# Radiometric Comparison of AVIRIS and SeaWiFS 1997-2000

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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 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).

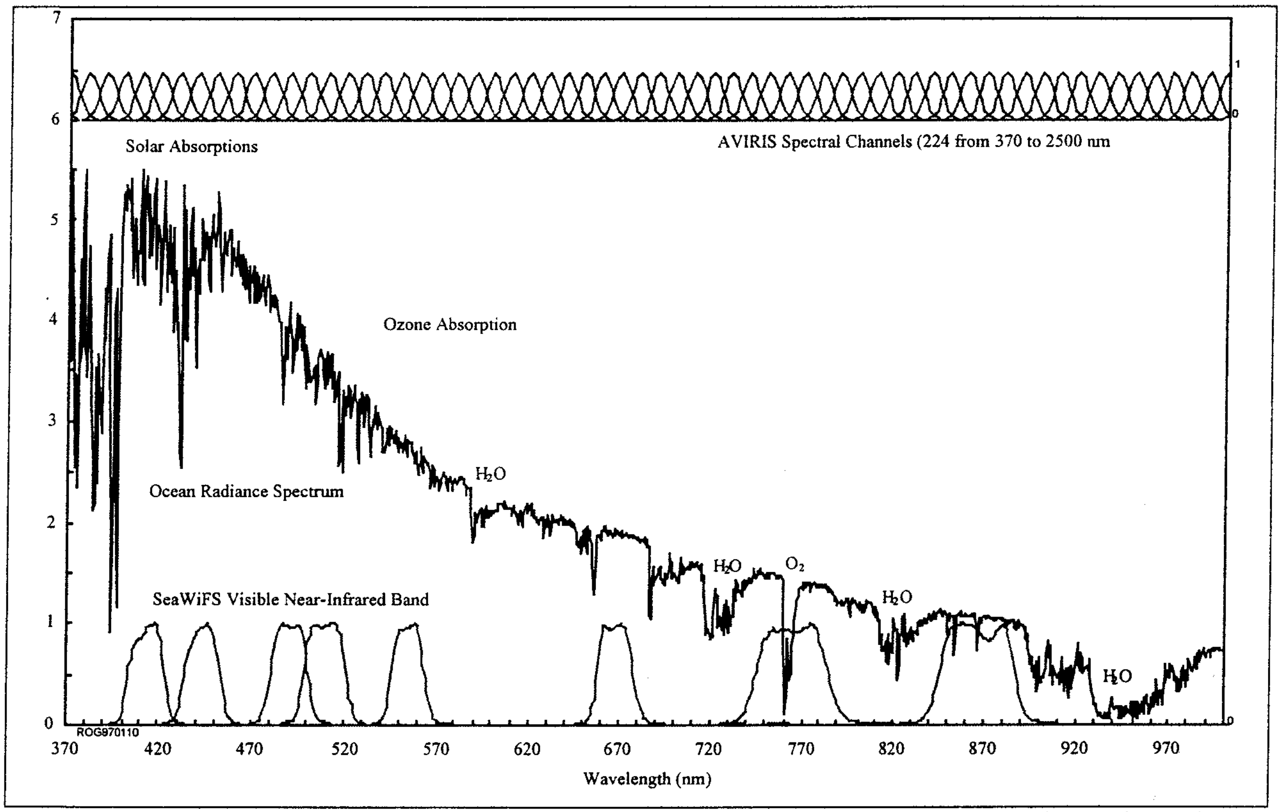

*Figure 1. The eight SeaWIFS bands and the AVIRIS spectrally contiguous channels in the region from 370 to 1000 nm. A high spectral resolution modeled plot of the typical upwelling spectral radiance for an ocean target is shown in blue.*

To date, the AVIRIS and SeaWIFS sensors have collected 8 sets of radiometric data which match in location, observation/illumination geometry, and timing. Three of the 8 sets were free of clouds and were chosen for further analysis. In addition to satellite sensor underflights, the AVIRIS project has supported comparison and analysis of the radiometric calibration standards used for AVIRIS and SeaWIFS.

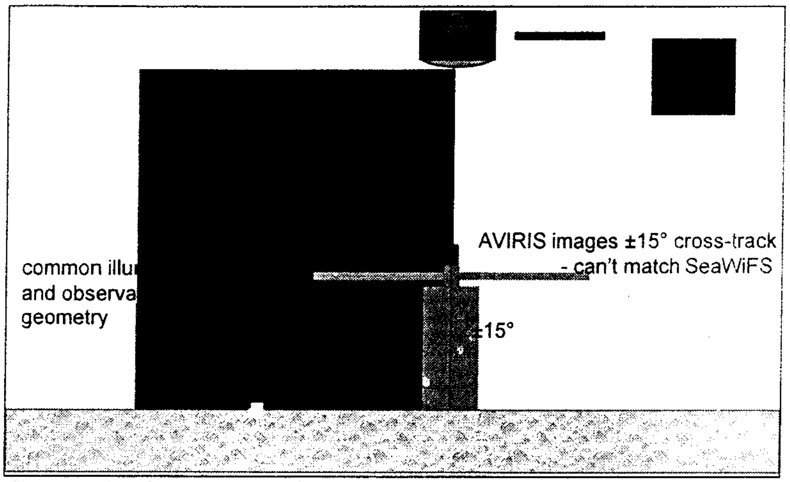

*Figure 2: Geometry of SeaWiFS observations, illustrating need to tilt AVIRIS ER-2 platform to match sensor observation angle.*

There is a systematic discrepancy in the radiometric results from AVIRIS and SeaWiFS. This discrepancy is repeatible from experiment to experiment, and was not removed by the SeaWiFS 2000 data reprocessing. This paper discusses the analysis technique, presents the results, and examines several possible sources of the observed disagreement between AVIRIS and SeaWiFS.

**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; (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).

SeaWiFS scans cross-track at an angle 20° behind the satellite to avoid sunglint in the field of view. AVIRIS has a 15° scan angle. In order to match the >20° view angle of SeaWIFS, the AVIRIS ER-2 platform is banked at ~20°. This continuous bank results in a circular "flightline" (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 atmospheric model, supplimented with TOMS ozone mapper data. The AVIRIS data are then convolved to the reported SeaWiFS spectral response functions.

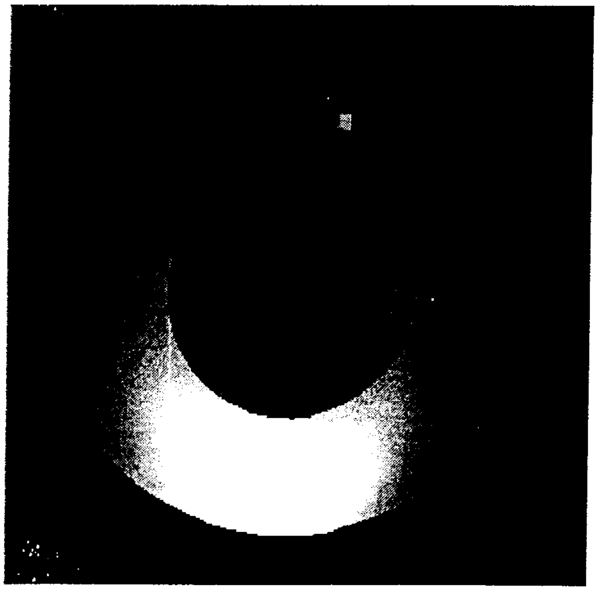

*Figure 4: AVIRIS 7 August 1999 under-flight data co-registered to SeaWiFS satellite sensor data. The highlighted regions show the zones of 2° and 5° overlap with the SeaWIFS azimuth and zenith angles.*

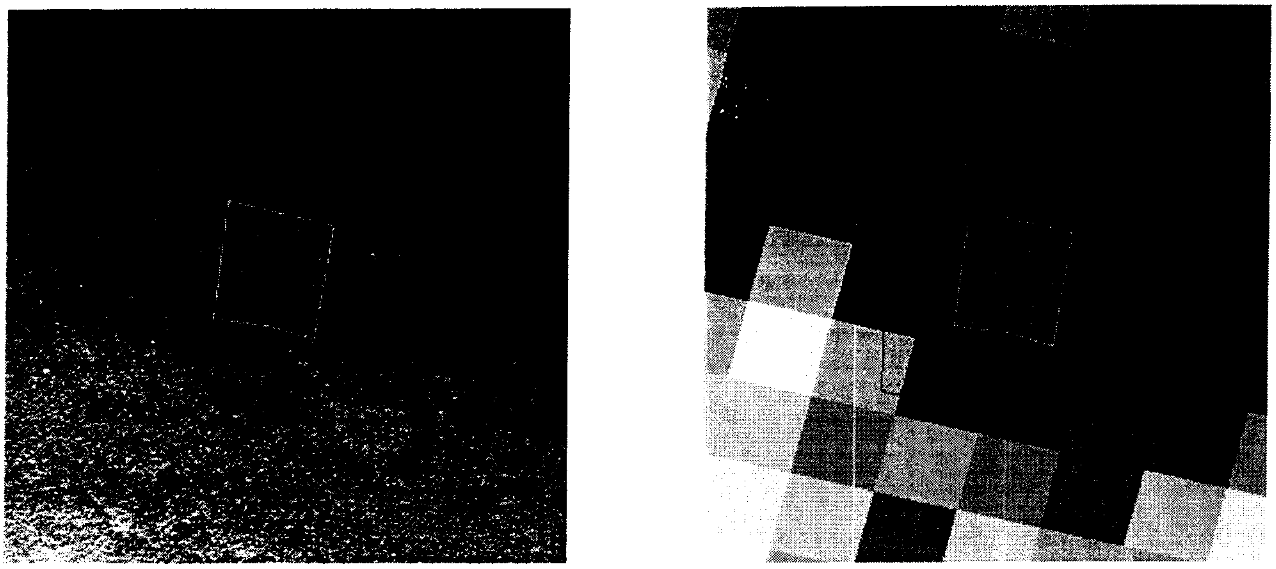

*Figure 5. AVIRIS (left) and SeaWiFS (right) images of same region, taken contemporaneously. Regions of matching sun angle and look angle are shown. Pixels matching to within 5° are shown in red shading, while pixels matching to within 2° are marked with green.*

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.

To compare SeaWIFS and AVIRIS data, the data sets must be warped into the same geometric space, so that direct comparisons are available between pixels which match in space, time, illumination angle, and observation angle. Joe Boardman of AIG developed algorithms and software to enable us to use IDL/ENVI 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 data sets are 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.

**Results**: Of the eight datasets collected for the SIMBIOS Project, those from 990807, 000412, and 001023 were selected for further analysis. The results are presented in Table 1 and graphically in Figure 6. Average radiance for matching geometry regions are shown, followed by the percent differences between the AVIRIS and SeaWIFS-derived radiance.

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

| | Band 1 | Band 2 | Band 3 | Band 4 | Band 5 | Band 6 | Band 7 | Band 8 |
|---|---|---|---|---|---|---|---|---|
| 990807circle 2 | | | | | | | | |
| AVIRIS 5° | 8.126 | 7.428 | 5.461 | 4.291 | 2.709 | 0.997 | 0.506 | 0.312 |
| SeaWiFS 5° | 8.218 | 7.261 | 5.278 | 4.162 | 2.754 | 1.179 | 0.576 | 0.354 |
| % difference 5° | 1.11% | -2.30% | -3.48% | -3.10% | 1.62% | 15.41% | 12.26% | 11.71% |
| 000412 circle 1 | | | | | | | | |
| AVIRIS 5° | 8.546 | 8.399 | 6.598 | 5.373 | 3.700 | 1.808 | 1.010 | 0.754 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SeaWiFS 5° | 9.088 | 8.149 | 6.180 | 5.002 | 3.572 | 1.938 | 1.145 | 0.850 |
| % difference 5° | 5.97% | -3.07% | -6.76% | -7.40% | -3.58% | 6.68% | 11.73% | 11.24% |
| 001023 circle1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| AVIRIS 5° | 6.158 | 5.940 | 4.532 | 3.801 | 2.602 | 1.059 | 0.517 | 0.328 |
| SeaWiFS 5° | 6.702 | 5.946 | 4.427 | 3.697 | 2.598 | 1.171 | 0.578 | 0.366 |
| % difference 5° | 8.12% | 0.11% | -2.36% | -2.82% | -0.15% | 9.57% | 10.56% | 10.41% |

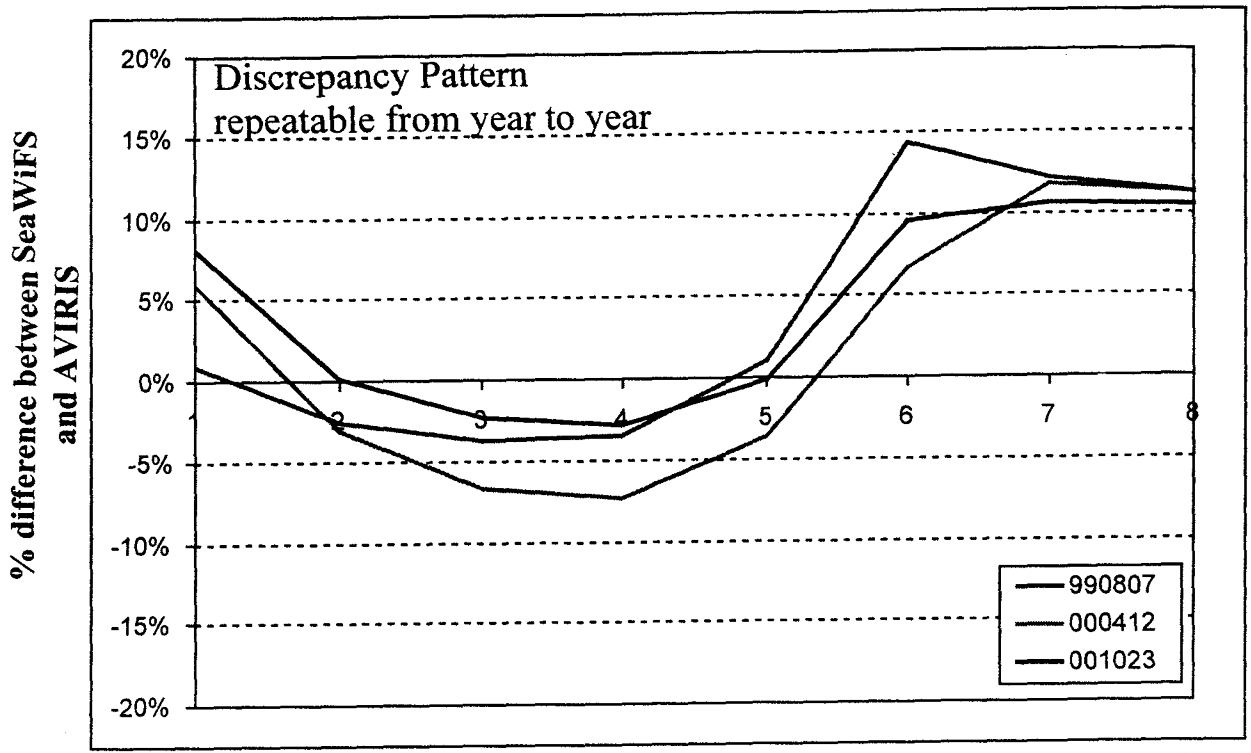

*Figure 6. Percentage difference between the SeaWIFS reported and AVIRIS -predicted radiance extracted for the overlapping observation geometry and closest timing, 5° match.*

**Discussion**: There are several possible explanations for this discrepancy. Each will be discussed below.

*1. AVIRIS Radiometric Uncertainty*: The magnitude of the AVIRIS/SeaWiFS discrepancy can not 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 |

In addition, The Landsat Transfer Radiometer (LXR) was able to view the AVIRIS radiometric calibration standard in June 1999 (Pavri and Green, 2000). Analysis of the cross comparison of the LXR and AVIRIS 1999 radiometric standard was completed with good stability before and after the measurements. 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.

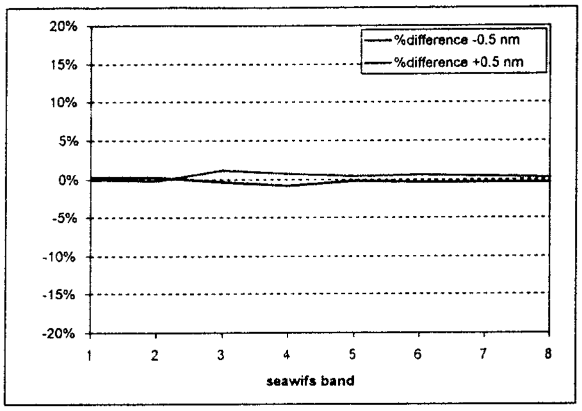

*Figure 7: Percentage change in AVIRIS modeled SeaWiFS radiance for spectral shifts of ±0.5nm.*

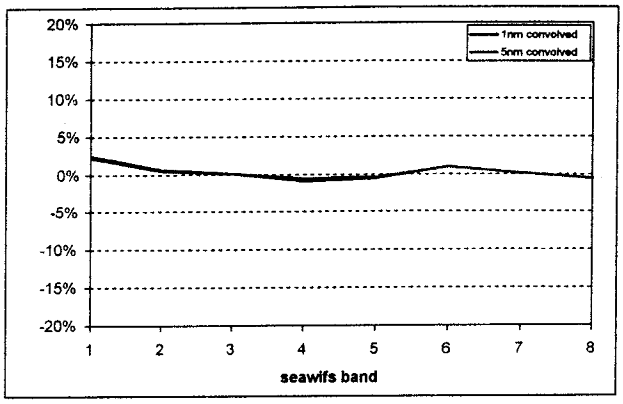

*Figure 8: Percentage change in AVIRIS modeled SeaWiFS radiance for various convolution sampling spacings.*

2. *AVIRIS Spectral Calibration Uncertainty or Error*. An error in AVIRIS' spectral calibration could lead to radiometric errors when convolving the AVIRIS data to SeaWiFS response functions. The uncertainty in AVIRIS' spectral calibration has been measured at ~0.1nm. Modeling the effect of a much larger spectral shift (0.5nm) on the AVIRIS-predicted SeaWiFS radiance can not explain the magnitude of the observed discrepancy (Figure 7). As expected, the greatest errors are incurred in the regions of greatest spectral slope (bands 3 and 4).

3. *Convolution of AVIRIS to SeaWiFS: sampling error due to AVIRIS bandwidth*. The AVIRIS bands are narrower than the SeaWiFS channels, but still close enough in bandwith to introduce sampling error into the convolution. To examine this effect, a MODTRAN modeled radiance was convolved with 1nm, 5nm, and 10nm (AVIRIS) spectral response functions. Each of these datasets was then convolved to the SeaWiFS response functions, enabling an analysis of the role of sample size on the convolution result. Figure 8 shows that this provides a small correctio n for the observed discrepancy, but one insufficient to explain the observed magnitude.

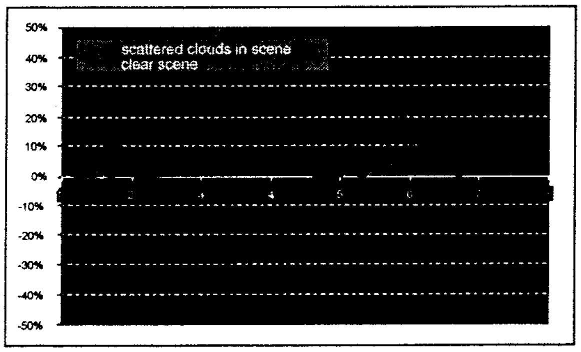

*Figure 9: Percentage difference in AVIRIS modeled SeaWiFS radiance for cloudless (blue) and cloudy (red) scenes.*

4. *Clouds*. The rejected datasets provide the opportunity to examine the effect of in-scene clouds on the AVIRIS/SeaWiFS comparison. Figure 9 shows that the effect of clouds is to introduce random error, not a systematic, repeatible discrepancy. Clear scenes show a tightly clustered pattern.

5. *Timing*. Since two circles are generally flown, the effect of timing offsets can be examined as possible sources of radiometric error. Figure 10 shows that the error introduced by shifting the

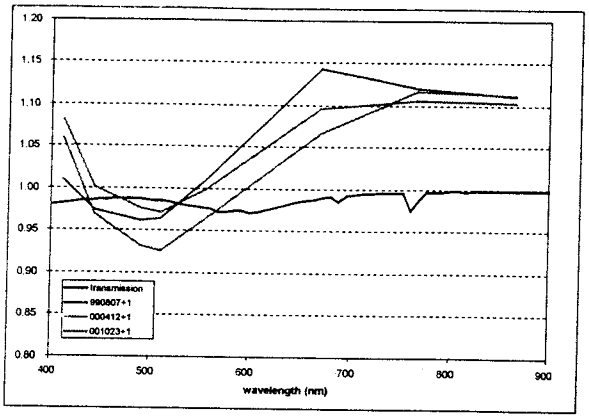

*Figure 11: Comparison of observed discrepancy to modeled ozone absorption from 20km altitude to top of the atmosphere.*

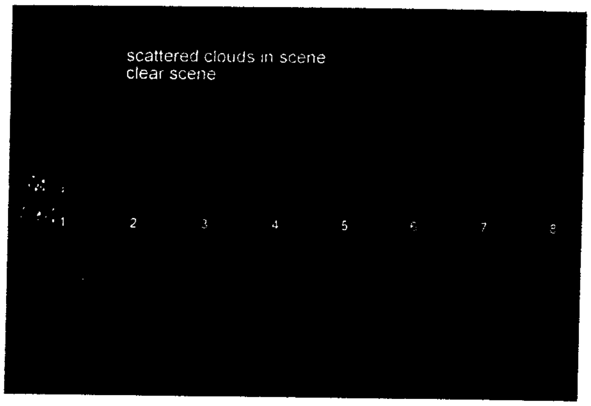

*Figure 12: Percentage difference in AVIRIS modeled SeaWiFS radiance after including path radiance.*

data collection by only 6 minutes can be very dramatic, and can not explain the observations.

6. *Ozone model.* Inaccuracies in the ozone model used to correct at - AVIRIS radiance (20km altitude) to top of the atmosphere radiance may introduce errors into the AVIRIS-modeled SeaWiFS radiance. The likelihood of this was evaluated by comparing the ozone absorption spectrum to the pattern of the AVIRIS/SeaWiFS discrepancy. The results are shown in Figure 11. There does not appear to be a close correlation between the atmospheric transmission function and the pattern of the AVIRIS/SeaWiFS discrepancy.

7. *Path radiance effect.* The effect of path radiance in the atmosphere from AVIRIS altitude to the top of the atmosphere was originally discounted as a significant effect. Including this effect produces the results shown in Figure 12.

The convolution sampling and path radiance corrections were found to be the most likely contributors to the observed discrepancy. Including these effects in the analysis for 000412 produces the results in Figure 13 - an improvement, but not sufficient to explain the magnitude of the observed disagreement.

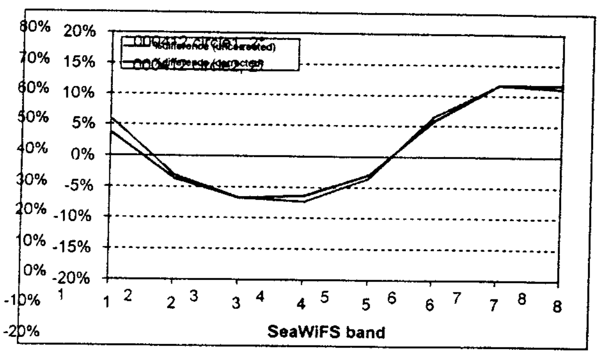

*Figure 13: Convolution sampling and path radiance corrections reduce the discrepancy between AVIRIS and SeaWiFS but can not explain the entire effect. (still need path radiance correction here)*

*Figure 10: Percentage difference in AVIRIS modeled SeaWiFS radiance for on-time data collection (blue) and a data collection 6 minutes later (red).*

**Conclusions**: Analysis of these data show radiometric calibration agreement ranging from 2% to 12% across the eight SeaWIFS bands. This discrepancy can not simply be explained by radiometric uncertainty within the AVIRIS calibration. Further, they are inconsistent with the results from the Landsat Transfer Radiometer experiment which show that the AVIRIS 1999 radiometric calibration standard agrees with the Goddard Space Flight Center LXR at the 2-3% level. Small corrections to the AVIRIS-modeled SeaWiFS radiance were made by correcting for convolution sampling error and the atmospheric path radiance.

Analysis of the SeaWiFS comparison is continuing in an attempt to understand the disagereement. 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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