Long Term Monitoring of Radiometer Sensitivity for Radiometric Comparisons among Optical Laboratories

Gerhard Meister[a], Giulietta S. Fargion[b], and Charles R. McClain[c]

[a]Futuretech Corp., NASA Ocean Biology Processing Group, Code 614.2, Goddard Space Flight Center, Greenbelt, MD 20771, USA;
[b]SDSU/CHORS, 6505 Alvarado Rd., Suite 206, San Diego, CA 92120, USA;
[c]NASA, Ocean Biology Processing Group, Code 614.2, Goddard Space Flight Center, Greenbelt, MD 20771, USA

ABSTRACT

The SIMBIOS (Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies) Program was conceived as a result of a NASA management review of the agency's strategy for monitoring the bio-optical properties of the global ocean through space-based ocean color remote sensing. SIMBIOS Radiometric Intercomparisons (SIMRICs) were carried out in 2001 and 2002. The purpose of the SIMRICs was to ensure a common radiometric scale among the calibration facilities that are engaged in calibrating in-situ radiometers used for ocean color related research and to document the calibration procedures and protocols. The SeaWiFS Transfer Radiometer (SXR-II) measured the calibration radiances at six wavelengths from 411nm to 777nm in the participating laboratories. The measured radiances were compared with the radiances expected by the laboratories. NIST calibrations of the SXR-II were obtained in December 2000, December 2001 and January 2003. Two independent light sources (SQMs, SeaWiFS Quality Monitors) were used to monitor changes in the SXR-II responsivity between the NIST calibrations and after, with monthly measurements until the end of 2003, and less frequent measurements thereafter. This paper discusses the calibration and trending history of the SXR-II from December 2000 to June 2008.

Keywords: radiometer, ocean color, long term monitoring

1. INTRODUCTION

Optical remote sensing of the earth has become an important data source for various science fields, from biology, geography, and geology to meteorology, oceanography and climate research. Especially for climate studies, it is important to obtain global data sets that cover large time periods of 10 years or more. The only technique to obtain global data sets is satellite data. For surfaces covered by land, the longest time series available so far is the NOAA (National Oceanic and Atmospheric Administration) AVHRR (Advanced Very High Resolution Radiometer) time series, which combines the data from four satellites into a continuous dataset covering twenty years from 1981 to 2001. No comparable dataset is available for oceans.

NASA's Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Project[1] had a worldwide ocean color data collection program, funded in-situ bio-optical data collection, plus an operational data processing and analysis capability. The SIMBIOS Program goal was to assist the international ocean color community in developing a multi-year time-series of calibrated radiances which transcends the spatial and temporal boundaries of individual missions.

The SIMBIOS Program consisted of the SIMBIOS Science Team and the SIMBIOS Project Office.[2] SIMBIOS Science Team Principal Investigators were primarily composed of persons selected under the SIMBIOS NASA Research Announcement (NRA) 1996 (i.e. SIMBIOS Team 1997-1999) and NRA 1999 (i.e. SIMBIOS Team 2000-2003). The SIMBIOS Program was discontinued in 2003. Some of its activities were continued by the Ocean Biology Processing Group (OBPG, www.oceancolor.gsfc.nasa.gov).

Further author information:
G.M.: E-mail: Gerhard.Meister@nasa.gov

Several calibration round-robin intercomparison experiments were conducted by the SIMBIOS Project, see Meister et al.[3] for a description of the specific goals of these round-robins and their motivation. The main purpose of the SIMRICs was to ensure a common radiometric scale among the calibration facilities that are engaged in calibrating in-situ radiometers used for ocean color related research and to document the calibration procedures and protocols. The participating laboratories include academic institutions, government agencies and instrument manufacturers.

Three round-robins took place under the SIMBIOS program, they have been documented in NASA Technical Memoranda:

- SIRREX-6 (Riley and Bailey[4])
- SIMRIC-1 (Meister et al., 2002[5])
- SIMRIC-2 (Meister et al., 2003[6])

All three round-robins were based on the SeaWiFS Transfer Radiometer II (SXR-II). The SIMBIOS Radiometric Intercomparison (SIMRIC) series was started by the SIMBIOS Project as a successor to the SIRREX (SeaWiFS Intercalibration Round-Robin Experiment) series. SIRREX-6[4] was a joint venture of the SeaWiFS and the SIMBIOS projects, during which 10 laboratories were visited by NASA personnel, who carried 2 radiance and 2 irradiance radiometers and had them calibrated at each laboratory. The calibration coefficients were compared, and it was found that the average agreement was about ± 2 %, but there were some outliers up to 8 %. For the SIMRIC series, the SXR-II was calibrated at NIST in yearly intervals. During the SIMRICs, the SXR-II measured radiances of the calibration sources were compared to the radiances expected by the participating laboratories.

A third SIMRIC was started, but not completed due to the termination of the SIMBIOS project. Preliminary results from SIMRIC-3 are given in the appendix as an example for the type of results achieved by the SIMRIC activities.

This report focuses on the calibration and trending history of the SXR-II. The yearly NIST calibrations of the SXR-II provided a radiometer of the highest quality available. The monitoring of the SXR-II with specialized light sources was critical for achieving the desired accuracy, especially for channel 1 (412nm) of the SXR-II. The trending of the SXR-II over more than 5 years after the final NIST calibration resulted in a unique time series.

2. NIST CALIBRATIONS OF SXR-II

The SeaWiFS Transfer Radiometer II (SXR-II, S/N 104) is a portable transfer radiometer with 6 wavelength channels. It has been designed by the Optical Technology Division at the NIST. It was built by Reyer Corp., New Market, MD. Its primary purpose is to measure radiances produced by calibration light sources in laboratories in order to assess the calibration accuracy of the respective laboratory. See Meister et al., 2002[5] and Johnson et al., 1998[7] for a complete description.

The SXR-II has been calibrated three times at the Optical Technology Division at the NIST, Gaithersburg, MD at the SIRCUS (Spectral Irradiance and Radiance Calibration with Uniform Sources) facility.[8] The calibrations were made in December 2000, December 2001 and January 2003. The calibration factors are given in Table 1. An estimation of the uncertainties is given in Table 2. Some estimates were copied from the uncertainties for the original SXR.[7] Although we use the same terminology for the uncertainty contributions as in Johnson et al., 1998,[7] the nature of some of these contributions is different: the size-of-source effect (u_a) is the uncertainty associated with the on-axis cavity measurement (see section 3.3 in Meister et al., 2003[6]), and the long-term drift (u_d) is the uncertainty after the linear interpolation in time of the calibration coefficients. The combined uncertainty for the SXR-II is estimated to be 0.8 % (k=1) by taking the root of the sum of the squares of the contributions listed in Table 2 (law of error propagation). We estimate that for channels 1 and 6 an additional 0.5% uncertainty should be included to account for a worse temporal stability (for time periods on the order of several days/weeks) as compared to the other channels. Adding this uncertainty quadratically yields a combined uncertainty of about 1.0% for channels 1 and 6. It is surprising that the two channels with

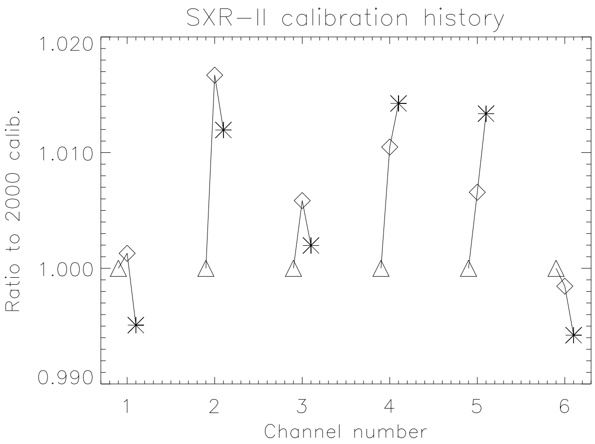

Figure 1. The NIST calibration coefficients for the SXR-II for the three SIRCUS calibrations, normalized to the first calibration. Triangles show the December 2000 calibration (equals 1 by definition), diamonds show the December 2001 calibration, and stars show the January 2003 calibration. Comparing the December 2001 and January 2003 calibrations, the biggest decrease is seen in channel 1 (the calibration coefficient dropped by 0.6%, i.e. the responsivity increased), the biggest increase is seen in channel 5 (the calibration coefficient increased by 0.7%, i.e. the responsivity decreased).

the worst temporal stability for time periods on the order of several days/weeks are the most stable over the two year calibration history, see Fig. 1. The changes in calibration coefficients from December 2001 to January 2003 for the two SXR-II calibrations on SIRCUS are within ±0.7%, see Table 1 and Fig. 1, which is much smaller than the changes from December 2000 to December 2001 (up to 1.6%).

To calculate the calibration coefficients at a certain date of a SIMRIC-2 measurement, the calibration coefficients were linearly interpolated in time between the December 2001 and the January 2003 calibrations. The error associated with this procedure (u_d) is about 0.5%. The temporal evolution of the calibration coefficients was adjusted to represent features seen in the monitoring data for SXR-II channel 1, see below.

Fig. 2 shows the responsivity of the SXR-II channels as a function of wavelength for the in-band wavelengths, this means for those wavelengths with a high responsivity, for the SIRCUS calibrations from December 2000, December 2001, and January 2003. It can be seen that there is almost no spectral shift in the responsivities between the three calibrations for the in-band region. Table 1 shows that the center wavelength varies by less than 0.1nm. The center wavelength is calculated as

$$\lambda_m = \frac{\int_0^\infty \lambda \cdot RSR(\lambda) d\lambda}{\int_0^\infty \cdot RSR(\lambda) d\lambda} \tag{1}$$

The out-of-band (OOB) response is shown in Fig. 3. The calibrations from December 2001 and January 2003 agree extremely well. The values from December 2000 are different in parts of the OOB region. It is not clear whether this is due to a real instrument sensitivity change or not. Except for the region around 800nm of channel 5, the differences are for values less than 10e-5. The maximum variation of the ratio of OOB to total RSR is in band 1 (0.06%, see table 1). It can be concluded that the RSRs have been very stable from December 2000 to January 2003, possibly with the exception of channel 5.

3. STABILITY MONITORING OF SXR-II

To monitor and assess the stability of the SXR-II between NIST calibrations, the SIMBIOS project acquired two commercially available light sources. These light sources were designed similar to the NIST/NASA designed SeaWiFS Quality Monitor (SQM).[9] The first light source acquired was the SQM-II from Satlantic, the second the OCS-5002 from YES, see Meister et al., 2003[6] for details on the light sources. The OCS-5002 has three internal monitors:

Table 1. SXR-II calibration coefficients $< \mathrm{D_{cs}} >$ $[\mathrm{V\,cm^2 sr\,nm}/\mu\mathrm{W}]$ for gain 1 on the SXR-II amplifier (multiplied by -1, the radiometer provides negative voltages) and moment wavelengths λ_m for the 6 SXR-II channels. The coefficients from January 2003 are called $< \mathrm{D_{cs}^{2002}} >$ for consistency in terminology with the two previous calibration coefficients ($< \mathrm{D_{cs}^{2000}} >$ and $< \mathrm{D_{cs}^{2001}} >$). The difference Δ in the coefficients between two consecutive calibrations is calculated as e.g. $< \mathrm{D_{cs}^{2002}} >$ minus $< \mathrm{D_{cs}^{2001}} >$ and given in %. The center wavelength λ_m^{2000} is provided for each calibration, as well as the ratio of out-of-band (OOB) RSR to total RSR, where OOB is defined as being less than 1% of the maximum RSR value.

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5	Channel 6
λ_m^{2000} [nm]	410.69	441.51	487.58	546.89	661.91	776.71
λ_m^{2001} [nm]	410.66	441.46	487.57	546.88	661.86	776.63
λ_m^{2002} [nm]	410.65	441.45	487.55	546.86	661.84	776.63
OOB^{2000} [%]	0.21	0.12	0.33	0.55	0.37	0.44
OOB^{2001} [%]	0.27	0.14	0.36	0.57	0.35	0.49
OOB^{2002} [%]	0.25	0.13	0.33	0.54	0.35	0.49
$< \mathrm{D_{cs}^{2000}} >$	0.65511	0.92577	0.11749	0.20207	0.17642	0.017722
$< \mathrm{D_{cs}^{2001}} >$	0.65595	0.94123	0.11818	0.20419	0.17758	0.017694
$< \mathrm{D_{cs}^{2002}} >$	0.651887	0.936835	0.117723	0.204956	0.178774	0.017619
$\Delta < \mathrm{D} >$ (2001 – 2000) [%]	0.1	1.6	0.6	1.0	0.7	-0.2
$\Delta < \mathrm{D} >$ (2002 – 2001) [%]	-0.6	-0.5	-0.4	0.4	0.7	-0.4

Table 2. Preliminary uncertainty estimates for SXR-II channels 2 to 5. The uncertainties $u_D, u_d, u_{\mathrm{flux}}, u_{\mathrm{rep}}, u_a$, relate to the calibration coefficient D, the drift of the calibration coefficient, the nonlinearity, the repeatability, the size-of-source effect, respectively (see Johnson et al., 1998[7] for a description of these errors in the original SXR). The statistical error from averaging over several scans/samples and the error produced by the amplifier for different gains are negligible ($< 0.1\%$). u_{setup} is the uncertainty from aligning the SXR-II. u_c is the combined uncertainty. For channels 1 and 6, u_c is about 1.0%, see text.

u_D [%]	u_d[%]	u_{flux} [%]	u_{rep} [%]	u_a [%]	u_{setup} [%]	u_c [%]
0.5	0.5	0.1	0.1	0.2	0.3	0.8

- Blue monitor (center wavelength at about 425nm, FWHM from about 375nm to 475nm)
- White monitor (center wavelength at about 525nm, FWHM from about 375nm to 650nm)
- Red monitor (center wavelength at about 625nm, FWHM from about 600nm to 675nm)

Both SQMs contain 16 light blubs, 8 with a lower wattage (LoBank) and 8 with a higher wattage (HiBank). The LoBank and HiBank can be used either separately or simultaneously, but there is no mechanism to control a single light bulb. Both SQMs have special mechanism for the ramp up of the current to the light bulbs.

3.1 Measurement Protocol

A time series of measurements of the SQMs with the SXR-II was taken in the SIMBIOS Optical Laboratory at NASA Goddard Space Flight Center, Greenbelt, MD. The facilities can be seen in Fig. 4. The room is not at a stable temperature. The baffling material is felt, which has a reflectance factor of about 0.02 in the wavelength range of the SXR-II. The SQM-II and the OCS-5002 are placed next to each other on an optical table. The SXR-II is placed on the other end of the optical table. The distance SXR-II/OCS-5002 is 1.3 m.

For a measurement of the OCS-5002 with the SXR-II, the following measurement protocol is used:

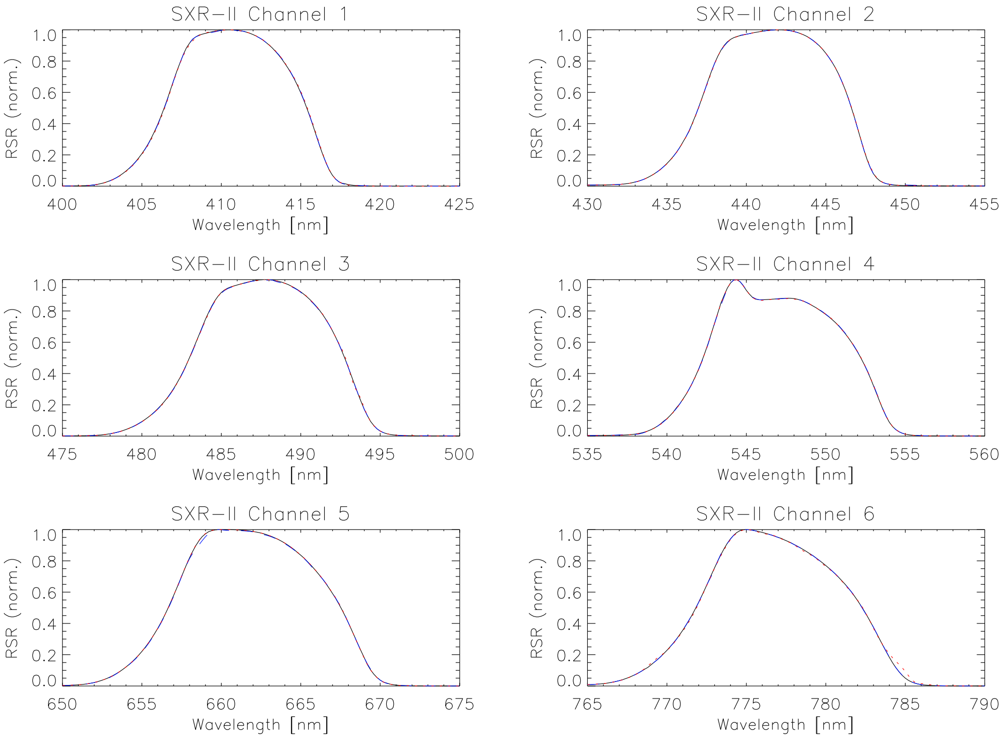

Figure 2. Responsivity $RSR(\lambda)$ of the SXR-II channels as a function of wavelength (interpolated values, normalized to the maximum value) for the in-band region. The solid black line shows RSR from the SIRCUS January 2003 calibration, the dashed blue line from the SIRCUS December 2001 calibration, the dotted red line from the SIRCUS December 2000 calibration. It is hard to identify any change in most channels from these plots.

- Turn on SXR-II, ILX temperature controller and Fluke voltmeter, at least 4 hours before taking measurements, preferably on the day preceding the measurements.
- Fine tune SXR-II orientation using SXR-II eyepiece and center of the SQM exit aperture marked on the SQM caps.
- Provide power to OCS-5002.
- Switch the OCS-5002 control knob to 'STBY'. Wait for at least half an hour. Usually the waiting period was extended until the heater for the electronics had heated the SQM to 35° C or at least 30° C. This was done to reduce the warmup period with the bulbs on.
- Start computer logging of OCS-5002 data.
- Measure the OCS dark current with the cap on the exit aperture for 3 minutes.
- Ramp up HiBank by switching the control knob to 'MED'.
- 18 minutes after HiBank rampup, remove cap from exit aperture.
- 20 minutes after HiBank rampup, start signal measurements with the SXR-II. Taking 6 scans usually takes 7 minutes. SXR-II dark current measurements (3 scans each) are taken before and after the signal measurements.
- Close the OCS-5002 exit aperture with cap for at least 1 minute.
- 30 minutes after HiBank rampup, switch control knob to 'LOW', i.e. ramp up the LoBank.

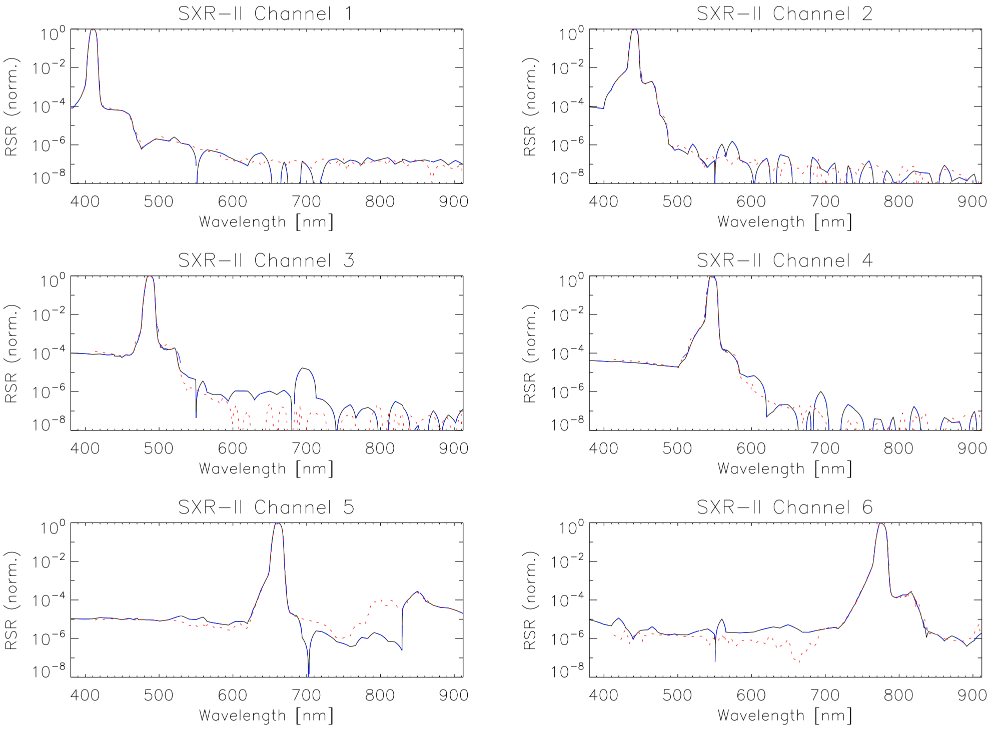

Figure 3. Responsivity $RSR(\lambda)$ of the SXR-II channels as a function of wavelength (interpolated values, normalized to the maximum value) for all measured wavelengths (logarithmic plot). The solid black line shows RSR from the SIRCUS January 2003 calibration, the dashed blue line from the SIRCUS December 2001 calibration, the dotted red line from the SIRCUS December 2000 calibration.

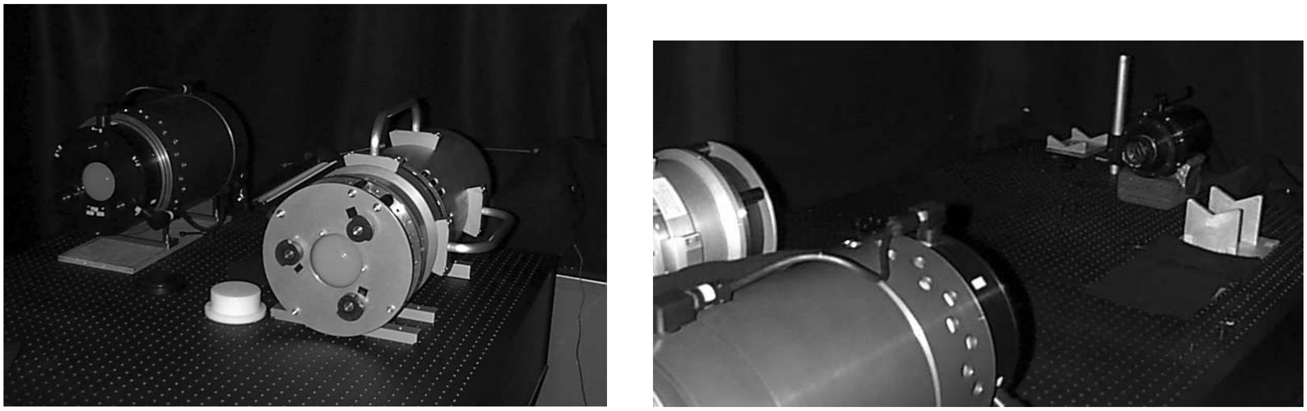

Figure 4. Left: the OCS-5002 (right) and the SQM-II (left) on the optical table in the SIMBIOS Optical Laboratory at NASA Goddard Space Flight Center. Right: there are two separate mounts for the SXR-II to view the SQMs. The SXR-II is in a temporary mount in the picture, between the two fixed mounts.

- Repeat the steps described for HiBank above with the LoBank.
- Switch control knob to 'STBY'.
- After the current has been ramped down to 0, measure OCS-5002 dark current for 3 minutes. In the processing of the OCS data, this dark current is subtracted from the internal monitor signals rather than the dark current measured before, because it is closer to the LoBank measurements, which are more sensitive to the dark current.
- Switch control knob to 'OFF'. Cut power from OCS-5002. Stop computer logging of SQM-II data. Backup SXR-II and SQM-II data.

These measurements were done on three consecutive days in 2002, once a month. After 2002, the frequency of measurements was reduced.

The protocols for SQM measurements suggest a 1 hour warmup period for HiBank and LoBank each. The warmup period was reduced to 20 minutes to reduce the burn time of the bulbs.

The protocol for the SXR-II/SQM-II measurements has been described in Meister et al., 2002.[5] The major difference is that the SQM-II has a 1 hour warmup time for LoBank and HiBank separately. During this warmup, the currents are in a 'coarse-adjust' mode, thus it is not possible to reduce the warmup time. For the SQM-II measurements, the SXR-II optics was inserted into the SQM-II aperture.

The SQM-II internal detector readings increased during SIMRIC-1 by about 10%, whereas the SXR-II measurements during that period were relatively stable (±0.5% for the corresponding SXR-II channel). It was concluded that the SQM-II detector was not usable.

3.2 Results

The measurements (normalized to the mean) of the OCS-5002 SQM are shown in Fig. 5. Due to the different centerwavelengths and bandwidths, the trends in the SXR-II channels and the internal monitor data are not expected to be identical. It can be seen that the variations over shorter time periods (up to several months), the differences between monitor data and SXR-II data are generally very consistent, to about the 0.5% level. There is a significant decrease in lamp output in 2002 which is captured similarly by the SXR-II and the OCS monitors.

Channel 2 of the SXR-II matches the wavelength of the blue OCS monitor relatively well, and the trends in both agree well. SXR-II channel 1 is at a shorter wavelength than the blue monitor, and it does degrade more over the whole time series: by about 4% for the LoBank, by about 7% for the HiBank. It is likely that these changes are due to real degradation of the lamp output at 412nm, but it cannot be proven from this data set.

For both the Hi and LoBank, SXR-II channel 3 trends very similar to the white OCS monitor. This could be a coincidence, since the white monitor covers a much broader wavelength range than channel 3 (275nm vs 10nm). The white OCS monitor (centered at 525nm) also seems to agree better with the long term trends in SXR-II channels 5 and 6 (centered at 662nm and 777nm) than the red monitor (centered at 625nm), which is surprising. Note that the red and the blue monitor readings decrease from 2004 to 2008 for the HiBank, where as the white monitor increases, which is also surprising.

Overall, the differences between the SXR-II measurements and the OCS monitor measurements are very consistent for HiBank and LoBank, e.g. channels 5 and 6 increased by about 2% relative to the OCS red monitor from 2004 to 2008 in both HiBank and LoBank.

It is interesting to note that for the SXR-II measurements of the SQM-II (shown in Fig. 6 for all 6 SXR-II channels), channels 4-6 show an increase of about 2% from 2004 to 2008. This could be either due to an increase in the SXR-II sensitivity of those channels, or an increase of the SQM-II output at those wavelengths.

At the beginning of the time series in Fig. 5, there seems to be an instability of channel 1 of the SXR-II. It is quite possible that it is not the SXR-II, but rather the SQM that is unstable. In 2002, both the OCS-5002 and the SQM-II were used to monitor the SXR-II. Fig. 7 shows the calibrated SXR-II measurements of both light

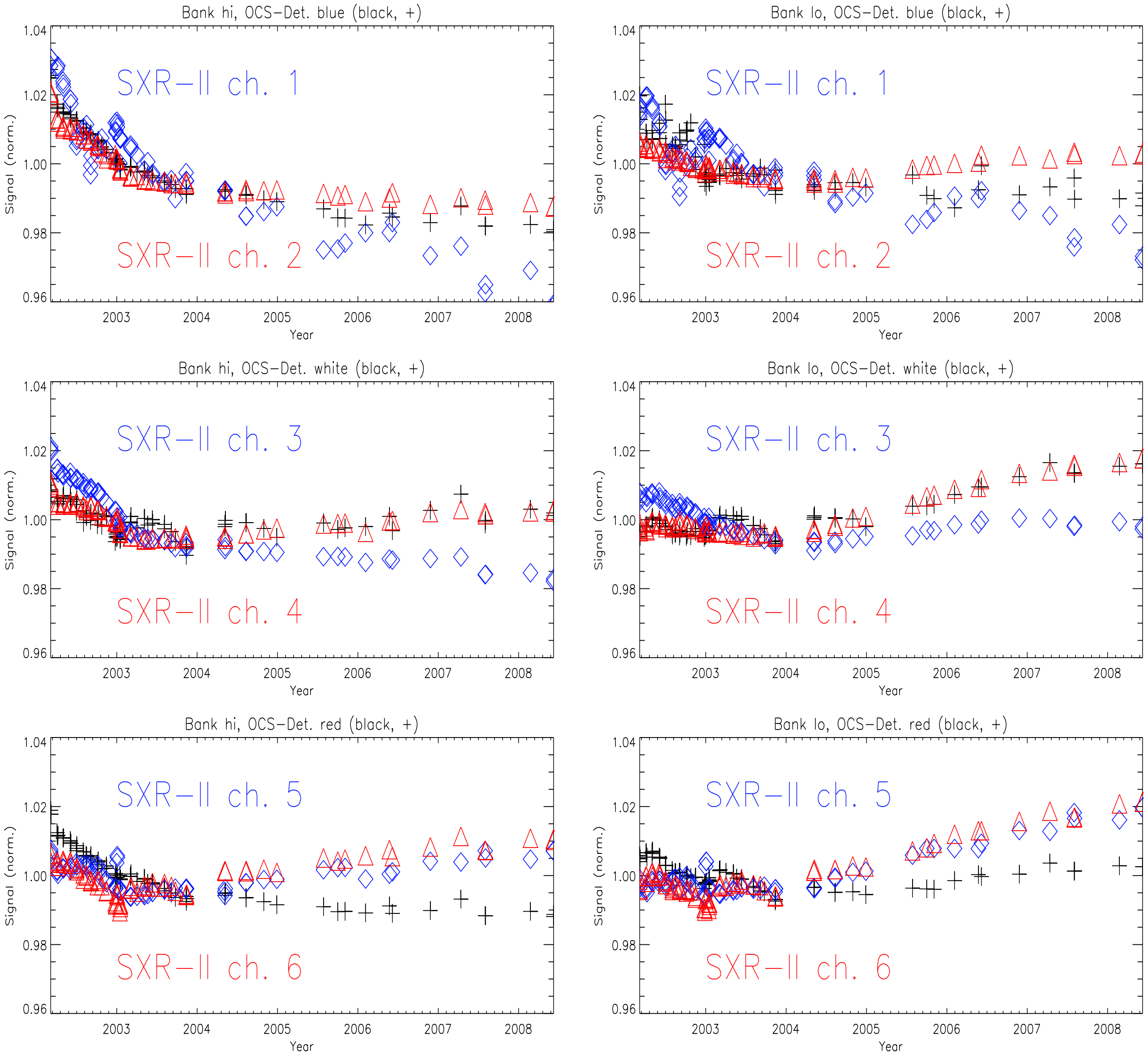

Figure 5. SXR-II measurements of the OCS-5002 HiBank (left) and LoBank (right) as blue diamonds and red triangles, internal OCS-5002 detector measurements as black plus signs. All measurements are displayed as uncalibrated signal divided by the mean signal over time.

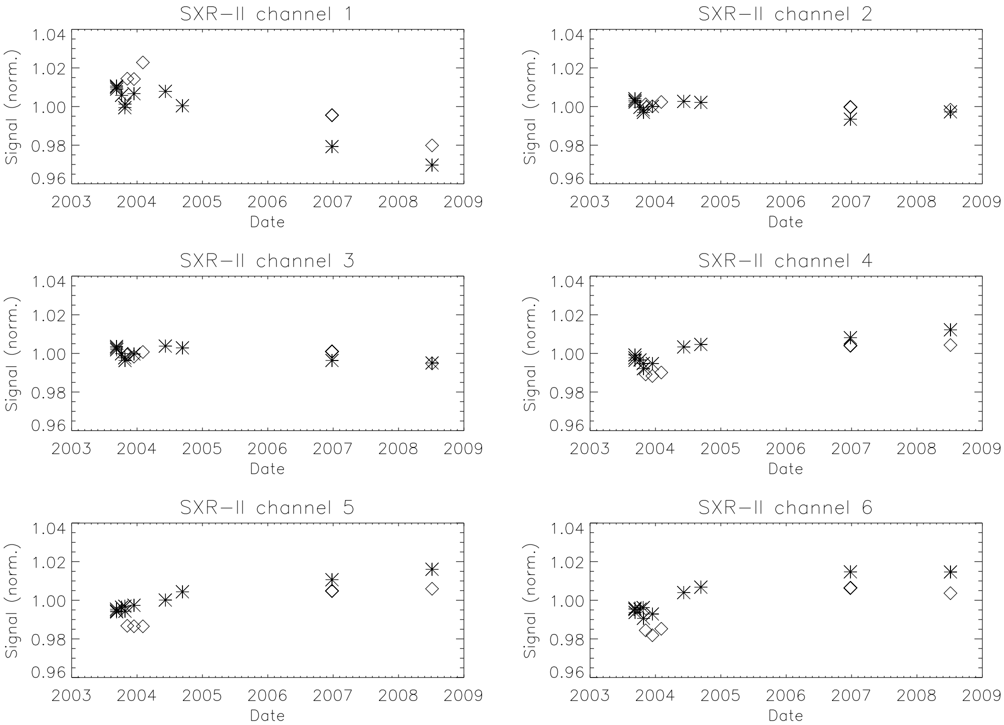

Figure 6. SXR-II measurements of the SQM-II HiBank (diamonds) and LoBank (stars). All measurements are displayed as uncalibrated signal divided by the mean signal.

sources (assuming that the calibration coefficients of the SXR-II evolved linearly between the December 2001 and the January 2003 NIST calibrations) relative to a linear trend in the SQM radiances (see section 2.4.3 in Meister et al., 2003[6] for further details). It can be seen that the SXR-II measurements show a drop of about 2% in the middle of 2002 for both SQMs. This consistent behaviour for both light sources (consistent for all three light sources when counting the OCS HiBank and LoBank as separate light sources) strongly suggests that the SXR-II was varying in 2002. The magnitude of the drop of about 2% is much larger than expected for a high quality transfer radiometer. For the SIMRIC-2 measurements of light sources in other optical laboratories, the SXR-II calibration of channel 1 was adjusted using the data shown in Fig. 7.

4. DISCUSSION AND CONCLUSIONS

The long term trending of the SXR-II using the SQMs revealed an instability of channel 1 of the SXR-II of about 2% in 2002. Such a large variation was not expected. This suggests that for a transfer radiometer of the SXR type, it is necessary to monitor the radiometer with a light source that is stable over several weeks.

Over shorter periods of time (up to several months), the internal monitors of the OCS-5002 agreed well with the SXR-II measurements, with differences of less than 0.5% (except for the 2002 instability of channel 1 of the SXR-II mentioned above). Over the whole time period of more than 6 years, differences between the SXR-II trends and the OCS-5002 monitor trends of typically 2% were seen. It is not clear whether this is due to changes in the SXR-II sensitivity or changes in the monitor sensitivity (or both).

The variations in the NIST calibrations of the SXR-II from December 2000 to January 2003 range from -0.5% in channel 1 (this corresponds to a decrease in sensitivity) to +1.4% in channels 4 and 5 (this corresponds to an increase in sensitivity). It is not clear how much of this variation is due to the uncertainty of the NIST calibrations, but assuming an uncertainty of 0.5%, it is possible that the SXR-II channels 2-5 were stable in the this period to within 1% or better. Stability to within 1% or better is also likely for the time period from early 2002 to the middle of 2008 for channel 2 of the SXR-II because of the good agreement to the blue channel of

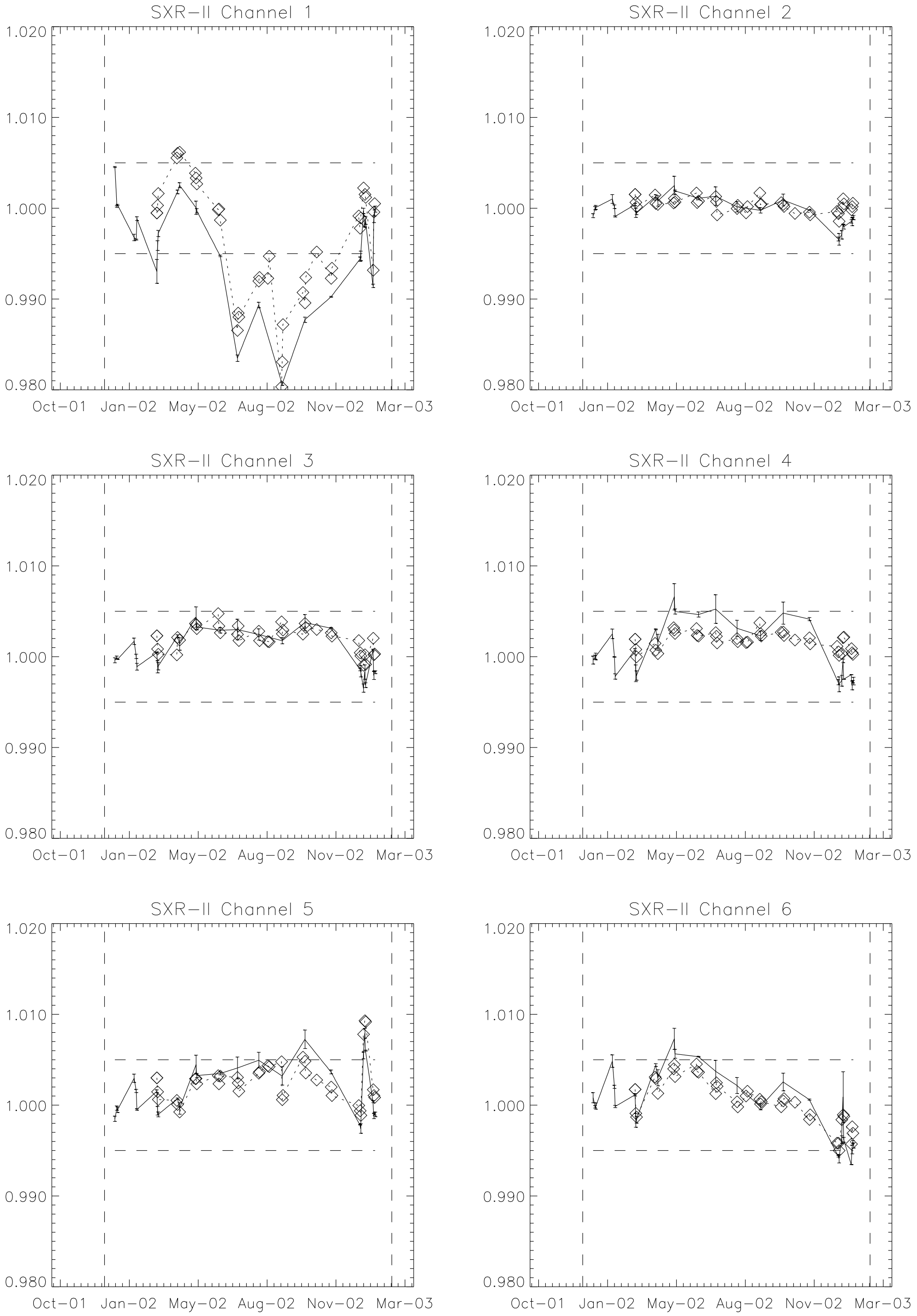

Figure 7. Ratio of the SXR-II measured radiances of the SQM-II (solid line, vertical error bars indicate difference between HiBank and LoBank) and OCS-5002 LoBank (diamonds, connected by dotted line) to the linear trend. The horizontal dashed lines show deviations of 0.5%. The times of the SIRCUS calibrations are marked by vertical dashed lines.

F-737 (primary standard (FEL lamp) of University of Miami) at 50cm

λ_m [nm]	410.7	441.5	487.6	546.9	661.9	776.7
$L_m[\mu\mathrm{W/cm^2\,sr\,nm}]$	0.904944	1.40567	2.29746	3.59116	5.92664	7.66176
$L_e[\mu\mathrm{W/cm^2\,sr\,nm}]$	0.912591	1.39320	2.26599	3.54642	5.81892	7.23013
$\Delta(L_e - L_m)[\%]$	0.844950	-0.887459	-1.36974	-1.24594	-1.81756	-5.63357

F474 (FEL lamp owned by SIMBIOS Project for comparison purposes) at 50cm

λ_m [nm]	410.7	441.5	487.6	546.9	661.9	776.7
$L_m[\mu\mathrm{W/cm^2\,sr\,nm}]$	0.699815	1.11121	1.86477	2.98665	5.07794	6.71012
$L_e[\mu\mathrm{W/cm^2\,sr\,nm}]$	0.726759	1.13283	1.89698	3.04139	5.14037	6.52233
$\Delta(L_e - L_m)[\%]$	3.85022	1.94558	1.72703	1.83286	1.22941	-2.79861

Table 3. SIMRIC-3 results at University of Miami, measured on August 26th, 2003.

the OCS-5002. For the other channels, no similar conclusions can be drawn because either the wavelength range of the OCS-5002 monitor did not agree well with the SXR-II channels (SXR-II channels 1, 3, 4, and 6) or the difference of the SXR-II trends and the OCS-5002 monitor (SXR-II channel 5 and red OCS monitor) is larger than 1%.

If the assumption is made that the OCS-5002 lamps were stable from 2004 to 2008 from 600nm to 800nm (this assumption is supported by the OCS red monitor measurements), the conclusion could be drawn that the SXR-II channels 5 and 6 increased in sensitivity by 2% in that period. During this period, the SXR-II and the OCS-5002 remained in the SIMBIOS Optical Laboratory, with the exception of one week in May 2006, where the SXR-II was moved into a cleanroom. There are no obvious features in the measurements in the middle of 2006 (see Fig. 5), so if indeed a change of the sensitivity of SXR-II channels 5 and 6 occured from 2004 to 2008, it was most likely a result of gradual change, and not event driven. Interestingly, assuming a stable output of the SQM-II above 600nm also suggests a 2% increase in the SXR-II sensitivity for channels 5 and 6.

The NIST calibrations show that there was no significant change in the spectral response of the SXR-II channels for the in-band wavelength region from December 2000 to January 2003. The response in the out-of-band spectral region has been stable as well, with the possible exception of channel 5 around 800nm.

5. APPENDIX

This appendix contains previously unpublished results of SIMRIC-3 measured at the participating laboratories at the University of Miami (table 3) and Wallops Flight Facility (table 4). The radiances measured by the SXR-II are calculated by

$$L_m = \Delta S / < \mathrm{D}_{\mathrm{cs}}^{2002} > \tag{2}$$

see Meister et al., 2003[6] for details on the calculation of the background subtracted signal ΔS, the calibration factors $< \mathrm{D}_{\mathrm{cs}}^{2002} >$ are given in table 1. For SIMRIC-1 and SIMRIC-2, the calibration factors were interpolated, so the results for SIMRIC-3 are likely of lesser quality than those of the preceeding SIMRICs. The radiances expected by the participating laboratories are calculated by

$$L_e = \int_0^\infty L_r(\lambda) \cdot RSR(\lambda) d\lambda \tag{3}$$

where L_r is the expected radiance of the light bulb after reflection of a plaque, and RSR is shown in Fig. 3. See Meister et al.,2003[6] for details regarding the calibration procedures at the University of Miami and Wallops Flight Facility.

ACKNOWLEDGMENTS

Thanks to Steve Brown and Carol Johnson from NIST and Stanford Hooker from NASA for valuable suggestions for the design and execution of the activities described here.

Oriel 7-1399 (primary standard (Oriel irradiance standard) of Wallops Flight Facility)

λ_m [nm]	410.7	441.5	487.6	546.9	661.9	776.7
L_m	0.209731	0.320734	0.516516	0.796760	1.29161	1.60945
L_e	0.195801	0.297457	0.482228	0.749196	1.22219	1.51718
$\Delta(L_e - L_m)[\%]$	-6.64199	-7.25735	-6.63829	-5.96967	-5.37462	-5.73279

Oriel 7-1026 (primary standard (Oriel irradiance standard) of Wallops Flight Facility)

λ_m [nm]	410.7	441.5	487.6	546.9	661.9	776.7
L_m	0.206181	0.316471	0.512169	0.793354	1.29080	1.61053
L_e	0.196613	0.299549	0.487404	0.759760	1.24273	1.54218
$\Delta(L_e - L_m)[\%]$	-4.64057	-5.34719	-4.83535	-4.23441	-3.72429	-4.24402

Table 4. SIMRIC-3 results at Wallops Flight Facility, measured on June 24th, 2003.

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