AVIRIS/SeaWiFS Cross-Calibration for 1999

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Background: The successful combination of data from different ocean color sensors depends on the correct interpretation of signal from each of these sensors. Ideally, the sensor-measured signals are calibrated to geophysical units of spectral radiance, and sensor artifacts are removed and corrected. The calibration process resamples the signal into a common radiometric data space so that subsequent ocean color algorithms that are applied to the data are based on physical processes and are inherently sensor independent.

The objective of this project is to calibrate and validate the on-orbit radiometric characteristics of the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) with underflights of NASA's calibrated Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). This objective is feasible because AVIRIS measures the same spectral range as SeaWiFS at higher spectral resolution (Figure 1).

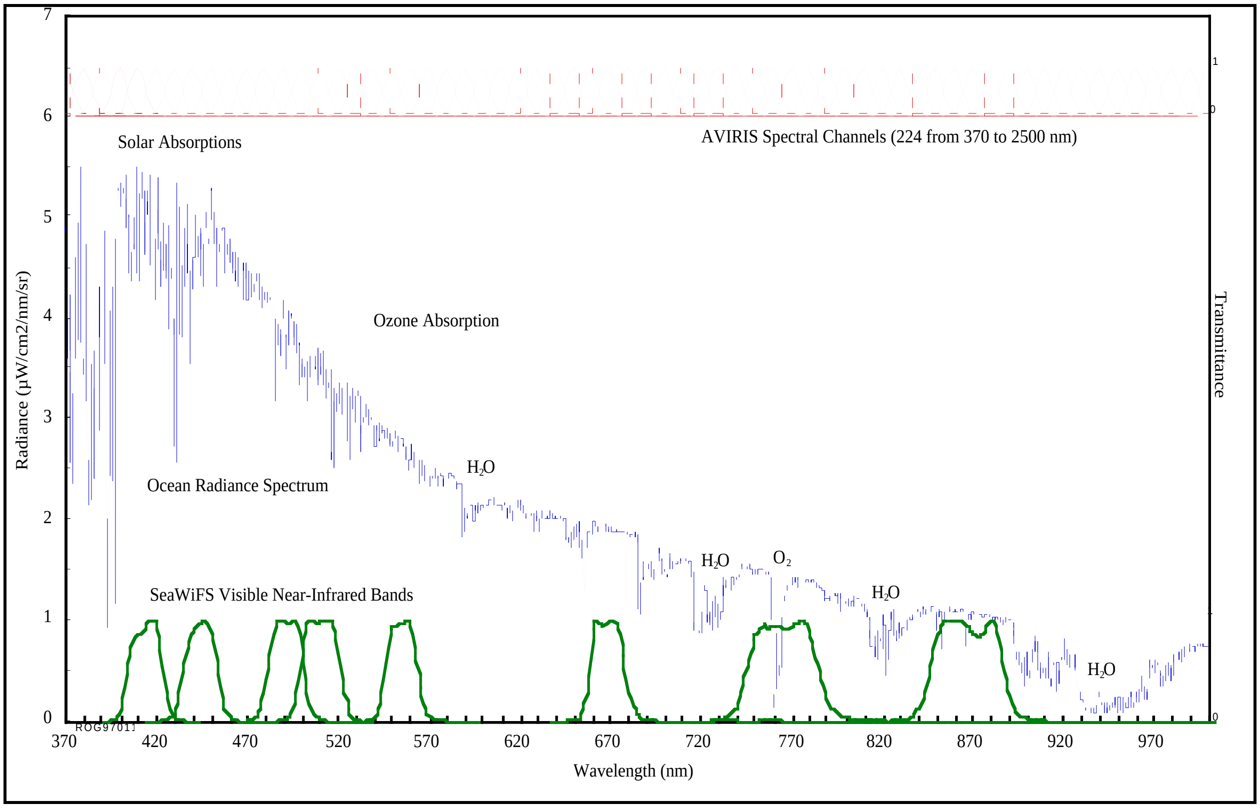

Figure 1. The eight SeaWiFS bands and the AVIRIS spectrally contiguous channels in the region from 370 to 1000 nm. A high spectral resolution modeled plot of the typical upwelling spectral radiance for an ocean target is shown in blue.

In addition to satellite sensor underflights, the AVIRIS project has supported comparison and analysis of the radiometric calibration standards used for AVIRIS and SeaWiFS. To date, both the Ocean Color and Temperature Scanner (OCTS) and SeaWiFS satellite sensors have been under-flown by AVIRIS, with matching spectral, spatial, geometric, radiometric, and temporal domains.

The calibration and validation objective of this project is pursued for the following reasons: (1) calibration is essential for the quantitative use of SeaWiFS and other Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) sensor data, (2) calibration in the laboratory of spaceborne sensors is challenging, (3) satellite sensors are subjected aging on the ground and to trauma during launch, (4) the Earth orbit environment is significantly different than the laboratory calibration environment, (5) through years of effort, AVIRIS has been demonstrated to be well calibrated, and (6) AVIRIS can match the spectral and spatial observation characteristics near the top of the atmosphere at the time of SeaWiFS measurements.

Method: The approach taken for the SIMBIOS Project has been to: (1) determine the calibration accuracy of AVIRIS with high confidence in the laboratory, in flight, and on the runway before flight, (2) underfly the SeaWiFS satellite sensor with AVIRIS matching observation geometry and addressing weather, satellite, aircraft, sensor, and location issues, (3) correct AVIRIS spectral image data to the top of the atmosphere radiance, (4) convolve AVIRIS spectral channels to SeaWiFS bands, (5) determine and extract matching areas with correct observation geometry, and (6) compare and analyze the matchup data and repeat acquisitions for monitoring.

Matching the location, time, and illumination/observation angles of SeaWiFS is critical for comparison of radiometric data. The calibration of the SeaWiFS sensor presented special challenges due to the geometry of the sensor's observations (Figure 2).

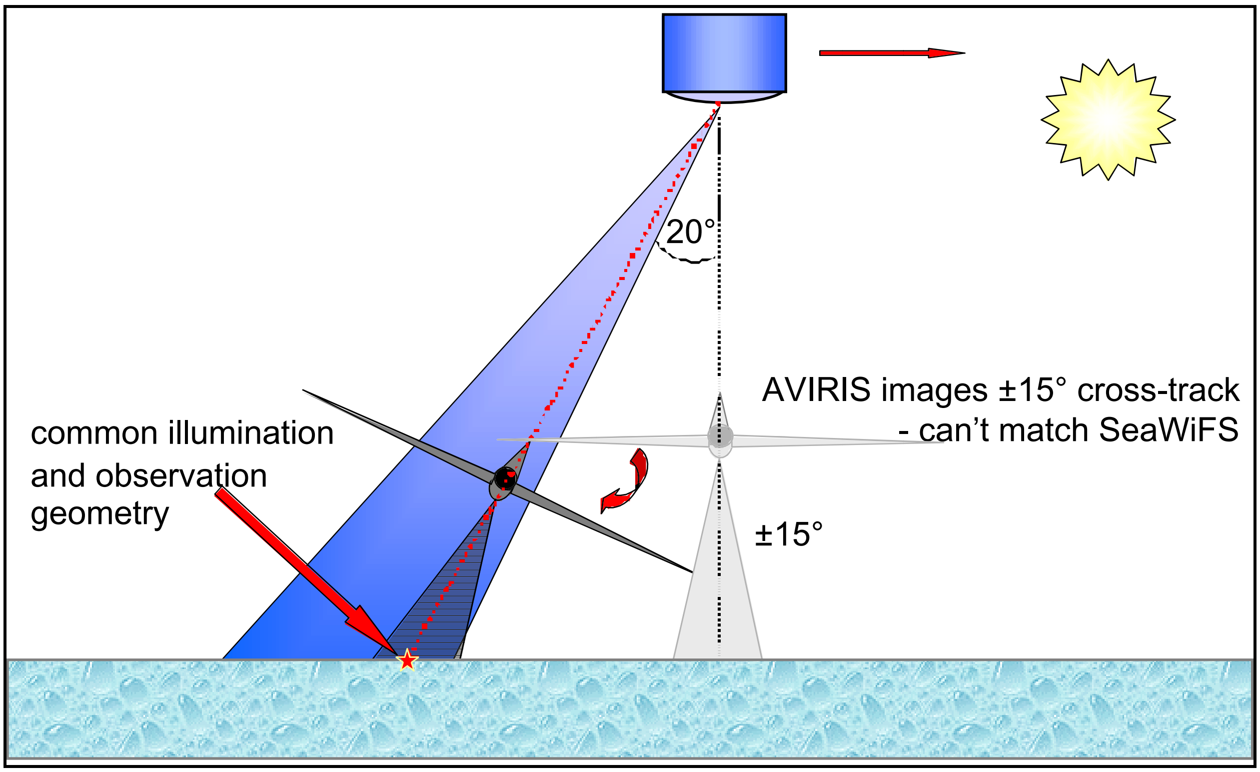

Figure 2: Geometry of SeaWiFS observations, illustrating need to tilt AVIRIS ER-2 platform to match sensor observation angle.

SeaWiFS scans cross-track at an angle 20 deg behind the satellite to avoid sunglint in the field of view. AVIRIS has a 15-deg scan angle. In order to match the >20-deg view angle of SeaWiFS, the AVIRIS ER-2 platform is banked at ~20 deg. This continuous bank results in a circular "flightline" (Figure 3).

Conversion of AVIRIS data to top-of-the-atmosphere radiance is achieved through the use of the MODTRAN atmospheric modeling package. The stability and repeatability of AVIRIS calibration is validated through a series of inflight calibration experiments. With pre- and post-flight calibrations of AVIRIS, coupled with the on-board calibrator, calibration accuracy of better than 2% spectral, 3% radiometric, and 3% spatial have been achieved.

Analysis: AVIRIS data have been measured for the SIMBIOS Project on 970520, 971002, 990807, and 991001. Results from 1997 have been presented elsewhere, and the 991001 analysis is not yet complete, so only the 990807 results will be discussed here.

On 7 August 1999, AVIRIS successfully underflew the SeaWiFS sensor off the east coast of the United States (Figure 4). AVIRIS is typically flown in two circles during the time of a SeaWiFS overpass, in order to span the time of the satellite overpass and ensure that some AVIRIS data is taken during the acquisition window. The data from the flight are processed to calibrated radiance.

Next, the data are corrected to top of the atmosphere radiance using the MODTRAN (Moderate Resolution Transmittance) software atmospheric model, supplemented with Total Ozone Mapping Spectrometer (TOMS) ozone mapper data. The AVIRIS data are then convolved to the reported SeaWiFS spectral response functions.

To compare SeaWiFS and AVIRIS data, the datasets must be warped into the same geometric space so that direct comparisons are available between pixels that match in space, time, illumination angle, and observation angle. Joe Boardman of Analytical Imaging and Geophysics (AIG) developed algorithms and software to enable us to use IDL/ENVI (Interactive Data Language/ Environment for Visualizing Images) software to warp and analyze the unusual circular flightlines and to produce observation and illumination angle from the AVIRIS navigation data. Using this new software, the datasets are co-registered.

With the two datasets projected into the same geometric space, the SeaWiFS and AVIRIS regions (Figure 5) with overlapping observation geometry can be selected, and the resulting radiance compared (Figure 6).

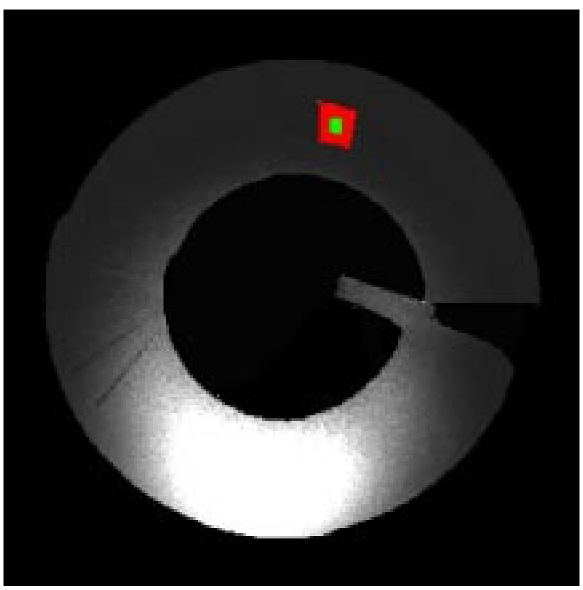

Figure 3: AVIRIS 7 August 1999 underflight data co-registered to SeaWiFS satellite sensor data. The highlighted regions show the zones of 2-deg and 5-deg overlap with the SeaWiFS azimuth and zenith angles.

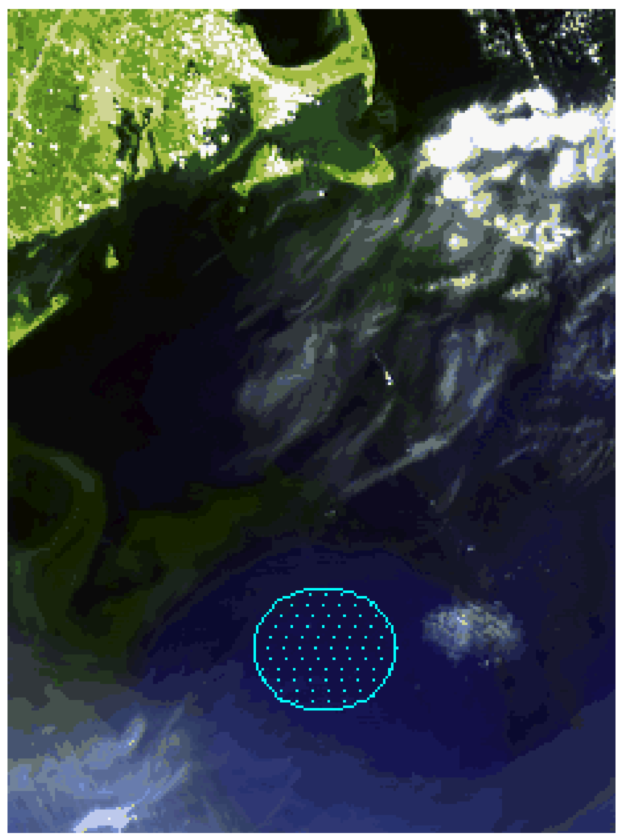

Figure 4. SeaWiFS image acquired at the time of the AVIRIS underflight on 7 August 1999.

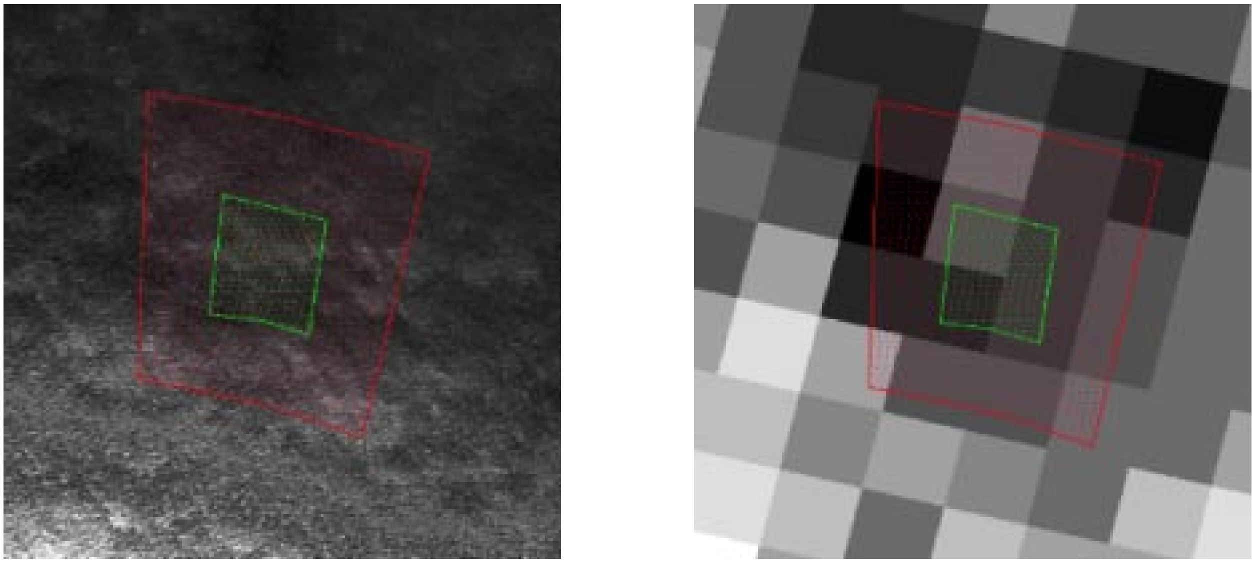

Figure 5. AVIRIS (left) and SeaWiFS (right) images of same region, taken contemporaneously. Regions of matching Sun angle and look angle are shown. Pixels matching to within 5 deg are shown in red shading, while pixels matching to within 2 deg are marked with green.

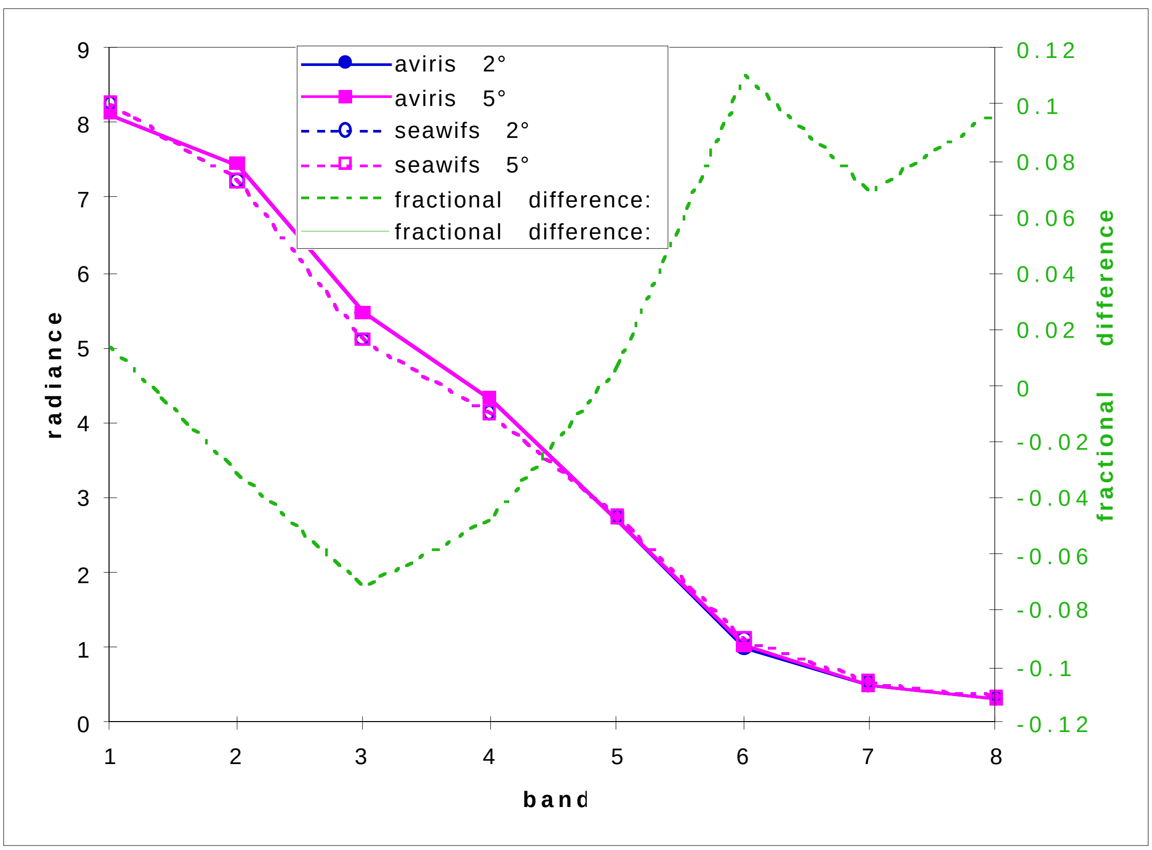

Figure 6. A plot of the SeaWiFS and AVIRIS radiance extracted for the overlapping observation geometry. The fractional differences are also plotted.

The results for the 990807 AVIRIS underflight are presented in Table 1. Two cases are presented: matching illumination/observation angles to within 2 deg, and matching geometry to within 5 deg. Average radiance for matching geometry regions are shown, followed by the fractional differences between the AVIRIS- and SeaWiFS-derived radiance. Agreement within 10% is achieved, with the exception of band 6.

Table 1: Average radiance (µW/cm2/nm/ster) of matching pixels for SeaWiFS and AVIRIS

band	AVIRIS 2 deg	AVIRIS 5 deg	SeaWiFS 2 deg	SeaWiFS 5 deg	fractional diff.: 2 deg	fractional diff.: 5 deg
1	8.14026059	8.14521251	8.257555	8.268457	0.0142045	0.014905
2	7.45552282	7.45220293	7.232165	7.231279	-0.0308839	-0.030551
3	5.48709078	5.48462669	5.121366	5.123866	-0.0714116	-0.070407
4	4.31417291	4.31130431	4.120119	4.123976	-0.0470991	-0.045424
5	2.72906715	2.72690948	2.749137	2.749279	0.00730042	0.008136
6	1.00464081	1.00922162	1.12969	1.131824	0.11069337	0.108322
7	0.50320551	0.50688427	0.540923	0.541329	0.06972802	0.063629
8	0.31177754	0.31496715	0.345674	0.346726	0.09805903	0.091596

The magnitude of this discrepancy is larger than expected and cannot be explained purely by AVIRIS radiometric uncertainty:

calibration	uncertainty	source of uncertainty
Pre-season lab calibration	2-3%	NIST-traceable radiance standard
Hangar calibration (monthly)	2-3%	NIST-traceable radiance standard
In-flight radiometric cal. (3/year)	4%	discrepancy between at-sensor radiance and predicted radiance based on MODTRAN atmospheric model and measured ground reflectance

The Landsat Transfer Radiometer (LXR) was able to view the AVIRIS radiometric calibration standard in June 1999. Analysis of the cross-comparison of the LXR and AVIRIS 1999 radiometric standard was completed with good stability before and after the measurements. Results of this analysis are given in Figure 7.

The LXR measurements show a maximum discrepancy of 2.5% between LXR measured and predicted radiance based on LXR reported spectral response functions and AVIRIS standard radiance. The results with the LXR are consistent with the expected uncertainty of 2% to 3% of the AVIRIS 1999 radiometric calibration standard in this spectral region.

Conclusions: Analysis of these data show radiometric calibration agreement ranging from 2% to 12% across the eight SeaWiFS bands. This discrepancy cannot simply be explained by radiometric uncertainty within the AVIRIS calibration. Further, they are inconsistent with the results from the Landsat Transfer Radiometer experiment that show that the AVIRIS 1999 radiometric calibration standard agrees with the Goddard Space Flight Center LXR at the 2-3% level. Analysis of the SeaWiFS comparison is continuing in an attempt to understand the disagreement. Drifting SeaWiFS filter functions, a systematic error in SeaWiFS reported radiance, and the AVIRIS technique for convolving AVIRIS data with the SeaWiFS filter functions are all being considered as possible sources of the observed discrepancy.

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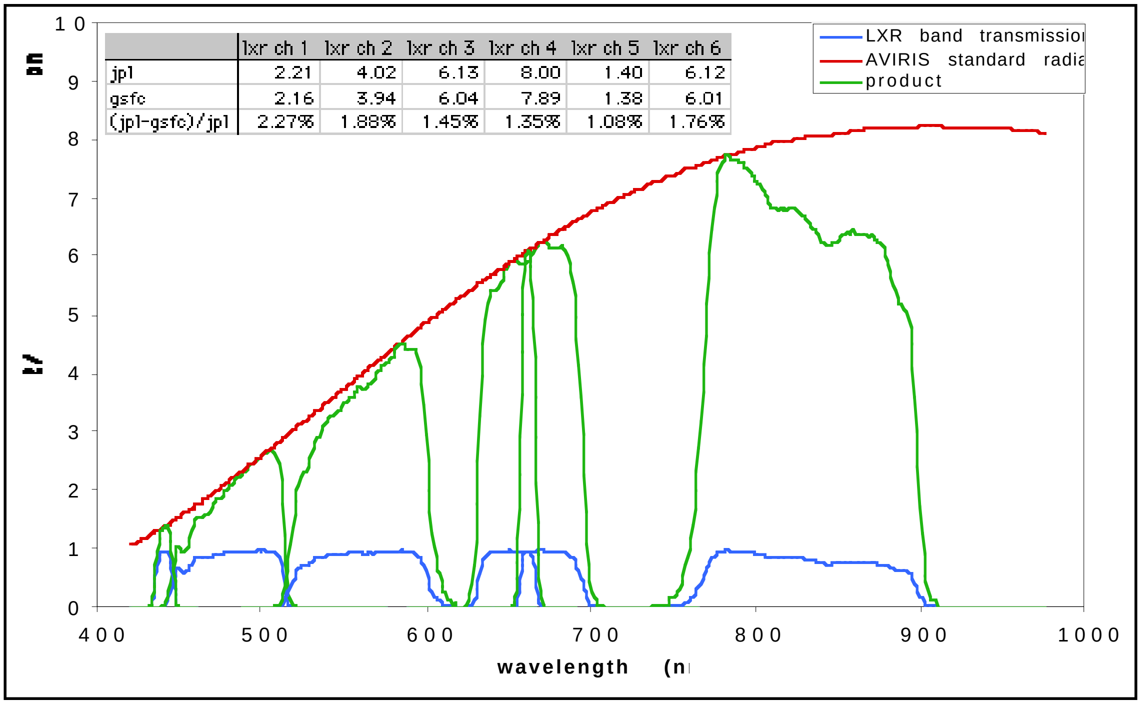

Figure 7. AVIRIS 1999 spectral radiometric calibration standard convolved and integrated to the Landsat Transfer Radiometer (LXR) bands.

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