447.37	444.89	445.65	19.13	17.04	15.82	0.9953
3	490	488.11	486.02	486.26	20.46	21.92	20.51	0.9960
4	510	509.55	507.63	507.25	20.65	19.79	20.17	0.9959
5	555	556.69	552.63	552.23	19.41	18.32	18.17	0.9924
6	670	670.37	666.64	666.61	18.64	18.77	18.04	0.9944
7	751	751.42	747.35	746.94	13.61	13.43	13.93	0.9943
8	865	865.79	861.70	862.31	36.60	35.65	37.05	0.9956
							Average:	0.9945

As you can see, the passband shift with wavelength is consistent between the two units. I will use an average of the averages, 0.9944, for 878 pixels, for all filters.

The 12 NASA integrating sphere radiance is shown in Figure One. Figure Two shows the response shift per nm as a function of wavelength. The sphere radiance increases with increasing wavelength over this range.

Figure One: 12 NASA Traveling Sphere Radiance as reported by John Cooper on 4/10/17

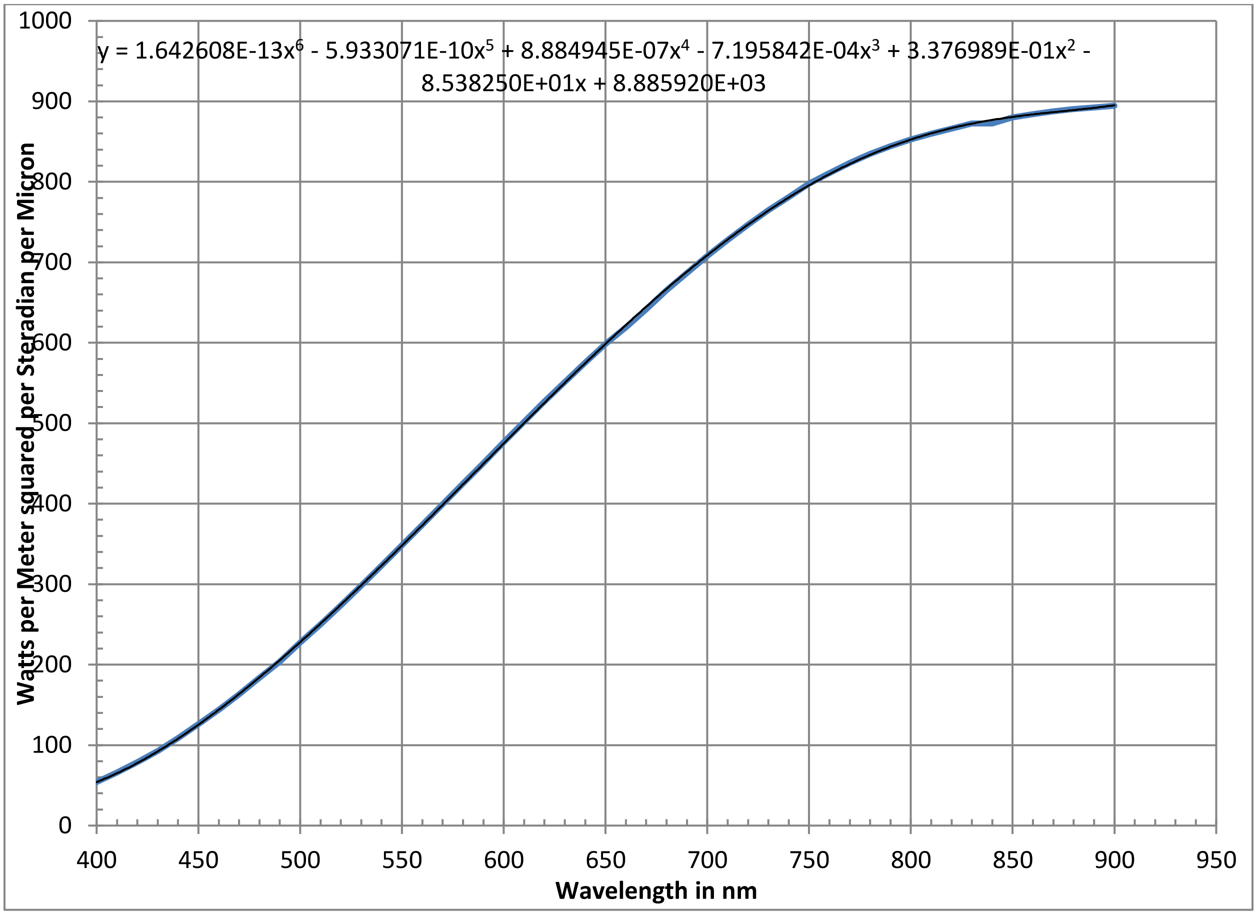

Figure Two: Radiance Increase in Percent per nm

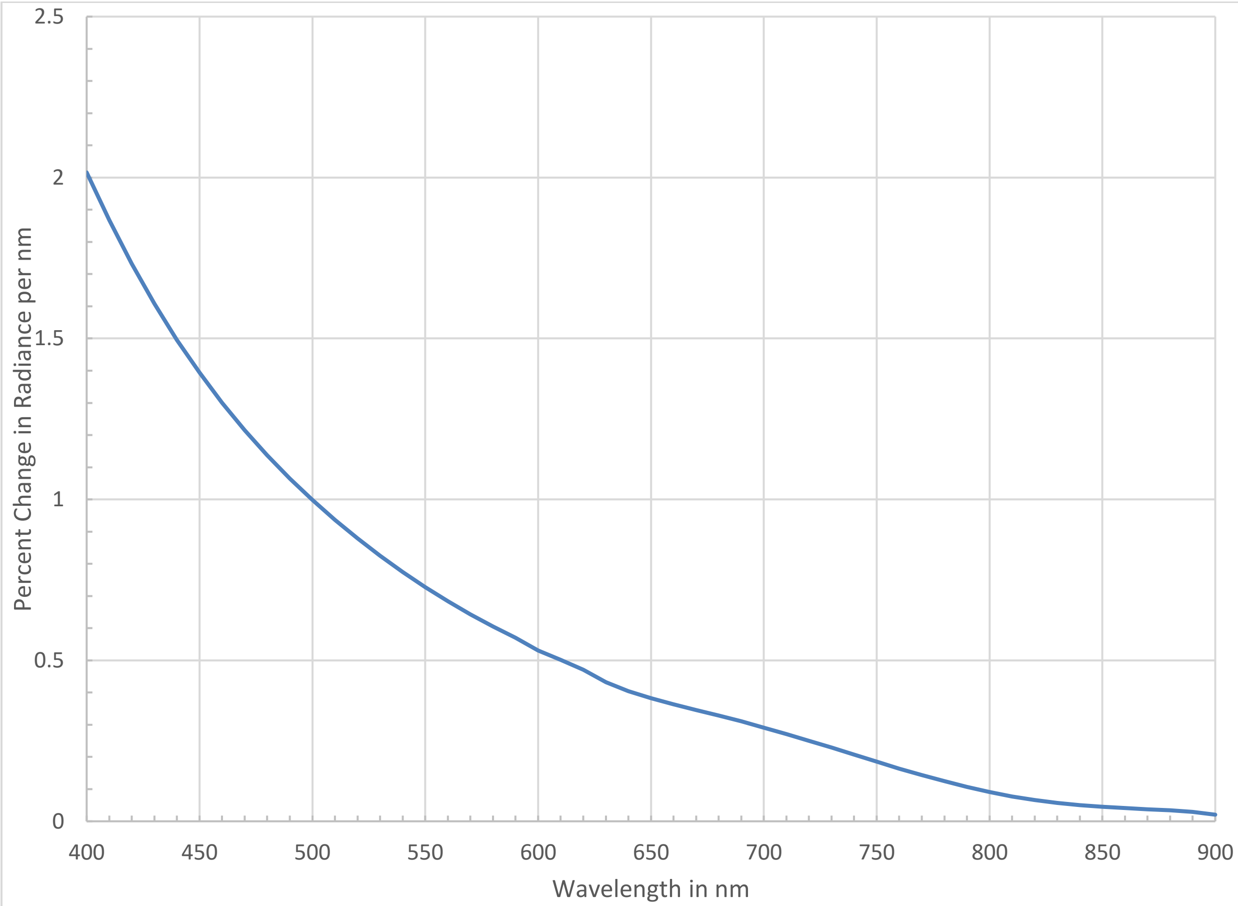

Table Two shows the radiance and percentage radiance shift per nm for Units One and Two, as well as the total percent drop in the sphere radiance (due to the wavelength shift toward shorter wavelengths) at the edges of the array. In other words, for Unit Two, Band 1, a 4.22% drop at the edges occurs because the sphere is dimmer at the shorter wavelength. With a spectrally flat source this drop would not occur. For best accuracy we would use the actual target spectral distribution in this calculation, but here we are correcting as if the atmosphere/ocean radiance was spectrally flat.

Table Two: Radiance and Percentage Radiance Shift – Radiance Units are Watts per Meter Squared Per Steradian per Micron

Unit One CW	Radiance	Percent per nm	Total Percent Drop At Passband Edges
411.91	68.19	1.840	4.24
446.97	120.39	1.427	3.57
487.06	198.36	1.084	2.96
510.97	252.33	0.927	2.65
555.56	362.36	0.701	2.18
670.85	644.39	0.344	1.29
751.19	798.85	0.182	0.77
863.85	885.28	0.031	0.15

Unit Two CW	Radiance	Percent per nm	Total Percent Drop At Passband Edges
412.97	69.53	1.826	4.22
447.37	121.07	1.423	3.57
488.11	200.62	1.077	2.94
509.55	249.00	0.936	2.67
556.69	365.24	0.696	2.17
670.37	643.32	0.345	1.29
751.42	799.19	0.181	0.76
865.79	885.96	0.030	0.15

The equation for the percent drop per pixel value, assuming the center pixel is Pixel 918, is:

Percent Drop at PixelNumber = Total Percent Drop at Edge *(918-PixelNumber)^2 / 770884

This equation should be used to correct the flat field data.

Instrument Counts when viewing Sphere: Table Three A and B lists the dark subtracted number of counts recorded by each instrument, the exposure time used, and the corrected exposure time. It also includes the linearity correction, and the temperature correction. This data is based on the last sphere calibration at Cloudland.

Table Three-A: Unit 1 Corrected Counts per millisecond

PostTV-FlatFieldData-061217				Factor					Derived			Percent	Counts
Unit 1	Raw			to correct	Exposure	Row	Over-	Leakage	Exposure	Counts	Temp	Change	per ms
Band	Counts	Dark	Counts	linearity	Time (ms)	Rate (ms)	Sampling	Factor	Time (ms)	per ms	(Deg C)	Per Deg C	at 35 C
1	14240	1029	13211	0.997	8	35	4	0.0023	8.020	1642	32	0.0184	1643
2	32190	1044	31146	1.011	8	35	4	0.0045	8.040	3918	32	-0.0696	3909
3	27432	1035	26397	1.007	3	15	4	0.0096	3.036	8759	34	-0.0418	8755
4	38063	1046	37017	1.016	3	15	4	0.0132	3.050	12333	34	-0.0322	12329
5	14772	1008	13764	0.997	0.6	5	2	0.0144	0.636	21578	35.5	-0.0148	21579
6	28783	1015	27768	1.008	0.6	5	2	0.0415	0.704	39790	35.5	0.0300	39784
7	27318	1008	26310	1.007	0.6	5	2	0.0630	0.758	34982	35.5	0.0799	34968
8	44834	1016	43818	1.022	0.6	5	2	0.0863	0.816	54868	35.5	0.2097	54810

Table Three-B: Unit 2 Corrected Counts per millisecond

LastRadCalWithND-071017				Factor					Derived			Percent	Counts
Unit 2	Raw			to correct	Exposure	Row	Over-	Leakage	Exposure	Counts	Temp	Change	per ms
Band	Counts	Dark	Counts	linearity	Time (ms)	Rate (ms)	Sampling	Factor	Time (ms)	per ms	(Deg C)	Per Deg C	at 35 C
1	14780	1130	13650	0.997	8	36	4	0.0039	8.035	1694	44.3	0.0000	1694
2	29345	1132	28213	1.009	8	36	4	0.0056	8.051	3535	44.3	-0.0666	3557
3	28394	1084	27310	1.008	3	15	4	0.0099	3.037	9065	43.7	-0.0296	9089
4	38170	1084	37086	1.016	3	15	4	0.0137	3.051	12350	43.7	-0.0141	12365
5	27371	1070	26301	1.007	1.25	5	2	0.0156	1.289	20554	43.5	-0.0136	20578
6	47027	1081	45946	1.023	1.25	5	2	0.0433	1.358	34618	43.5	0.0333	34520
7	24315	1062	23253	1.005	0.6	5	2	0.0611	0.753	31037	43.5	0.0649	30865
8	42501	1067	41434	1.020	0.6	5	2	0.0808	0.802	52673	43.5	0.2033	51763

Calculation of On-Axis Calibration Values: the sphere calibration data is used in conjunction with the data of Table Three to find the on-axis calibration for the instrument.

Table Four: On-Axis Instrument Calibration

						Unit 1	Unit 2
	Unit 1	Unit 2		Unit 1	Unit 2	Counts/ms	Counts/ms
	Counts	Counts		Sphere	Sphere	per	per
	per ms	per ms		Radiance	Radiance	Rad Unit	Rad Unit
Band	at 35 C	at 35 C					
1	1643	1694		68.19	69.53	24.09	24.36
2	3909	3557		120.39	121.07	32.47	29.38
3	8755	9089		198.36	200.62	44.14	45.30
4	12329	12365		252.33	249.00	48.86	49.66
5	21579	20578		362.36	365.24	59.55	56.34
6	39784	34520		644.39	643.32	61.74	53.66
7	34968	30865		798.85	799.19	43.77	38.62
8	54810	51763		885.28	885.96	61.91	58.43

Finally, one must apply the flat field data, corrected by the wavelength shift effect, to determine the relative response at any pixel number. Below I illustrate in Figure Three the flat field file for Unit Two, Band 8, to show the magnitude and spatially rapid variation of this data. As dust particles come and go in orbit, or the instrument ages, this data can be expected to change. As noted before, this is the simple technique, which is good enough for radiometry but not if one wants the smoothest possible data. The complex technique will be discussed in another technical report.

Figure Three: Unit 2 Band 8 Relative Response (Flat Field)– Simple Version