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The Sixth SeaWiFS/SIMBIOS Intercallibration Round-Robin Experiment (SIRREX-6) August–December 1997

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ABSTRACT

For the sixth Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) Intercallibration Round-Robin Experiment (SIRREX-6), NASA personnel carried the same four Satlantic in-water radiometers to nine separate laboratories and calibrated them. Two of the sensors were seven-channel radiance heads and two were seven-channel irradiance heads. The calibration and data reduction procedures used at each site followed that laboratory's normal procedures. The reference lamps normally used for the calibration of these types of instruments by the various laboratories were also used for this experiment. NASA personnel processed the data to produce calibration parameters from the various laboratories for comparison.

These tests showed an overall agreement at better than the ± 2% level. Analysis of each laboratory's efforts and specific data handling procedures are included.

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FIGURES

TABLES

1. INTRODUCTION

This document details SIRREX-6. It describes the test equipment, calibration procedures, and data reduction procedures that were used. The Data Analysis section documents data collection at the participating laboratories and gives specific software procedures.

The full names of the participating laboratories are given in table 1 and repeated in appendix A with addresses and points of contact.

SIRREX-6 was performed in a completely different manner from SIRREX-1 through SIRREX-5. In those tests, laboratory references were brought to a central location and tested against one another. In SIRREX-6, four commonly used field instrument were taken to each laboratory and tested using the laboratory's standards and procedures.

Conclusions drawn from this effort and suggestions for future SIRREX efforts are given at the end this document.

2.1.1 Field of View of Radiance Heads

The laboratories provided the plaque or integration sphere for the radiance tests.

The plaque had to be large enough and the instrument close enough so that the field of view of the instrument lay on the plaque. The 99% field of view for the irradiance heads is an ellipse 450 mm (17.7 inches) by 300 mm (11.8 inches) when the head is set at 300 mm from the plaque at an angle of 45°. The instrument center line passes through one focus of the ellipse and is therefore off center.

Some laboratories had plaques large enough (650 mm, 25.6 inches) to cover this ellipse with the instrument center line on the center of the plaque. Most laboratories adjusted the setup to more closely center the ellipse on the plaque. Standard procedures used by the laboratory were employed where they existed.

Table 1. Participating Laboratories

1.	Satlantic	Satlantic Inc.	August 11, 1997
2.	GSFC	Goddard Space Flight Center	August 20, 1997
3.	PML	Plymouth Marine Laboratory	September 8, 1997
4.	JRC-SAI	Joint Research Center	September 17, 1997
5.	CHORS	Center for Hydro-Optics & Remote Sensing	October 2, 1997
6.	Biosphere	Biospherical Instruments	October 3, 1997
7.	UCSB	University of California at Santa Barbara	October 4, 1997
8.	NRL	Naval Research Laboratory	November 6, 1997
9.	GSFC	Goddard Space Flight Center	November 21, 1997
10.	DLR	Institut für Weltraumsensorik	September 12, 1997
11.	WFF	Wallops Flight Facility	December 2, 1997
12.	GSFC	Goddard Space Flight Center	February 19, 1998

2. SIRREX-6 TEST PROCEDURE

For SIRREX-6, NASA personnel carried the same four Satlantic in-water radiometers to nine separate laboratories and calibrated them. The calibration procedures used followed the individual laboratory's normal procedures and lamps for calibrations of these types of instruments. Variations from the standard procedures are covered in section 3.3 and section 3.4.

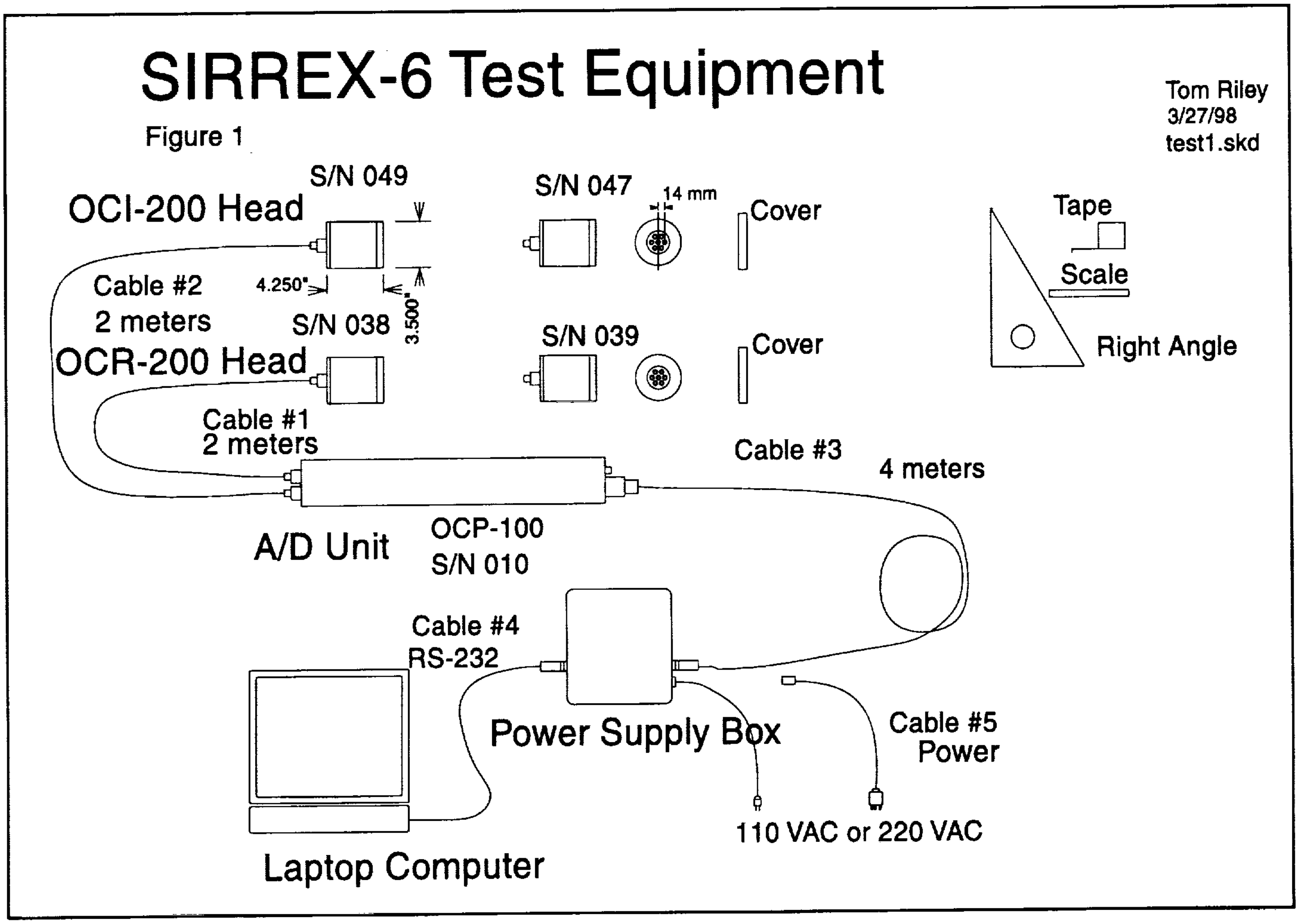
2.1 Instruments

The instruments used for the SIRREX-6 are shown in figure 1 and listed in table 2. The choice of Satlantic radiance and irradiance sensor heads was based upon their availability and ubiquitous use within the ocean color community.

Table 2. Hardware Used for SIRREX-6

2 — Satlantic OCR-200, in-water, 7 sensor, Radi ance, S/N 038 and S/N 039 (a cylinder 3.5 inches in diameter and 4.25 inches long)
2 — Satlantic OCI-200, in-water, 7 sensor, Irradi ance, S/N 047 and S/N 049
1 — Satlantic in water A/D unit, S/N 10
1 — Laboratory Interface and Power Unit
Cables:
- 2 — Sensor Head to A/D, 2 meters
- 1 — A/D to Deck Interface Unit, 5 meters
- 1 — Deck Interface Unit to Lap Top, 1.5 meters
- 2 — AC Power Cables, 1.5 meters

1 — Laptop computer with control and acquisition hardware loaded
2 — Metric rule and a right angle
3 — Carrying cases



A second data set was also taken with the head rotated 180 degrees around the optical axis. The field of view of the channel closest to the lamp is most likely to extend off the plaque, while the channel farthest from the lamp is nearly always completely on the plaque. The center channel, the two top channels, and the two bottom channels should show little change with the 180° rotation. A significant difference between the near and far channels would have been interpreted as evidence that part of the field of view was off the plaque. No significant variation of this type was found.

For the case where laboratories used integrating spheres for the calibration of the radiance sensors, the position of the radiance head relative to the sphere was critical. The radiance heads needed to be positioned such that the field of view of the head saw only the aperture of the sphere. If the head was placed too far from the sphere aperture, the field of view of the head would include a portion of the external face of the sphere and radiance values would be abnormally low.

In the opposite situation, if the head was positioned too close to the sphere aperture, the quartz face of the radiance head reflected a significant amount of light back into the sphere. The total reflectance from both sides of the quartz window and the surrounding black aluminum can amount to 3% of the light falling on the face. If this light reenters the sphere it is reintegrated and increases the observed radiance values. At greater distances the head face fills a smaller portion of the sphere's illuminated field, and less light is reflected back at the smaller angles. For most spheres examined in this study, the sphere-to-radiance head distance fell between 200 mm and 500 mm.

2.1.2 Spectral Characteristic of Heads

The Center Wavelength (CWL) for each of the seven filters on each instrument is given in table 3 through table 6 below. Three different values are given. The wavelength calculation approach normally used at a laboratory was applied.

Table 3. Spectral Dependence of Head S/N 049

CWL[a] 20 Degree Cone	CWL[b]	Centroid[c]	Radiance[d] Full Scale
OCI-200 S/N 049			
411.0	411.90	411.60	N/A
442.8	443.78	445.25	N/A
490.4	491.40	490.85	N/A
509.3	510.38	510.70	N/A
554.6	555.65	554.10	N/A
665.5	665.72	665.25	N/A
682.7	684.02	683.55	N/A

Notes:

(a) The spectral dependence tests for these filters were run with a very narrow field-of-view instrument. This Center Wavelength with 20 Degree Cone value included a slight blue shift attributed to rays entering the instrument from wider angles. The units are nm.

(b) This Center Wavelength (CWL) was calculated with Full Width Half Maximum (FWHM). The units are nm.

(c) This Centroid is the center wavelength calculated from the entire area under the curve. The units are nm.

(d) The Radiance Full Scale value in air is used to set the maximum output for radiance tests with integration spheres. Units are uW/cm^2/nm/Sr.

Table 4. Spectral Dependence of Head S/N 038

CWL[a] 20 Degree Cone	CWL[b]	Centroid[c]	Radiance[d] Full Scale
OCR-200 S/N 038			
411.3	411.90	411.60	2.78
443.0	433.78	445.25	2.82
489.0	491.40	490.85	2.81
509.7	510.38	510.70	2.87
554.1	555.65	554.10	2.90
665.9	666.72	665.25	1.24
682.8	684.02	683.55	1.11

Table 5. Spectral Dependence of Head S/N 047

CWL[a] 20 Degree Cone	CWL[b]	Centroid[c]	Radiance[d] Full Scale
OCI-200 S/N 047			
411.0	411.92	411.55	N/A
442.5	443.50	442.35	N/A
489.9	490.90	490.90	N/A
509.4	510.48	511.10	N/A
554.6	555.72	552.60	N/A
665.8	666.95	665.40	N/A
682.8	684.10	684.60	N/A

Table 6. Spectral Dependence of Head S/N 039

CWL[a] 20 Degree Cone	CWL[b]	Centroid[c]	Radiance[d] Full Scale
OCR-200 S/N 039			
411.5	412.38	411.8	2.74
442.9	443.85	443.70	2.65
489.7	490.70	490.55	2.71
509.6	510.68	510.85	2.89
554.2	555.33	552.30	2.92
665.7	666.90	665.43	1.27
682.9	684.22	684.80	1.15

2.1.3 Equipment Furnished by Laboratory

The laboratory supplied:

1. Mounting for Head — This was either a pair of rings with three adjustment screws that can handle a 3.5 inch (90 mm) cylinder, 4.25 inches (115 mm) long centered in the light path, "V" blocks, or a vise. An adjustable stage was also commonly used to control the height of the head.

2. Alignment Equipment — The equipment normally employed by the laboratory to align sensors. This generally included a laser, a lamp replacement cross hair, and front surface mirrors.

The heads were aligned with its central axis on the optical axis. Some laboratories also offset the head and aligned each input aperture in turn. This procedure had very little effect on the calculated values.

3. Lamp — The reference lamp that was normally used by the laboratory. The laboratory provided a valid calibration report for the lamp used. Some laboratories did the interpolation calculations to the specific sensor wavelengths

themselves. For the others the four point Lagrange method developed by NIST was used (see section 3.4).

4. Diffuser Plaque — The diffuser plaque normally used by the laboratory. The laboratory provided a valid calibration report for the plaque. The four point NIST procedure was used for interpolation.

5. Integration Sphere — Some laboratories used an integration sphere and provided valid calibration reports for them.

2.1.4 Additional Tests

Some laboratories calibrated each of the seven optical apertures separately, with each moved to the optical axis. Where this was the practice, the center channel was taken, then the head was offset, and each of the six other channels was read. The on-axis reading for each channel was used for the data reduction.

Some laboratories use a black lollipop to shadow the head for an ambient reading. Where this was standard practice, both a cover and ambient reading were taken.

Some laboratories requested additional tests with a second lamp.

2.2 Nominal Test Procedure

The laboratory was requested to run through its normal calibration procedure for the irradiance and radiance sensors using their light sources and diffuser plaques or integration spheres. If the laboratory did not normally test these heads, their procedures for similar instruments were used.

2.2.1 Nominal Test Procedure

The SIRREX-6 tests followed the normal laboratory procedures for in-water radiometers as closely as possible. Generally the test included the following steps:

Radiance Test:

1. Align lamp and plaque
2. Mount first radiance head
3. Develop procedure for exchange of heads
4. Warm up the lamp (10 to 20 minutes)
5. Record 16 seconds of data with head covered
6. Record 16 seconds of data with head uncovered
7. Record additional data if needed
8. Mount second radiance head, in the same position as the first
9. Record 16 seconds of data with head covered
10. Record 16 seconds of data with head uncovered
11. Record additional data if desired
12. Cool lamp
13. Repeat with second lamp if necessary

Irradiance Test:

1. Align irradiance head
2. Develop head replacement procedure
3. Check 50 centimeter distance with cross-hair front surface
4. Warm up the lamp (10 to 20 minutes)
5. Record 16 seconds of data with head covered
6. Record 16 seconds of data with head uncovered
7. Record additional data if desired
8. Mount second irradiance head in the same position
9. Record 16 seconds of data with head covered
10. Record 16 seconds of data with head uncovered
11. Record additional data if desired
12. Turn off lamp and log lamp on-time

3. SIRREX-6 DATA REDUCTION

The SIRREX-6 test data were reduced with the following steps:

1. Collect data
2. Convert to ASCII
3. Add mean and standard deviation
4. Interpolate lamp, plaque, and sphere for exact wave lengths
5. Summarize for each test
6. Summarize for each head
7. Make overall comparisons
8. Review special tests

3.1 Take Data

The data were collected using the software program PROVIEW.EXE provided by Satlantic. A binary file was stored for each test with the file name extension ".RAW" and the test description was entered in the lab notebook.

This software read the instantaneous light intensity of each channel with a separate silicon photodiode about every 100 msec. A slow count of twenty was allowed for each test. Given the instrument's sampling frequency this produced more than 150 sets of readings per test file.

3.2 Convert to ASCII

The files were converted to ASCII using the program ASCIICON.EXE provided by Satlantic. This was done with a batch file and took about 20 minutes for a day's testing. The files were saved with the extension ".DAT". Table 7 is an example of this file type. The units are in counts with zero at 32768 counts.

Table 7. Abbreviated Sample ASCII Data

SN(0010)	ED(411.0)	LU(411.3)	LU(443.0)	LU(489.0)	LU(509.7)	LU(554.1)	LU(665.9)	LU(682.8)
10	32779 ...	32779	32778	32779	32769	32777	32780	32773
10	32779 ...	32779	32778	32780	32769	32778	32780	32773
	.							
	.							
	.							
10	32778 ...	32778	32777	32779	32770	32777	32779	32774
10	32778 ...	32779	32778	32780	32769	32778	32779	32774
10	32777 ...	32776	32780	32780	32769	32778	32778	32775
10	32777 ...	32777	32779	32779	32771	32778	32779	32774

3.3 Add Mean and Standard Deviation

The ASCII files were read into MS-Excel as tabulation delimited tables. The data from the active head was identified. A summary box was added below the data listing giving the wavelength heading, the average data counts, and the standard deviation of the counts. The average was labeled with the file name. The file was then saved with an ".XLS" extension. This process took about 5 minutes per data file. Table 8 is an example of this file type.

Table 8. Mean Addition to Sample ASCII Data

	LU(411.3)	LU(443.0)	LU(489.0)	LU(509.7)	LU(554.1)	LU(665.9)	LU(682.8)	
Mean	32777.62	32778.78	32779.06	32769.59	32777.36	32779.40	32774.049	AT0811A.XLS
STD	1.002	0.818	0.704	0.863	0.683	0.692	0.762	

3.4 Interpolation of Calibration Constants

The calibration constants available for the lamps, plaques, and integration spheres were not taken at the exact wavelengths of the heads. The available calibration data were entered into an Excel spreadsheet that calculates the interpolated values. Some laboratories provided this information using their standard software. This step took about 30 minutes.

Most laboratories used the four point Lagrange method developed by NIST. The reference lamp supplier, Optronic Laboratories, Inc., recommends this method and provides the equation in the "Report of Calibration" for their FEL lamps.

This procedure uses the four points spanning the desired wavelength and is shown in equation 1. Applying this equation to the GSFC F-474 lamp data shown in figure 2 yields figure 3 and figure 4. A graphic equivalent of this equation draws a line between the two central points and then warps the line with the two outside points. Figure 3 shows the interpolated values from 400 nm to 450 nm and is slightly concave. Figure 4 shows the interpolated values from 654.6 nm to 700 nm and is very slightly convex.

Plymouth Marine Laboratory (PML) used a procedure of fitting an equation by linear regression to the calibration data. This procedure was also developed by NIST. Equation 2 shows this form. The fit was done in two stages. First the

NIST Lagrange interpolation formula

$$D(\lambda)=\sum_{k=1}^{4}\left|\prod_{\substack{i=1\\ i\neq k}}^{4}(x-x_i)/(x_k-x_i)\right| * E(\lambda) \qquad (1)$$

where x = the wavelength to be interpolated

x_i, x_k = 4 consecutive wavelengths whose values are already given in the datafile such that $x_1 < x_2 < x < x_3 < x_4$.

$E(\lambda)$ = spectral data value for wavelength x_k

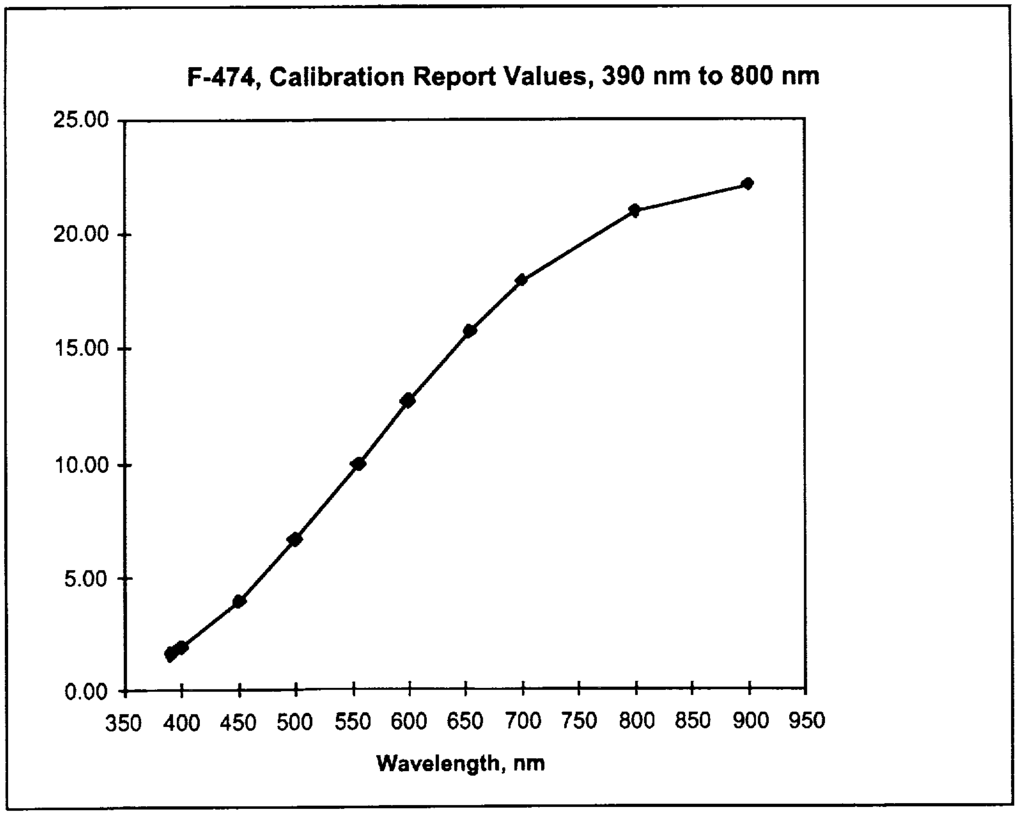


Figure 2

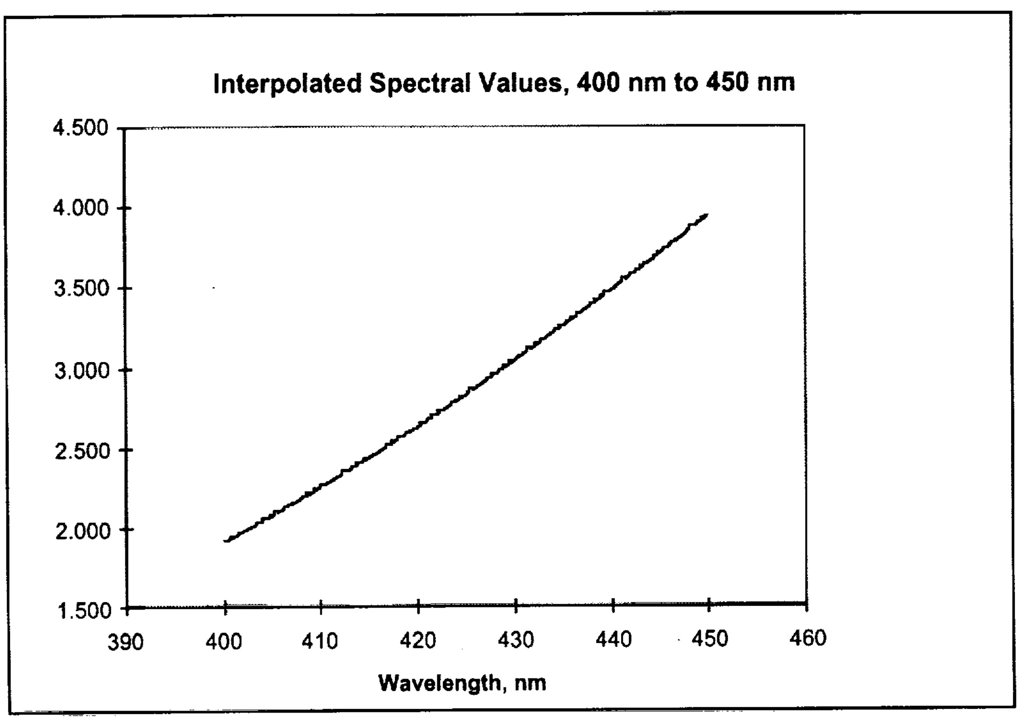


Figure 3

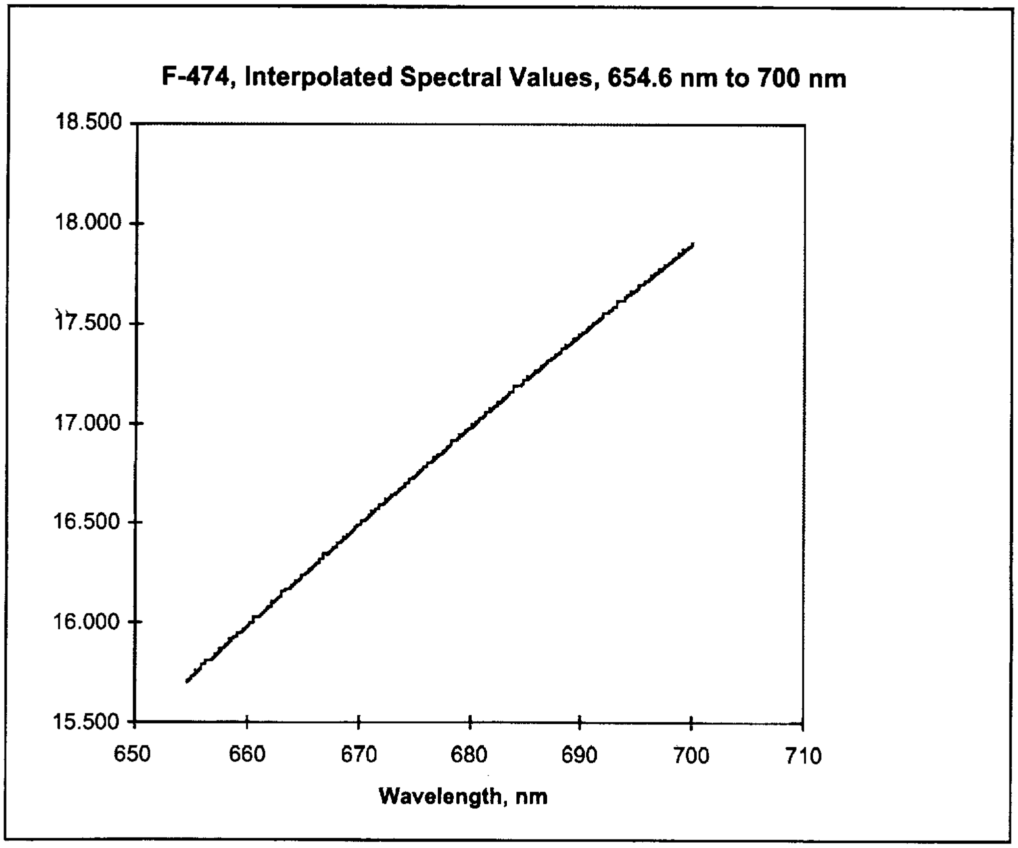


Figure 4

logarithmic component was fitted to the data by linear regression, producing coefficients A_0 and A_1. Then a quadratic equation was added with a second fitting, while holding A_0 and A_1 constant. This produced coefficients B_0 through B_4. The complete equation was then used to calculate the irradiance at specific wavelengths.

Figure 2 shows that the slope of the curve is well behaved through the range of interest (410 nm to 682 nm). At the short wavelength end (410 nm) the signal is much lower than at the long wavelength end (682 nm). This means that small errors in the interpolation at the short wavelengths result in a much larger error as a percentage of the signal.

3.5 Test Summary Sheet

The test data averages are copied to a spread sheet with all the data for one test on a specific head. This includes (at least) an illuminated test and a dark test with the head covered. It may additionally include an ambient test with the view blocked but not completely covered, and seven off-set tests with each of the head's seven optical ports moved to the optical axis.

This spreadsheet calculates the calibration constants for the head and it used calibration information about the lamp and plaque, or sphere.

This process took about 20 minutes per test.

Linear regression lamp interpolation fit:

$$E(\lambda)=\left(B_0+B_1\lambda+B_2\lambda^2+B_3\lambda^3+B_4\lambda^4\right)*\left(\exp\left(A_0+A_1/\lambda\right)\right)*\lambda^{-5} \quad (2)$$

where A_0,A_1 = primary fit coefficients for greybody equation

$B_0,\ldots B_4$ = secondary fit coefficients for quadratic equation

Table 9. Single Test Spread Sheet Example

	Satlantic		File:	S1I047A.XLS				
	11-Aug-97		Used:	SAT0811G.TXT SAT0811H.TXT				
	OCI-200 S/N 047, Pair 2			First data set				
	ED(411.0)	ED(442.8)	ED(490.4)	ED(509.3)	ED(554.6)	ED(665.5)	ED(682.7)	
Dark	32777.2	32779.1	32774.6	32775.4	32777.7	32776.8	32779.2	SAT0811H.XLS
Stdev	0.642	0.557	0.644	0.515	0.787	0.581	0.565	
Light	33147.9	33345.9	33790.7	33881.5	34286.4	36799.0	36798.0	SAT0811G.XLS
Stdev	0.456	0.659	0.718	0.614	0.775	1.164	1.558	
F459	2.361	3.711	6.268	7.373	10.170	16.660	17.510	uW/cm²nm
Distance	mm	500						
Lcal	2.361E+00	3.711E+00	6.268E+00	7.373E+00	1.017E+01	1.666E+01	1.751E+01	uW/cm²nm
Cal Coefficient	6.370E-03	6.547E-03	6.168E-03	6.665E-03	6.740E-03	4.142E-03	4.357E-03	uW/cm²nm/count
Lab Val	6.377E-03	6.524E-03	6.141E-03	6.676E-03	6.741E-03	4.147E-03	4.362E-03	uW/cm²nm/count
% Dif	0.11	-0.35	-0.44	0.15	0.01	0.14	0.14	%

3.6 Summary for Each Head

The results for each laboratory were then entered in the SIRREX.XLS file by optical head. The calibration parameters were compared as a percentage of the mean for all laboratories. This sheet is reviewed in detail in section 4.

3.7 Overall Comparisons

Overall comparisons were then worked up in the lead Summary Sheet in SIRREX.XLS.

3.8 Special Tests

Special test data were also reduced in SIRREX.XLS.

4. SIRREX-6 TEST RESULTS

The following tables and figures were derived from the SIRREX-6 data.

4.1 Overviews of Results

This overview starts at the most reduced data and works back toward the basic data.

4.1.1 Deviation From Mean

Figure 5 gives the highest level overview. It shows the percentage deviation from the mean of the calibration coefficients averaged over all instrument wavelengths for all four instrument heads.

This figure shows an overall consistency within 1%. The Max and Min bars do show that there are a few outliers in the data. This is a very positive overall result and demonstrates excellent compliance with the goals of the program.

The most significant outliers were investigated and found to be the result of questionable calibration numbers. In one case the reference lamp used to obtain the calibration number failed after only a few more hours of use. In another, the calibration number was thought to be suspect but was the best available on the day of the test. Both these references were retested before they were used for other published results.

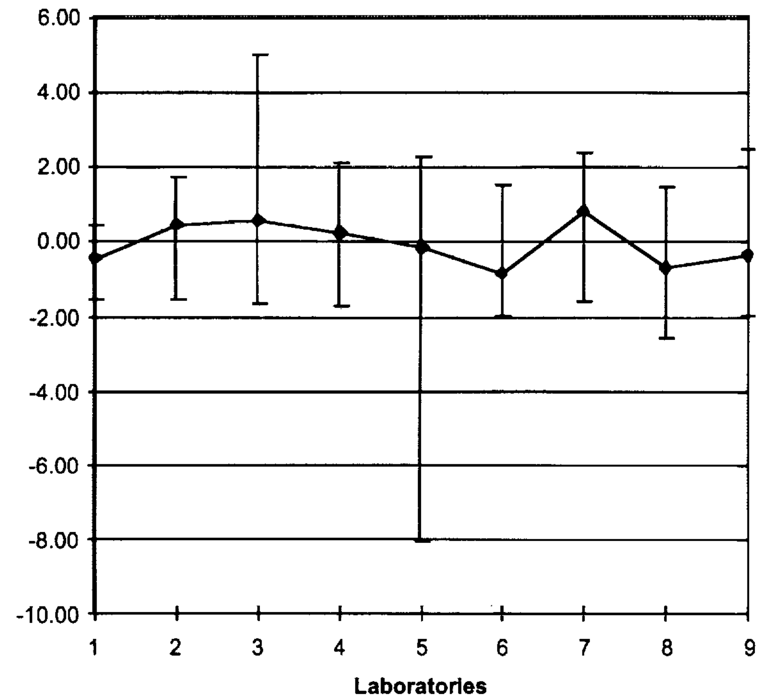


Figure 5. Percent Difference from Mean for All Wavelengths and All Heads

Table 10, table 11, and figure 6 show the same information but separated for the radiance and the irradiance tests. The radiance tests include laboratories that use plaques and those that use integration spheres. Any trends, such as those caused by instrument drift, are small compared to the variation between laboratory sources.

Table 13 and table 14 show the same information expanded by wavelength. Two outliers show in the LU(410.x) column for the radiance heads. Integration spheres designed for calibration of space instruments saturate the radiance heads at long wavelengths. The radiance tests show less variation.

Table 10. Percent Difference From Mean for All Wavelengths, Two Radiance Heads

Radiance	Mean	Max	Min	STD	
1 **Satlantic**	**-0.67**	0.10	-1.55	0.48	%
2 **GSFC 1**	**0.19**	1.29	-1.10	1.02	%
3 **PML**	**1.85**	5.02	-0.39	1.55	%
4 **JRC-SAI**	**0.32**	2.14	-1.76	1.19	%
5 **CHORS**	**-1.19**	0.86	-8.05	2.93	%
6 **Biosphere**	**-1.10**	-0.25	-2.04	0.52	%
7 **UCSB**	**0.35**	2.31	-0.63	0.99	%
8 **NRL**	**-0.28**	1.28	-2.56	1.29	%
9 **GSFC 2**	**0.36**	2.52	-0.59	1.26	%

Table 11. Percent Difference From Mean for all Wavelengths, Two Irradiance Heads

Irradiance	Mean	Max	Min	STD	
1 Satlantic	-0.26	0.44	-0.76	0.38	%
2 GSFC 1	0.76	1.76	-1.56	0.86	%
3 PML	-0.74	0.86	-1.65	0.89	%
4 JRC-SAI	0.20	1.55	-1.57	1.03	%
5 CHORS	0.87	2.29	-1.14	1.00	%
6 Biosphere	-0.55	1.53	-1.80	0.84	%
7 UCSB	1.31	2.28	-1.59	1.20	%
8 NRL	-1.13	1.46	-2.51	1.13	%
9 GSFC 2	-1.03	1.61	-1.99	1.08	%
10 GSFC 3	0.07	0.62	-0.25	0.25	%

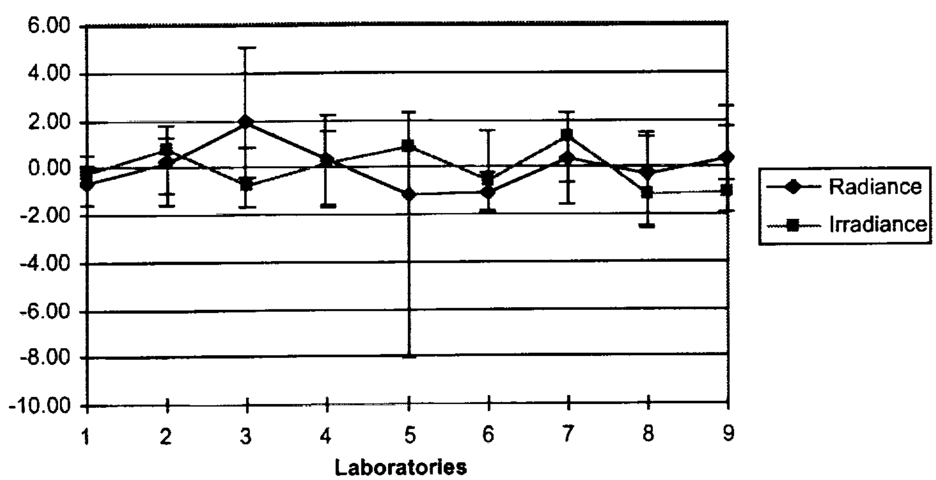


Figure 6. Percent Difference From Mean, Radiance and Irradiance

Table 12. Percent Difference From Mean by Wavelengths, Two Radiance Heads

	LU(411.x)	LU(443.x)	LU(489.x)	LU(509.x)	LU(554.x)	LU(665.x)	LU(682.x)	
1 Satlantic	-0.58	-0.69	-0.72	-1.46	-0.82	0.05	-0.45	%
2 GSFC 1	1.04	-1.02	-0.91	0.72	1.11	Sat	Sat	%
3 PML	4.88	-0.28	1.97	1.26	1.94	0.89	2.28	%
4 JRC-SAI	1.69	1.94	0.36	0.27	-1.54	0.15	-0.60	%
5 CHORS	-7.92	-0.19	0.13	0.10	-0.35	0.09	0.76	%
6 Biosphere	-0.53	-1.33	-1.66	-1.64	-1.18	-0.51	-0.85	%
7 UCSB	2.11	1.40	0.21	-0.03	-0.45	-0.46	-0.35	%
8 NRL	-2.21	-0.06	0.75	0.41	Sat	Sat	Sat	%
9 GSFC 2	-0.31	-0.52	0.33	1.94	2.43	Sat	Sat	%

Sat -- Reading Saturated

Table 13. Percent Difference From Mean by Wavelengths, Two Irradiance Heads

	ED(411.x)	ED(442.x)	ED(490.x)	ED(509.x)	ED(554.x)	ED(665.x)	ED(682.x)	
1 Satlantic	-0.67	-0.34	0.04	-0.49	-0.45	0.16	-0.08	%
2 GSFC 1	0.79	0.72	1.18	1.18	1.05	0.27	0.10	%
3 PML	0.22	-1.00	-1.59	-1.50	-1.27	-0.14	0.08	%
4 JRC-SAI	1.05	1.53	0.45	0.10	-1.46	-0.10	-0.17	%
5 CHORS	0.83	0.24	0.72	2.10	1.73	0.05	0.40	%
6 Biosphere	-1.09	-1.15	-0.84	-0.69	-0.70	0.42	0.22	%
7 UCSB	1.85	2.11	1.81	1.73	1.88	-0.14	-0.10	%
8 NRL	-2.19	-1.51	-1.26	-1.14	-1.29	-0.31	-0.24	%
9 GSFC 2	-1.87	-1.80	-1.42	-1.20	-0.90	-0.07	0.03	%

4.1.2 Comparison With Protocols

The desired test levels are set out in "Volume 25, Ocean Optics Protocols for SeaWiFS Validation, Revision 1," pp 15, table 4, "Required instrument sensitivities for SeaWiFS validation and algorithm development as a function of radiometric measured variable and wavelength." This table gives the following desired parameters at 412, 489, and 665 nm:

$E_d(0)_{max}$ — Saturation Irradiance in uW/cm^2/nm
$L_u(0)_{max}$ — Saturation Radiance (Case-2/coccoliths) in uW/cm^2/nm/sr
E_{cal} — Calibration Irradiance
L_{cal} — Calibration Radiance

These are the ideal levels for calibration of in-water instruments. Significant departures from these levels indicate that the instrument is not in the same operating range for the calibration and the test.

Table 14 compares the results found in SIRREX-6 for the radiance tests with these protocol levels. It separates the radiance tests done with plaques from those done with integration spheres.

The $L_u(0)_{max}$ levels for the plaque tests are very low. There is only 11% of the desired value. This is only a small signal of a few hundred counts (742 out of a possible 32,767). This low signal level leaves the test open to problems both of signal-to-noise ratio and A-to-D converter step size. The test is then sensitive to the use of lollipop for ambient counts and the room darkness.

The $L_u(0)_{max}$ levels for the integration spheres are much higher but this can lead to saturation at longer wavelengths. The highest level that did not produce saturation at a specific wavelength was selected for inclusion in the reduced data in SIRREX-6.

To cover the entire SeaWiFS bandwidth an integration sphere must be able to adjust its light level over a wide range. The spheres designed for testing space instruments, such as the one at GSFC, are so bright that even at their lowest levels they still saturate the in-water instruments at the two longest wavelengths.

Other integration spheres have their lamps mounted in separate cambers that can be isolated from the main sphere with mechanical stops to reduce the light that enters the sphere. This arrangement produced the needed adjustment range but complicated the sphere design and means that each stop requires a separate calibration.

Table 14. Radiance Percent Protocol Levels at Three Wavelengths, by Laboratory

Radiance: Plaques	**411.x nm**		**489.x nm**		**665.x nm**		
	%Lcal	**%Lumax**	**%Lcal**	**%Lumax**	**%Lcal**	**%Lumax**	
Satlantic	17.62	11.60	18.60	11.57	16.88	15.74	%
JRC-SAI	12.65	11.86	15.09	11.69	16.57	15.75	%
Biosphere	3.89	11.60	3.97	11.46	3.45	15.65	%
UCSB	8.36	11.91	8.50	11.67	7.42	15.65	%
Protocol	*0.60*	*24.00*	*1.50*	*24.00*	*4.50*	*8.00*	uW/cm^2/nm
Mean Flux	**0.06**	**2.82**	**0.17**	**2.78**	**0.50**	**1.26**	uW/cm^2/nm
Mean % Protocol	**10.63**	**11.74**	**11.54**	**11.60**	**11.08**	**15.70**	%
Max	**17.62**	**11.91**	**18.60**	**11.69**	**16.88**	**15.75**	%
Min	**3.89**	**11.60**	**3.97**	**11.46**	**3.45**	**15.65**	%
Counts	**742**		**2037**		**13010**	Counts out of 32,767	
%/Count	**0.01**		**0.01**		**0.00**		%
Radiance: Spheres							
GSFC 1	287.75	11.79	177.77	11.55	*45.48*	*25.58*	Saturated
PML	33.67	12.26	33.80	11.88	7.61	15.87	%
CHORS	14.14	10.75	21.18	11.67	22.09	15.74	%
NRL	383.43	11.41	127.01	11.74	*140.26*	*78.90*	Saturated
GSFC 2	287.75	11.63	177.77	11.70	*45.48*	*25.58*	Saturated
Protocol	*0.60*	*24.00*	*1.50*	*24.00*	*4.50*	*8.00*	uW/cm^2/nm
Mean Flux	**1.21**	**2.78**	**1.61**	**2.81**	**0.67**	**1.26**	uW/cm^2/nm
Mean % Protocol	**201.35**	**11.57**	**107.50**	**11.71**	**14.85**	**15.80**	%
Max	**383.43**	**12.26**	**177.77**	**11.88**	**22.09**	**15.87**	%
Min	**14.14**	**10.75**	**21.18**	**11.55**	**7.61**	**15.74**	%
Counts	**14260**		**18803**		**17319**	Counts out of 32,767	
%/Count	**0.01**		**0.01**		**0.00**		%

Table 15. Irradiance Percent Protocol Levels, at Three Wavelengths, by Laboratory

	411.x nm		489.x nm		665.x nm		
Irradiance:	%Ecal	%Eumax	%Ecal	%Eumax	%Ecal	%Eumax	
Satlantic	115.11	67.85	122.41	65.89	108.92	47.32	%
GSFC 1	139.80	68.76	140.93	66.57	118.53	47.89	%
PML	114.88	67.79	119.35	64.41	106.71	46.69	%
SAI	47.52	68.91	57.43	66.03	62.51	47.52	%
CHORS	136.55	69.24	137.60	66.11	116.94	47.63	%
Biosphere	134.55	67.49	139.02	65.17	119.70	46.94	%
UCSB	140.57	70.65	134.61	69.00	113.51	47.23	%
NRL	114.32	66.74	120.70	64.91	107.39	46.67	%
GSFC 2	127.15	68.70	130.96	66.02	113.54	44.73	%
Protocol	*2.00*	*300.00*	*5.00*	*300.00*	*15.00*	*300.00*	uW/cm^2/nm/sr
Mean Flux	**2.38**	**205.38**	**6.13**	**198.04**	**16.13**	**140.87**	uW/cm^2/nm/sr
Mean %	**118.94**	**68.46**	**122.56**	**66.01**	**107.53**	**46.96**	%
Max	**140.57**	**70.65**	**140.93**	**69.00**	**119.70**	**47.89**	%
Min	**47.52**	**66.74**	**57.43**	**64.41**	**62.51**	**44.73**	%
Counts	**380**		**1014**		**3752**	Counts out of 32,767	
%/Count	**0.31**		**0.12**		**0.03**		%

Table 15 gives the percentage of the protocol levels for the irradiance heads. Here the levels match the protocols very well, but the number of counts in the short wavelength channels is very low. A few stray counts thus have a significant effect on the data.

4.2 Coefficients

The primary data set for SIRREX-6 was the measured calibration coefficient for each of the four heads as taken at each laboratory. These are the numbers that are used to convert raw counts taken in the field into radiances or irradiances.

4.2.1 Radiance Heads

Table 16 and table 17 give the measured calibration coefficients for the two radiance heads S/N 038 and S/N 039. The units are (uW/cm^2/nm/sr)/count. The wavelengths vary between the two units slightly, so the actual value measured by the filter manufacturer for the individual filters was used. The readings taken with an integration sphere versus plaque were marked.

Where two capital letters appear in the "Test" column, two data sets were taken very close together in time and the results averaged. The difference between such tests was very small in all cases.

At two laboratories, two separate reference lamps were used. The results shown as "% Dif., 2 Lamps" show excellent repeatability between separate lamps for tests run on the same day.

Table 16. Head OCR-200 S/N 038, Calibration Coefficients by Wavelength

Date	Lab	Test	LU(411.3)	LU(443.0)	LU(489.0)	LU(509.7)	LU(554.1)	LU(665.9)	LU(682.8)
8/11/97	**Satlantic**	A	8.544E-05	8.648E-05	8.644E-05	8.787E-05	8.962E-05	3.801E-05	3.386E-05
8/12/97	*Plaque*	B	8.556E-05	8.646E-05	8.608E-05	8.772E-05	8.933E-05	3.804E-05	3.371E-05
% Dif. 2 lamps			-0.13	0.02	0.42	0.17	0.32	-0.09	0.45
8/29/97	**GSFC** *Sphere*	A,B	8.701E-05	8.595E-05	8.582E-05	8.942E-05	9.082E-05	6.249E-05	3.708E-04
9/8/97	**PML** *Sphere*	A	9.022E-05	8.657E-05	8.801E-05	9.005E-05	9.165E-05	3.831E-05	3.484E-05
9/17/97	**JRC-SAI** *Plaque*	A,B	8.745E-05	8.877E-05	8.707E-05	8.953E-05	8.880E-05	3.818E-05	3.362E-05
10/4/97	**CHORS** *Sphere*	A,B	7.899E-05	8.683E-05	8.683E-05	8.907E-05	8.964E-05	3.803E-05	3.412E-05
10/3/97	**Biosphere** *Plaque*	A	8.522E-05	8.573E-05	8.497E-05	8.791E-05	8.900E-05	3.781E-05	3.366E-05
10/6/97	**UCSB 1**	A,B	8.749E-05	8.787E-05	8.673E-05	8.907E-05	8.936E-05	3.770E-05	3.360E-05
	Plaque	C,D	8.760E-05	8.803E-05	8.679E-05	8.883E-05	8.954E-05	3.780E-05	3.377E-05
% Dif, 2 lamps			-0.13	-0.18	-0.07	0.27	-0.20	-0.26	-0.50
11/6/97	**NRL 1** *Sphere*	A,B	8.430E-05	8.689E-05	8.779E-05	8.914E-05	1.059E-04	1.927E-04	2.046E-04
11/21/97	**GSFC 2** *Sphere*	A,B	8.570E-05	8.640E-05	8.693E-05	9.059E-05	9.209E-05	6.249E-05	2.182E-04

Table 17. Head OCR-200 S/N 039, Calibration Coefficients by Wavelength

Date	Lab	Test	LU(411.5)	LU(442.9)	LU(489.7)	LU(509.6)	LU(554.2)	LU(665.7)	LU(682.9)
8/11/97	**Satlantic**	A	8.436E-05	8.111E-05	8.341E-05	8.848E-05	8.961E-05	3.882E-05	3.527E-05
8/12/97	*Plaque*	B	8.450E-05	8.114E-05	8.318E-05	8.836E-05	9.004E-05	3.886E-05	3.504E-05
% Dif, 2 Lamps			-0.17	-0.03	0.27	0.14	-0.48	-0.09	0.65
8/29/97	**GSFC 1** *Sphere*	A,B	8.569E-05	8.107E-05	8.342E-05	9.070E-05	9.197E-05	6.246E-05	6.556E-05
9/8/97	**PML** *Sphere*	A	8.905E-05	8.170E-05	8.614E-05	9.103E-05	9.264E-05	3.919E-05	3.599E-05
9/17/97	**JRC-SAI** *Plaque*	A,B	8.636E-05	8.326E-05	8.434E-05	8.977E-05	8.921E-05	3.876E-05	3.522E-05
10/4/97	**CHORS** *Sphere*	A,B	7.838E-05	8.160E-05	8.418E-05	8.994E-05	9.050E-05	3.886E-05	3.566E-05
10/3/97	**Biosphere** *Plaque*	A	8.479E-05	8.076E-05	8.298E-05	8.798E-05	8.966E-05	3.862E-05	3.500E-05
10/6/97	**UCSB 1**	A,B	8.728E-05	8.336E-05	8.439E-05	9.023E-05	9.088E-05	3.889E-05	3.536E-05
10/6/97	*Plaque*	C,D	8.667E-05	8.294E-05	8.437E-05	8.942E-05	9.015E-05	3.856E-05	3.530E-05
% Dif, 2 lamps			0.70	0.51	0.03	0.89	0.80	0.87	0.18
11/6/97	**NRL 1** *Sphere*	A,B	8.283E-05	8.176E-05	8.429E-05	9.043E-05	1.059E-04	1.927E-04	2.046E-04
11/21/97	**GSFC 2** *Sphere*	A,B	8.469E-05	8.146E-05	8.442E-05	9.171E-05	9.309E-05	6.246E-05	6.556E-05

Table 18 and table 19 give the same information as the two tables above, but give it as a percentage of the difference from the mean for all laboratories. This percentage was calculated by subtracting the value from the mean and dividing by the mean.

Note that two entries have the two long wavelengths completely saturated and a third has the three long wavelengths saturated. These were all taken with integration spheres originally designed for space instruments.

The four outliers in the LU(411.x) columns are the result of using calibration numbers that were thought to be questionable, but were the best available on the day of the test. All the outliers occurred in the shortest wavelength where the signal is weakest. Experienced personnel have no difficulty recognizing questionable readings, but may not have the time and resources available to repeat the tests necessary to address the problem.

Table 18. Head OCR-200 S/N 038, Percent Difference From the Mean by Laboratory and Wavelength

		LU(411.3)	LU(443.0)	LU(489.0)	LU(509.7)	LU(554.1)	LU(665.9)	LU(682.8)
Mean		8.591E-05	8.691E-05	8.668E-05	8.902E-05	8.998E-05	3.798E-05	3.390E-05
Satlantic	%	-0.47	-0.50	-0.48	-1.38	-0.57	0.10	-0.33
GSFC 1 *(4) (5)*	%	1.28	-1.10	-0.99	0.45	0.93	*64.52*	*993.92*
PML *(5)*	%	5.02	-0.39	1.53	1.16	1.85	0.87	2.77
JRC-SAI *(2)*	%	1.79	2.14	0.45	0.58	-1.32	0.50	-0.81
CHORS *(5)*	%	-8.05	-0.08	0.18	0.06	-0.38	0.12	0.66
Biosphere	%	-0.80	-1.35	-1.97	-1.24	-1.10	-0.46	-0.69
UCSB *(3)*	%	1.91	1.20	0.09	-0.08	-0.59	-0.62	-0.63
NRL *(6) (5)*	%	-1.87	-0.03	1.28	0.13	*17.68*	*407.29*	*503.61*
GSFC 2 *(4) (5)*	%	-0.24	-0.59	0.29	1.77	2.33	*64.52*	*543.67*

(2) Non-Lambertian correction used
(3) Central wavelengths used
(4) Two longest wavelength channels are saturated
(5) Integration sphere used
(6) Three longest wavelength channels are saturated

Table 19. Head OCR-200 S/N 039, Percent Difference From the Mean by Laboratory and Wavelength

		LU(411.5)	LU(442.9)	LU(489.7)	LU(509.6)	LU(554.2)	LU(665.7)	LU(682.9)
Mean		8.501E-05	8.184E-05	8.411E-05	8.981E-05	9.080E-05	3.884E-05	3.535E-05
Satlantic	%	-0.68	-0.87	-0.97	-1.55	-1.07	0.00	-0.56
GSFC 1 *(4) (5)*	%	0.80	-0.94	-0.82	0.99	1.29	*60.81*	*85.44*
PML *(5)*	%	4.75	-0.17	2.41	1.35	2.02	0.90	1.79
JRC-SAI *(2)*	%	1.59	1.74	0.28	-0.04	-1.76	-0.21	-0.40
CHORS *(5)*	%	-7.79	-0.29	0.09	0.15	-0.33	0.05	0.86
Biosphere	%	-0.25	-1.32	-1.35	-2.04	-1.26	-0.56	-1.02
UCSB *(3)*	%	2.31	1.61	0.32	0.02	-0.31	-0.30	-0.07
NRL *(6) (5)*	%	-2.56	-0.09	0.21	0.69	*16.61*	*396.09*	*478.70*
GSFC 2 *(4) (5)*	%	-0.37	-0.45	0.36	2.11	2.52	*60.81*	*85.45*

(2) Non-Lambertian correction used
(3) Central wavelengths used
(4) Two longest wavelength channels are saturated
(5) Integration sphere used
(6) Three longest wavelength channels are saturated

4.2.2 Irradiance Heads

Table 20 and table 21 give the measured calibration coefficients for the two irradiance heads S/N 038 and S/N 039. The units are (uW/cm²/nm)/count. The wavelengths vary between the two units slightly as the actual value measured for the individual filters is used.

Table 20. Head OCR-200 S/N 049, Calibration Coefficients by Wavelength

Date	Lab	Test	ED(411.0)	ED(442.8)	ED(490.4)	ED(509.3)	ED(554.6)	ED(665.5)	ED(682.7)
8/11/97	**Satlantic**	A	6.070E-03	6.232E-03	5.929E-03	6.808E-03	6.890E-03	4.534E-03	4.403E-03
8/12/97		B	6.045E-03	6.203E-03	5.869E-03	6.736E-03	6.846E-03	4.515E-03	4.351E-03
% Dif, 2 lamps			0.41	0.47	1.01	1.06	0.64	0.42	1.18
8/29/97	**GSFC 1**	A,B	6.138E-03	6.300E-03	5.987E-03	6.882E-03	6.991E-03	4.576E-03	4.481E-03
9/8/97	**PML**	A	6.126E-03	6.198E-03	5.810E-03	6.700E-03	6.814E-03	4.478E-03	4.372E-03
9/17/97	**JRC-SAI**	C	6.166E-03	6.338E-03	5.925E-03	6.807E-03	6.785E-03	4.539E-03	4.350E-03
10/2/97	**CHORS**	A	6.160E-03	6.261E-03	5.959E-03	6.950E-03	7.016E-03	4.556E-03	4.488E-03
10/4/97		C	6.227E-03	6.307E-03	5.955E-03	6.819E-03	6.944E-03	4.556E-03	4.454E-03
% Dif, 2 lamps			-1.08	-0.72	0.06	1.89	1.03	0.01	0.77
10/3/97	**Biosphere**	A	5.983E-03	6.149E-03	5.856E-03	6.717E-03	6.843E-03	4.493E-03	4.394E-03
10/6/97	**UCSB 1**	A	6.173E-03	6.345E-03	5.976E-03	6.849E-03	6.979E-03	4.546E-03	4.426E-03
10/6/97		C	6.259E-03	6.427E-03	6.065E-03	6.974E-03	7.074E-03	4.621E-03	4.479E-03
% Dif, 2 lamps			-1.38	-1.29	-1.48	-1.83	-1.36	-1.64	-1.19
11/6/97	**NRL**	A	5.940E-03	6.127E-03	5.814E-03	6.683E-03	6.776E-03	4.448E-03	4.318E-03
11/21/97	**GSFC 2**	A	5.922E-03	6.072E-03	5.782E-03	6.663E-03	6.774E-03	4.429E-03	4.309E-03
11/21/97		B	6.020E-03	6.179E-03	5.862E-03	6.751E-03	6.863E-03	4.501E-03	4.361E-03
% Dif, 2 Lamps			-1.65	-1.76	-1.38	-1.33	-1.32	-1.63	-1.22
2/19/98	**GSFC 3**	A B	6.078E-03	6.237E-03	5.899E-03	6.778E-03	6.895E-03	4.522E-03	4.422E-03
		C D	6.083E-03	6.278E-03	5.925E-03	6.804E-03	6.910E-03	4.550E-03	4.440E-03
% Dif, 2 Lamps			-0.08	-0.65	-0.45	-0.39	-0.22	-0.61	-0.41

Table 21. Head OCR-200 S/N 047, Calibration Coefficients by Wavelength

Date	Lab	Test	ED(411.0)	ED(442.5)	ED(489.9)	ED(509.4)	ED(554.6)	ED(665.8)	ED(682.8)
8/11/97	**Satlantic**	A	6.370E-03	6.548E-03	6.169E-03	6.666E-03	6.741E-03	4.142E-03	4.357E-03
8/12/97		B	6.339E-03	6.533E-03	6.120E-03	6.621E-03	6.739E-03	4.121E-03	4.315E-03
% Dif, 2 Lamps			0.49	0.22	0.79	0.67	0.03	0.51	0.95
8/29/97	**GSFC 1**	A,B	6.457E-03	6.592E-03	6.192E-03	6.760E-03	6.823E-03	4.169E-03	4.423E-03
9/8/97	**PML**	A,B	6.396E-03	6.474E-03	6.036E-03	6.581E-03	6.682E-03	4.113E-03	4.318E-03
9/17/97	**JRC-SAI**	C,D	6.461E-03	6.659E-03	6.167E-03	6.689E-03	6.684E-03	4.166E-03	4.318E-03
10/2/97	**CHORS**	A,B	6.439E-03	6.570E-03	6.165E-03	6.815E-03	6.889E-03	4.169E-03	4.430E-03
10/4/97		C,D	6.541E-03	6.616E-03	6.138E-03	6.685E-03	6.792E-03	4.170E-03	4.380E-03
% Dif, 2 lamps			-1.58	-0.69	0.43	1.90	1.42	-0.02	1.12
10/3/97	**Biospher**	A	6.379E-03	6.505E-03	6.081E-03	6.672E-03	6.730E-03	4.106E-03	4.394E-03
10/6/97	**UCSB 1**	A,B	6.496E-03	6.671E-03	6.212E-03	6.772E-03	6.868E-03	4.191E-03	4.384E-03
10/6/97		C,D	6.524E-03	6.700E-03	6.258E-03	6.836E-03	6.932E-03	4.229E-03	4.441E-03
% Dif, 2 lamps			-0.43	-0.44	-0.74	-0.95	-0.93	-0.90	-1.31
11/6/97	**NRL**	A,B	6.285E-03	6.482E-03	6.072E-03	6.644E-03	6.716E-03	4.100E-03	4.292E-03
11/21/97	**GSFC 2**	A	6.220E-03	6.382E-03	5.996E-03	6.552E-03	6.676E-03	4.064E-03	4.246E-03
		B	6.363E-03	6.508E-03	6.095E-03	6.675E-03	6.778E-03	4.128E-03	4.325E-03
% Dif, 2 Lamps			-2.29	-1.97	-1.66	-1.87	-1.52	-1.58	-1.86
2/19/98	**GSFC 3**	A,B	6.376E-03	6.553E-03	6.122E-03	6.659E-03	6.790E-03	4.142E-03	4.343E-03
		C,D	6.406E-03	6.569E-03	6.131E-03	6.682E-03	6.795E-03	4.152E-03	4.365E-03
% Dif, 2 Lamps			-0.48	-0.24	-0.16	-0.35	-0.07	-0.26	-0.51

Table 22 and table 23 give the same information as the two tables above, but give it as a percentage of the difference from the mean for all laboratories. This percentage was calculated by subtracting the value from the mean and dividing by the mean.

Note (3) indicates one laboratory that used the central wavelength for each of the filters instead of the 20 Degree Cone Wavelengths. These data, with and without this correction, were analyzed in section 4.4.1.

Table 22. Head OCR-200 S/N 049, Percent Difference From the Mean by Laboratory and Wavelength

		ED(411.0)	ED(442.8)	ED(490.4)	ED(509.3)	ED(554.6)	ED(665.5)	ED(682.7)
Mean		6.093E-03	6.244E-03	5.908E-03	6.795E-03	6.893E-03	4.524E-03	4.403E-03
Satlan	%	-0.58	-0.42	-0.14	-0.33	-0.37	0.00	-0.59
GSFC 1	%	0.75	0.91	1.35	1.28	1.41	1.15	1.76
PML	%	0.55	-0.73	-1.65	-1.40	-1.16	-1.02	-0.70
JRC-SAI	%	1.21	1.52	0.29	0.18	-1.57	0.33	-1.20
CHORS	%	1.11	0.28	0.87	2.29	1.78	0.71	1.94
Biosphere	%	-1.80	-1.51	-0.88	-1.14	-0.72	-0.70	-0.21
UCSB *(3)*	%	2.03	2.28	1.91	1.72	1.93	1.31	1.12
NRL	%	-2.51	-1.88	-1.58	-1.64	-1.70	-1.69	-1.93
GSFC 2	%	-1.99	-1.89	-1.45	-1.29	-1.08	-1.30	-1.55
GSFC 3	%	-0.20	0.22	0.07	-0.05	0.13	0.26	0.62

(3) Central Wavelengths Used

Table 23. Head OCR-200 S/N 047, Percent Difference From the Mean by Laboratory and Wavelength

		ED(411.0)	ED(442.5)	ED(489.9)	ED(509.4)	ED(554.6)	ED(665.8)	ED(682.8)
Mean		6.404E-03	6.558E-03	6.130E-03	6.687E-03	6.776E-03	4.144E-03	4.355E-03
Satlantic	%	-0.76	-0.26	0.23	-0.66	-0.53	0.3	0.4
GSFC 1	%	0.84	0.53	1.01	1.09	0.70	-0.6	-1.6
PML	%	-0.11	-1.27	-1.53	-1.59	-1.39	0.7	0.9
JRC-SAI	%	0.90	1.55	0.60	0.03	-1.35	-0.5	0.9
CHORS	%	0.56	0.20	0.57	1.91	1.68	-0.6	-1.1
Biosphere	%	-0.39	-0.80	-0.81	-0.23	-0.67	1.5	0.7
UCSB *(3)*	%	1.67	1.95	1.70	1.75	1.83	-1.6	-1.3
NRL	%	-1.86	-1.14	-0.94	-0.65	-0.88	1.1	1.5
GSFC 2	%	-1.75	-1.72	-1.38	-1.10	-0.72	1.2	1.6
GSFC 3	%	-0.19	0.06	-0.06	-0.25	0.25		

(3) Central Wavelengths Used

4.3 Laboratories Using Different Standards

During SIRREX-6, two laboratories were tested that did not use the same lamp types or reference laboratories as was used for the bulk of the SIRREX-6 tests. These tests are considered separately here and were not included in the calculation of the means.

4.3.1 DLR in Germany

The SIRREX-6 test was run at the Institut für Weltraumsensorik (DLR) in Berlin. This laboratory supports the Modular Opto-electronic Scanner (MOS) space instrument. It uses a 1000-W standard lamp from "Gigahertz-Optik," (Fischerstraße 4, D-82178 Puchheim/ München) and calibrated from the "Deutscher Kalibrierdienst DKD, calibration laboratory for optical radiometry" (a part of Gigahertz-Optik) in November 1996. The radiometric values are traceable to the national radiometric standards of the Physikalisch-Technische Bundesanstalt PTB.

Their plaque was built in-house, has a barium sulfate surface, and is a disk 308 mm in diameter. The plaque is calibrated in place at their normal angle of 35 degrees using a dedicated bench spectrometer with a small field of view. The plaque is X-Y scanned with 56 readings.

Table 24 shows the percent difference from the mean separately for the radiance and irradiance heads. These results are in quite reasonable agreement with the SIRREX-6 mean.

Table 24. Percentage Difference From Mean Using European Stand Lamp

	411.x nm	443.x nm	489.x nm	509.7 nm	554.1 nm	665.x nm	682.x nm	
Radiance								
% Diff	**1.90**	**1.00**	**0.56**	**-0.54**	**-0.19**	**0.65**	**2.02**	%
Max	2.29	1.37	1.48	-0.52	0.26	0.68	2.23	%
Min	1.51	0.63	-0.37	-0.56	-0.65	0.62	1.81	%
Irradiance								
% Diff	**3.32**	**2.54**	**1.35**	**1.59**	**1.49**	**2.10**	**2.68**	%
Max	3.40	2.56	1.67	1.61	1.51	2.18	2.83	%
Min	3.24	2.52	1.04	1.56	1.48	2.02	2.52	%
Mean of all tests			**1.46**					%
Maximum of all tests			3.32					%
Minimum of all tests			-0.54					%

4.3.2 Wallops Flight Facility

NASA's Wallops Flight Facility (WFF) flies a variety of ocean color instruments in aircraft. They are mounted to look down through a window in the bottom of the aircraft. WFF investigators maintain a small calibration laboratory to support this effort.

Due to limited laboratory space, WFF uses a 200-watt reference lamp instead of the 1000 watt lamps used in the SIRREX-6 tests. This lamp was set 500 mm from the diffuser as compared to the 1300 mm typically used with the more powerful lamp. This shorter distance increases geometric effects in the test. Table 25 shows reasonable agreement with the SIRREX-6 mean.

Wallops also has used a 30-inch diameter integration sphere that can rotate with its window directly up so that it may be run directly under the aircraft. At the time of the SIRREX test this sphere was thought to be out of calibration and was not used for field instrument calibration. This sphere was tested by being turned horizontally with its stops set a level 5 for the minimum light. This test did not produce good agreement with SIRREX-6, as shown in table 26. The reason for this discrepancy is thought to be a yellowing of the internal coating of the sphere. This sphere will be recalibrated before further use.

Table 25. Percent Difference From Mean for 200 Watt Lamp at WFF

	411.x nm	443.x nm	489.x nm	509.7 nm	554.1 nm	665.x nm	682.x nm	
Radiance								
% Diff	**1.42**	**1.86**	**0.79**	**0.54**	**0.94**	**0.61**	**2.98**	%
Max	1.64	2.05	1.44	0.99	1.00	0.64	3.25	%
Min	1.19	1.67	0.13	0.09	0.87	0.57	2.71	%
Irradiance								
% Diff	**-1.78**	**-2.83**	**-3.70**	**-2.03**	**-0.73**	**-1.43**	**-1.36**	%
Max	-1.36	-2.52	-3.64	-1.71	-0.27	-0.99	-1.32	%
Min	-2.19	-3.15	-3.76	-2.34	-1.20	-1.87	-1.41	%
Mean of all tests			**-0.34**					%
Maximum of all tests			2.98					%
Minimum of all tests			-3.70					%

Table 26. Percent Difference From Mean for Integration Sphere at WFF

	411.x nm	443.x nm	489.x nm	509.7 nm	554.1 nm	665.x nm	682.x nm	
Radiance								
% Diff	**62.76**	**43.83**	**26.79**	**25.54**	**17.56**	**144.73**	**183.77**	%
Max	63.03	44.06	27.05	25.68	17.57	147.51	189.72	%
Min	62.49	43.61	26.53	25.39	17.56	141.94	177.82	%
Mean of all tests			**72.14**					%
Maximum of all tests			183.77					%
Minimum of all tests			17.56					%

4.4 Special Tests

The SIRREX-6 allows the examination of the impact of variations in calibration procedures.

4.4.1 Satlantic Calibration

Satlantic is the manufacturer of the underwater photometer heads used in SIRREX-6. During their first tests, Satlantic independently ran their standard calibration procedure for these units. Table 27 shows the relationship between the calibration numbers provided by Satlantic and the mean of all the tests under SIRREX-6. The agreement is quite good.

4.4.2 20 Degree Cone Correction

The light filters used on the heads are manufactured by laying down thin alternating layers of metal and transparent material. These layers were very precisely controlled to set the bandpass wavelength. Light passing through the filter at an angle sees the layers as farther apart than light passing directly through, so the effective bandpass wavelength changes slightly.

The filter manufacturer's bench spectrograph used to measure the filters has a field of view of only 3 degrees. The radiance heads used for SIRREX-6 have a field of view of 20 degrees and the irradiance heads have an even wider cosine-weighted field of view. This means that the effective bandpass wavelength for these heads was slightly bluer (shifted to shorter wavelength) than the original filter test would indicate. The manufacturer provides a calculated correction for this effect called the "20 Degree Cone."

Most of the laboratories in SIRREX-6 used the 20 Degree Cone bandpass wavelengths but UCSB did not. This created the opportunity for demonstrating the level of this effect on the data. Table 28 shows the percentage difference between the data calculated with and without the 20 Degree Cone correction. The coefficients with the corrections were subtracted from those without and divided by those without.

The mean effect is a reduction of 1% across all wavelengths for both the radiance and irradiance heads. The effect is stronger in the shorter wavelengths and for the irradiance heads.

Table 27. Percent Difference Between Satlantic Calibration and Mean

	411.x nm	443.x nm	489.x nm	509.7 nm	554.1 nm	665.x nm	682.x nm	
Radiance	-1.08	-1.17	-1.01	-1.83	-1.71	-0.46	-0.64	%
Irradiance	-0.68	-0.66	-0.29	-0.61	-0.63	-0.09	-0.59	%
Mean of all tests			**-0.82**					%
Maximum of all tests			-0.09					%
Minimum of all tests			-1.83					%

Table 28. Effect of 20 Degree Cone in Percent Deviation From Mean

	411.x nm	443.x nm	489.x nm	509.7 nm	554.1 nm	665.x nm	682.x nm	
Radiance	1.45	1.28	0.95	0.92	0.69	0.36	0.35	%
Irradiance	1.38	1.23	0.94	0.86	0.65	0.20	0.33	%
Mean of all tests			**0.63**					%
Maximum of all tests			1.23					
Minimum of all tests			0.63					

4.4.3 On Axis Measurements

At some laboratories each head was measured seven times, once with each filter on the optical axis. This was done by offsetting the head and rotating it to bring the six outside filters on-axis.

This procedure produced a significant change in the readings only if:

1. The input aperture of the integration sphere was small.
2. The uniformly illuminated area of a plaque was smaller than the field of view of the offset channels.

4.4.4 SXR

The SeaWiFS Transfer Radiometer (SXR) is a laboratory reference instrument developed by NIST and used with the GSFC 42-inch integration sphere in preflight testing of the SeaWiFS instrument in the spring of 1997. SIRREX-6 provided an opportunity to compare SXR readings of the same GSFC integration sphere with the standards used for SeaWiFS preflight measurements.

The readings from the SXR were used to shift a model curve of the sphere wavelength response. Then the shifted curve was used to obtain the radiance value at the Satlantic Head wavelengths. Only four of the wavelengths were close enough for this approach.

The wavelengths of the SXR and the Satlantic Heads do not exactly match, and neither match the calibration points on the model curve. The same four-point interpolation method recommended by NIST for FEL lamps and plaques was used. Other methods are possible and the result is sensitive to the interpolation method used.

Table 29 shows that the results for the SXR reading the sphere are about 1% less than the level calculated with the mean of the Satlantic radiance head data. The published values for the SXR calibration and the mean calibration constants from the nine SIRREX-6 tests were used.

Also available in the same test period was the VXR, which is a second version of the SXR design with only a few mechanical changes. Table 30 shows a comparison of the VXR data taken at the same time as the SXR data and reduced in the same manner.

This data and analysis shows that the results for the VXR reading the sphere are about 1% greater than the level calculated with the mean of the Satlantic radiance head data. The mean calibration constants from the nine SIRREX-6 tests were used.

Table 29. Percent Difference Between SXR and Radiance Heads

		411.x nm	443.x nm	489.x nm	509.x nm	554.x nm	665.x nm	682.x nm
SXR	Adj	1.704	1.453	2.647		1.173	2.013	2.171
38, 39	Mean	1.726	1.478	2.658	0.822	1.188	42.795	1.134
	% Diff	**-1.28**	**-1.74**	**-0.42**		**-1.34**	*-2025.85*	*47.74*
					N/A		Out of range	

Mean % STD
-1.19 0.85

N/A -- Wavelength not available

Table 30. Percent Difference Between VXR and Radiance Heads

		411.x nm	443.x nm	489.x nm	509.x nm	554.x nm	665.x nm	682.x nm
VXR	Adj	1.772	1.505			1.177	2.016	2.136
38, 39	Mean	1.726	1.478	2.658	0.822	1.188	42.795	1.134
	% Diff	**2.62**	**1.81**			**-0.92**	*-2022.67*	*46.90*
				N/A	N/A		Out of range	

Mean % STD
1.17 1.82

N/A -- Wavelength not available

4.4.5 Multiple Tests at GSFC

The initial SIRREX-6 plan called for tests at Goddard Space Flight Center (GSFC) early and late in the series. To resolve questions that arose after the second test, the irradiance portion of the test was rerun a few weeks later for a third time. The integrations sphere was not available to repeat the radiance tests.

Table 31 shows the difference between the first and last test as a fraction of the mean from all tests. The radiance data is about 0.58% higher for the second test. The irradiance data is about 1.2% lower for the third test.

The second and third irradiance tests were reviewed in detail and a difference was found in the current driving the lamps. In the first and last tests a preprogrammed level in the power supply was used, resulting in a lamp current of 7.999 amps as read on the current shunt. In the second test the power supply was set manually to the same value on the indicator but the current shunt reading was 7.996 amps. The light output of the lamp is proportional to the fourth power of the current. The difference in the second and third data set is what is expected from this change in current. The third GSFC irradiance test was the most precise repeat of the first GSFC test.

This retest shows how sensitive this testing is to the procedures used.

Table 31. Percent Difference GSFC 2/GSFC 1 and GSFC 3 /GSFC 1

Radiance	411.x nm	443.x nm	489.x nm	509.x nm	554.x nm	665.x nm	682.x nm	
GSFC2/1	-1.35	0.50	1.23	1.22	1.32	O/R	O/R	7.999 amp
Irradiance								
GSFC2/1	-3.62	-3.43	-3.34	-3.16	-2.66	2.89	3.99	7.996 amp
GSFC3/1	-1.13	-0.80	-1.32	-1.52	-0.93	-0.93	-1.60	7.999 amp

	Mean	Max	Min
Rad	**0.58**	1.32	-1.35
Irr	**-1.18**	-0.80	-1.60
Both	**-0.44**	1.32	-1.60

5. SIRREX-6 RECOMMENDATIONS

The authors would like to make the following recommendations to improve SeaWiFS ground truth procedures and future SIRREX efforts.

5.1 Future SIRREX

Future SIRREX tests would benefit from the following:

1. A standard 500-mm rod—SIRREX personnel will carry their own 500 mm rod to set the lamp head distance for irradiance tests. This is the most critical distance in these tests. Errors of only a few millimeters will result in the instrument calibration being off by several percent. A fixed rod is the best way for a repeatable setting of this distance.

Some laboratories have baffle arrangements that make the use of this rod or any other measuring method difficult. Such arrangements should be modified.

2. A traveling lamp—NASA will transfer the calibration from its Optronic laboratories FEL-M Standard of Spectral Irradiance Lamp (S/N F-474) to four Hoffman FEL lamps. One of these lamps will then be carried throughout SIRREX as a traveling standard. This will help distinguish between data changes caused by changes in the test instruments and data changes caused by laboratory procedure variations.

5.2 NASA-Provided Equipment

NASA can facilitate the consistency of the ground truth tests by providing each laboratory with the following:

1. 500-mm rod
2. Standard black lollipops

5.3 Consistency of Test Procedures

The SIRREX-6 effort can serve as the basis for discussions of uniform test procedures on the following points:

1. 20 degree cone correction
2. Ambient tests with lollipop
3. Interpolation method of lamp reference data
4. Non-Lambertian correction for plaques

6. CONCLUSIONS

Laboratories tested were uniform to better than ± 2% on average. This is an encouraging result.

Improvements in this agreement can be achieved by working low-level details of the equipment and the data reduction practices of the individual laboratories.

Future SIRREX tests of some sort will be needed to monitor and improve these results.

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REFERENCES

1. "Report of Calibration of One Standard of Spectral Irradiance, OL FEL-M S/N: F-474," Optronic Laboratories, Inc, Project No: 904-711, September 20, 1997
The SeaWiFS Technical Report Series

2. Vol. 25
Mueller, J.L., and R.W. Austin, 1995: Ocean Optics Protocols for SeaWiFS Validation, Revision 1. *NASA Tech. Memo. 104566*, Vol. 25, S.B. Hooker, E.R. Firestone, and K.G Acker Eds., NASA Goddard Space Flight Center, Greenbelt, Maryland, 67pp

3. Vol. 34
Mueller, J.L., B.C. Johnson, C.L. Cromer, S.B. Hooker, J.T. McLean, and S.F. Bigger, 1996: The Third SeaWiFs Intercalibration Round-Robin Experiment (SIRREX-3), 19-30 September 1994. *NASA Tech. Memo. 104566*, Vol. 34, S.B. Hooker, E.R. Firestone, and K.G Acker Eds., NASA Goddard Space Flight Center, Greenbelt, Maryland, 78pp

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For the sixth Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) Intercallibration Round-Robin Experiment (SIRREX-6), NASA personnel carried the same four Satlantic in-water radiometers to nine separate laboratories and calibrated them. Two of the sensors were seven-channel radiance heads and two were seven-channel irradiance heads. The calibration and data reduction procedures used at each site followed that laboratory's normal procedures. The reference lamps normally used for the calibration of these types of instruments by the various laboratories were also used for this experiment. NASA personnel processed the data to produce calibration parameters from the various laboratories for comparison.

These tests showed an overall agreement at better than the ± 2% level. Analysis of each laboratory's efforts and specific data handling procedures are included.

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