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A Three-Year Intercomparison of Oceanic Optical Properties from MOS and SeaWiFS

Bryan A. Franz[1], Joel M. Gales[2], and Menghua Wang[3]

1 Science Applications International Corporation, Beltsville, MD
2 Futuretech Corporation, Greenbelt, MD
3 University of Maryland, Baltimore County, MD

http://simbios.gsfc.nasa.gov/

Introduction

Since 1996, following in the success of the Coastal Zone Color Scanner (CZCS), a fleet of spaceborne sensors with ocean color capability have been put into operation by various research institutions throughout the world. The NASA SIMBIOS Project has been funded to evaluate the consistency of oceanic optical properties retrieved by these different sensors, with the ultimate goal of merging data from multiple missions to enhance temporal, spectral, or spatial resolution and improve the temporal continuity of the global dataset. The work presented here is a three-year comparative study between two such missions: Germany's Modular Optoelectronic Scanner (MOS), and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) operated by NASA and the OrbImage Corporation. While the MOS sensor is a technology demonstrator with limited geographic coverage, it is unique among the latest generation of space-borne ocean color instruments in that it has been in operation since early 1996, and thus spans the lifetime of all the global ocean color sensors launched after CZCS. MOS has the potential to act as a consistent calibration source between these global missions, including the Japanese OCTS sensor which ended operations in June of 1997, and SeaWiFS which launched shortly thereafter in August of 1997. In 1998, Wang and Franz presented a cross-calibration between MOS and SeaWiFS at the 2nd International Workshop on MOS-IRS and Ocean Color in Berlin, Germany [1]. Since that time, a groundstation was established at NASA Wallops to collect MOS data along the Atlantic coast of North America. The SIMBIOS Project now has an archive of approximately three years of MOS data, with the ability to perform automated scene matching and extraction from the SeaWiFS data archives. In the work presented here, we use this match-up capability to examine the long-term relative stability of the ocean color retrievals between MOS and SeaWiFS, while applying the intercalibration established in 1998 with a consistent atmospheric correction approach. We also identify a number of changes which have been made to the MOS and SeaWiFS products since the cross-calibration was derived, and evaluate the effect of those changes on the relative calibration and atmospheric correction process.

The Atmospheric Correction Process

The conversion of MOS and SeaWiFS products from Level-1 sensor radiances to Level-2 oceanic optical properties was performed using the Multi-Sensor Level-1 to Level-2 (MSL12) software developed by the SIMBIOS Project. MSL12 is able to process both MOS and SeaWiFS data from top-of-atmosphere (TOA) radiances to water-leaving reflectances using a consistent atmospheric correction algorithm. The same software is used by the SeaWiFS Project for generation of all standard SeaWiFS products, and by the SIMBIOS project for the reprocessing of the OCTS global dataset. While a full discussion of the atmospheric correction algorithm is beyond the scope of this presentation (see [9]), it is useful to understand that the method relies on a ratio of near-infrared (NIR) reflectances to select an appropriate aerosol model. Thus, the relative calibration between the NIR bands will have a major impact on the accuracy of the atmospheric correction process.

The Calibration of SeaWiFS

For SeaWiFS, the 1-km resolution (HRPT) data from the groundstation at Wallops Island, Virginia was processed through standard calibration software, as developed for SeaWiFS reprocessing #3 [3]. Briefly, the calibration process includes removal of dark offsets and conversion to physical units, correction for temperature effects, scan modulation, mirror side differences, and stray light, and correction for long-term temporal variability based on a lunar reference. The calibrated radiances are then adjusted vicariously to yield agreement with a mission-long, daily record of *in situ* upwelling radiance measurements from the Marine Optical Buoy (MOBY) in Lanai, Hawaii [4]. The basic calibration approach for SeaWiFS has changed little since 1998, with refinements to the vicarious calibration being the most significant. The vicarious calibration is affected by changes in the atmospheric correction algorithm, which was significantly modified for SeaWiFS reprocessing #3. The largest change in atmospheric correction was the elimination of the dark pixel assumption for the NIR water-leaving radiances [5].

The Calibration of MOS

The MOS data from the Wallops groundstation was processed from raw format to Level-0 and Level-1B using standard software provided by the Indian Space Research Organization (ISRO) and the MOS Project at the DLR Remote Sensing Technology Institute, respectively. The processing to Level-1B includes the removal of dark offsets and conversion of detector output to radiance, as well as the removal of temporal variability in detector responsivities based on DLR analyses of the solar and internal calibration [6]. The Level-1B MOS radiances are then processed through the destriping algorithm developed by Corsini et al. [7] to remove the effects of relative calibration errors between detectors. Finally, the vicarious calibration developed by Wang and Franz is applied to each detector of the eight MOS-B channels which most closely approximate the SeaWiFS bands. The comparable bands are listed in Table 1.

The destriping procedure noted above differs from what was done in 1998 to develop the vicarious calibration of MOS to SeaWiFS, as no standard destriping correction was available at that time. By necessity, Franz developed an algorithm for removing the striping in the calibration scenes, wherein the coefficients of equalization were independently optimized for each scene [8]. The approach works well for relatively homogenous scenes, but the derived relative calibration may not be consistent between scenes. In principal, the method developed by Corsini is superior in that the relative calibration is predetermined and uniform from scene to scene; however, the method developed by Franz has the potential to yield better results for any individual scene.

To evaluate the impact of this newly available destriping correction on the calibration of MOS, a comparison of the two destriping approaches is provided in Figure 1. All panels display results from a MOS scene of the Western Mediterranean from 28 February 1998. This particular scene was used to derive the original intercalibration of MOS and SeaWiFS. The left column is the TOA radiance at 870 nm. The 870-nm channel is critical to the atmospheric correction, as it controls the apparent concentration of aerosols. The right column of Figure 1 shows the ratio of TOA radiances at 685 and 870 nm. This near-infrared (NIR) ratio is used in the atmospheric correction to determine aerosol types. The first row of Figure 1 shows results with no destriping applied, while the second and third rows show results for the standard MOS destriping of Corsini et al. and the SIMBIOS destriping of Franz, respectively.

The results in Figure 1 are not intended to show that one destriping method is better than another. The comparison is provided simply to identify differences between the original MOS calibrated radiances used in deriving the cross-calibration with SeaWiFS in 1998, and the current MOS calibration to which that cross-calibration is applied. For the scene in Figure 1, the standard MOS destriper leaves some residual striping artifacts in the TOA radiances, which will tend to increase dispersion relative to SeaWiFS. What is more problematic, however, is that the standard destriper does not remove the broad stripe visible toward the left edge of the scene. The effect is particularly noticeable in the NIR band ratio, and it will therefore effect the aerosol model selection process. Similar residual striping has been observed in all scenes processed to date, so it appears to be a limitation of the Corsini et al. algorithm or associated tuning coefficients.

Table 1: Comparable MOS and SeaWiFS spectral channels

Band	MOS λ (nm)	SeaWiFS λ (nm)
1	408	412
2	443	443
3	485	490
4	520	510
5	570	555
6	685	670
7	750	765
8	865	865

Figure 1: Destriping results for MOS, Western Mediterranean, 1998 day 59

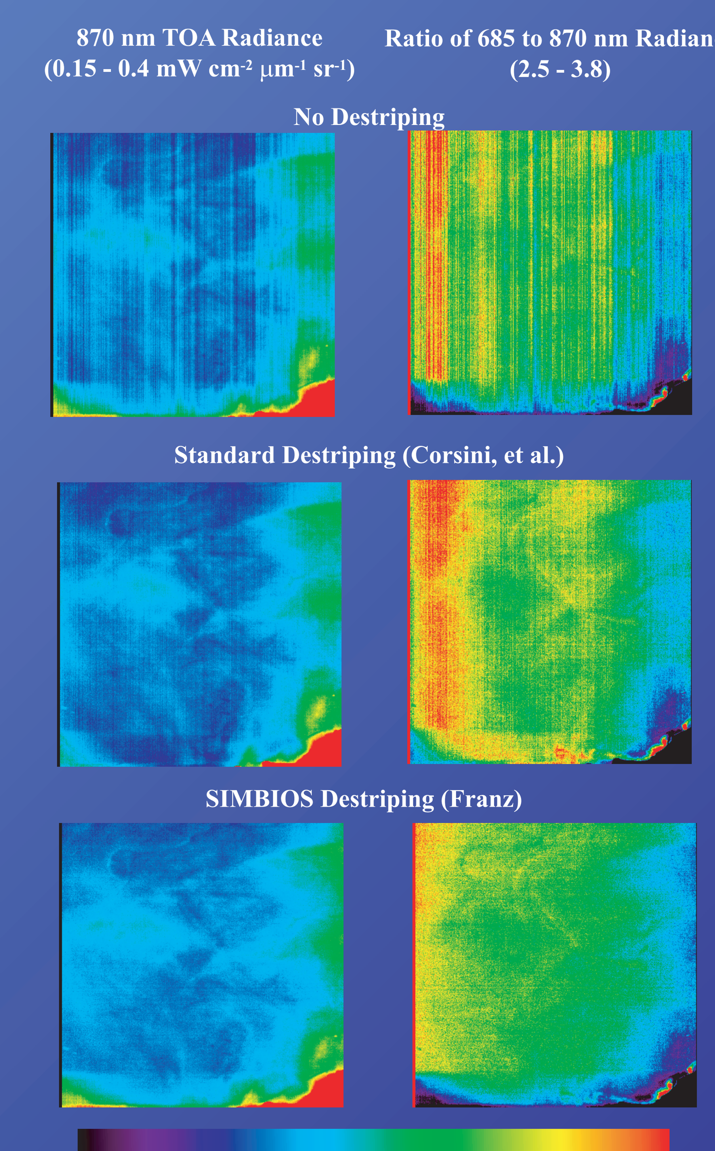


Figure 2: MOS vicarious gains derived from SeaWiFS water-leaving reflectance and aerosol retrievals, SIMBIOS destriping

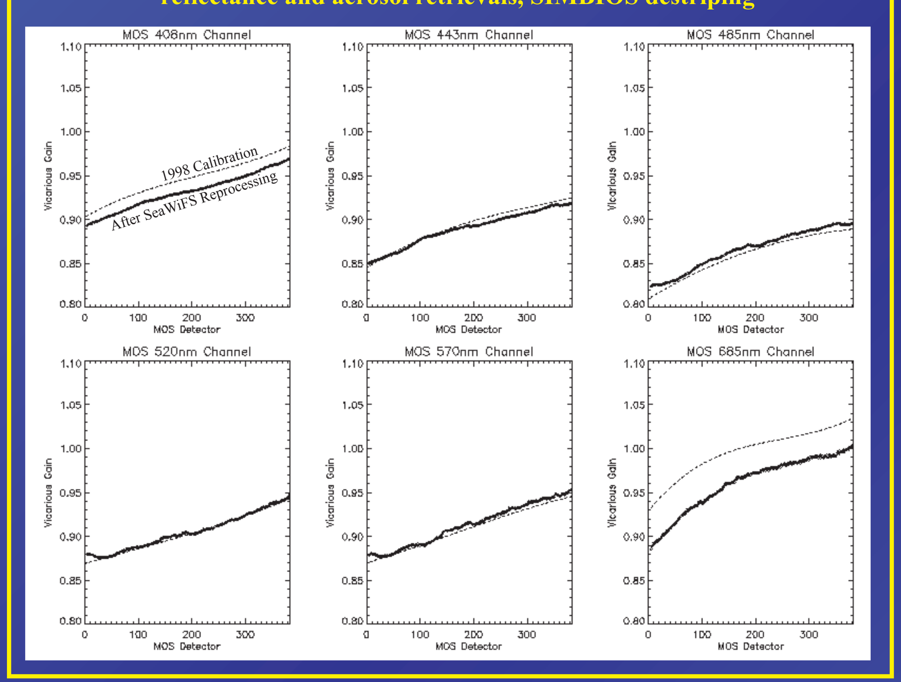


Figure 3: MOS vicarious gains derived from SeaWiFS water-leaving reflectance and aerosol retrievals, standard destriping

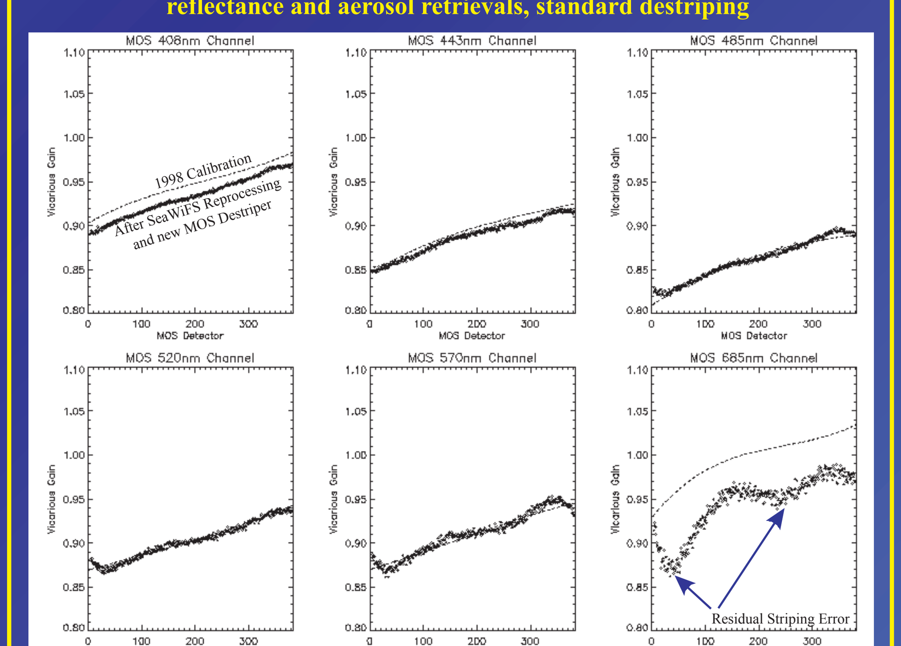


Figure 4: MOS and SeaWiFS water-leaving reflectance at 443 and 510-520 nm
Date: 18 January 2000, Location: 88.58W, 23.70N

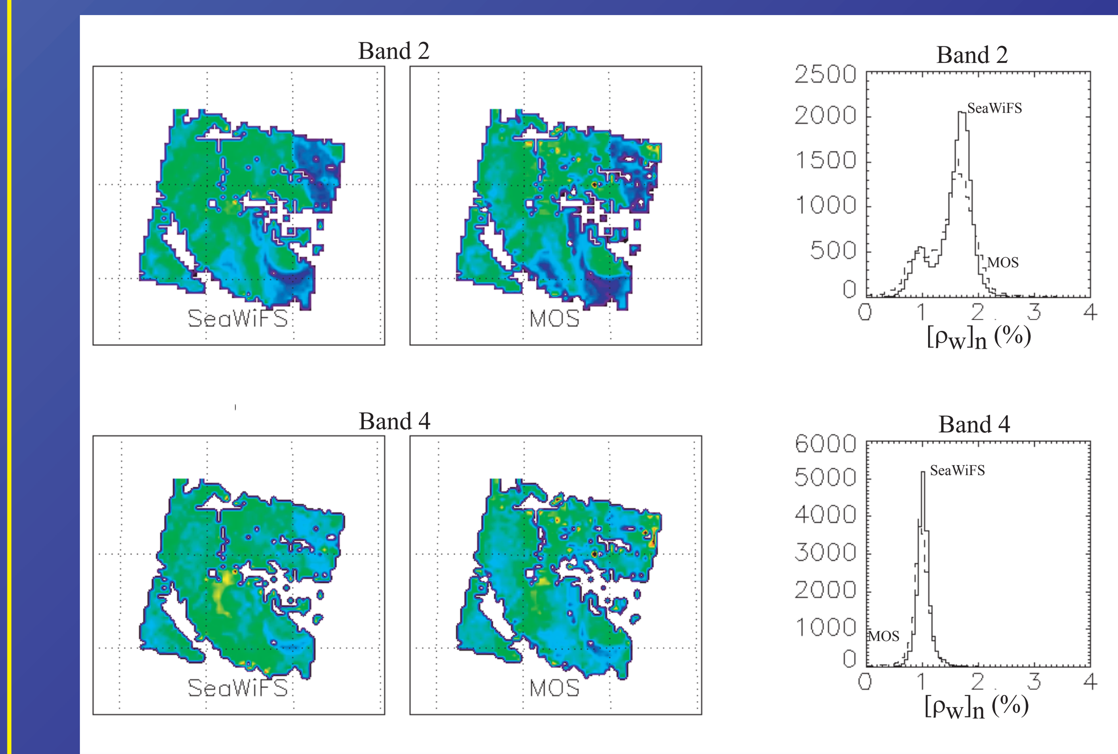


Figure 5: MOS and SeaWiFS daily-averaged water-leaving reflectances, Wallops data from February 1999 through March 2001.

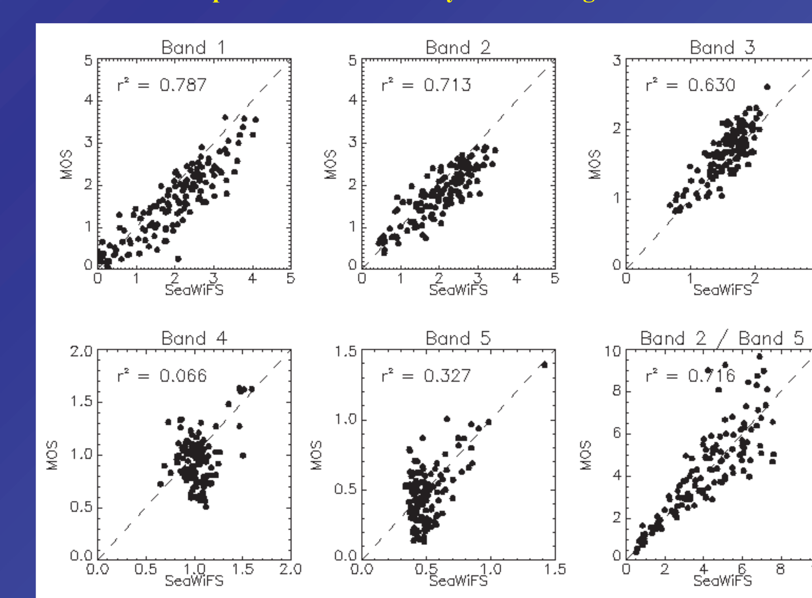
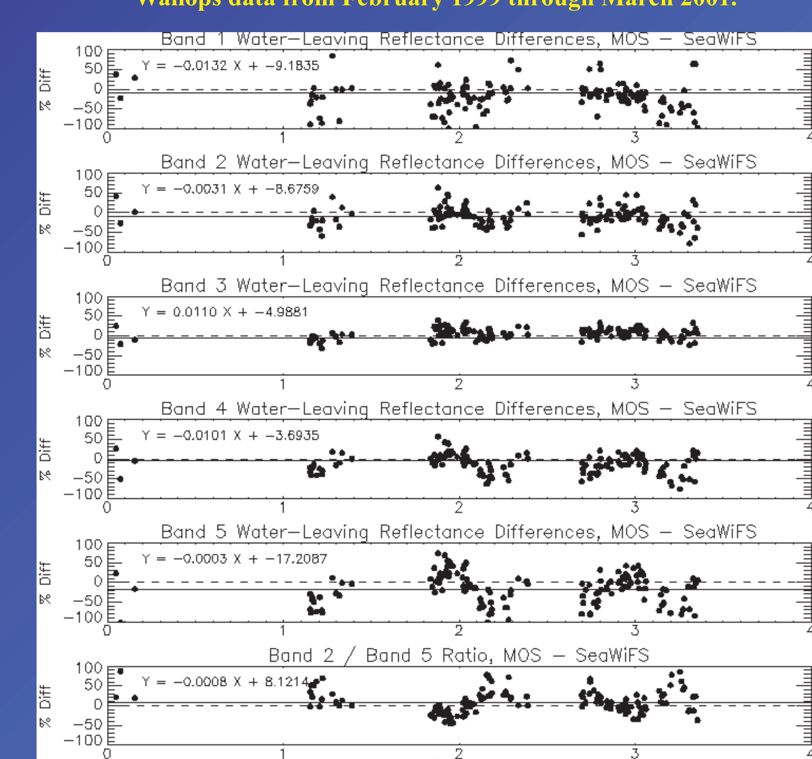


Figure 6: MOS and SeaWiFS daily-averaged water-leaving reflectances Differences, Wallops data from February 1999 through March 2001.



The Cross Calibration of MOS and SeaWiFS

The cross-calibration process is well described in [9]. In short, the concept is to use the normalized water-leaving reflectances from the six visible channels of SeaWiFS, in conjunction with the aerosol type retrievals from SeaWiFS, to predict the TOA radiances that MOS should see. This is done over a full MOS scene segment of 384 detectors by 384 lines, thus allowing for the derivation of gain coefficients for each MOS detector in the CCD line. The cross-calibration gains derived by Wang and Franz [1,9] are presented as the dashed lines in Figures 2 and 3. Each panel shows the gain as a function of detector number for a particular MOS channel. Note that the cross-calibration gains show a substantial trend which is relatively consistent from channel to channel. The gain change is on the order of 10% from east to west. The solid line in Figure 2 (actually a tight distribution of symbols) shows the gain as it would be derived today, using the SeaWiFS calibration and atmospheric correction algorithms of reprocessing #3. The gain curves derived using the latest SeaWiFS processing are very similar to those derived in 1998, with the exception of a general shift at 408 and 685 nm. The differences between the two calibrations can be attributed to the changes in SeaWiFS processing algorithms and vicarious calibration, as mentioned earlier.

All of the results presented in Figure 2 were derived using the SIMBIOS destriping algorithm. Figure 3 shows the gain curves as they would be derived using the standard MOS destriping code and the current SeaWiFS calibration and atmospheric correction. Again, the dashed line is the original cross-calibration from 1998. Comparing Figures 2 and 3, it can be seen that the introduction of the Corsini et al. destriping algorithm increases the noise in the cross-calibration gains and leaves a large-scale systematic variability in the gain as a function of detector number. This variability is most pronounced in the longer wavelengths, where aerosol scattering is a larger contributor to the signal. The most noticeable effect is a low-valued trough in the curves near detector 50, which corresponds with the residual striping noted in Figure 1.

The Match-up Process and Discussion of Results

Given an archive of MOS and SeaWiFS data from the Wallops groundstation, we wish to test the stability of the 1998 Wang and Franz cross-calibration over time. The first step in that process is to colocate and coregister the two datasets. The MOS format divides the data into convenient square scene segments of 384 CCD elements x 384 lines. Database procedures were developed to search through the entire MOS archive, looking for MOS scene segments which contain 80% cloud-free ocean. The longitude and latitude range of each clear MOS scene is then used to locate and extract the SeaWiFS data for the same date and location. When a match-up is generated, the MOS data is destriped using the code of Corsini et al., and both MOS and SeaWiFS are processed to water-leaving reflectance using MSL12 The level-2 products for each sensor are then binned and mapped to a common 1-km resolution grid.

Figure 4 shows an example of this match-up result for a single scene from 18 January 2000. The comparison of water-leaving reflectance is shown for two of the primary ocean color channels at 443 and 510-520 nm. The right-most panels show the frequency distribution of reflectance for each sensor, with MOS indicated by the dashed line. In this case, the match-up is very good, and there is no obvious east-west trend. These observations suggest that the vicarious gain curves derived in 1998 are still valid for data collected two years later, at least for this one scene.

In truth, Figure 4 is an example of one of the better match-up results, but on average the process is working reasonably well. Figure 5 shows a scatterplot of the daily mean water-leaving reflectance values derived from all match-up scenes collected between February 1999 and April 2001. For bands with significant dynamic range (1, 2, and 3), the scatterplots show good correlation, with r^2 greater than 0.6. However, there is a significant amount of dispersion around the 1-to-1 line. The last panel of Figure 5 shows the comparison of the band 2 to band 5 water-leaving reflectance ratio, which is a common input to empirical chlorophyll algorithms. The reflectance ratio scatterplot indicates good agreement in the ocean color retrieval between the two sensors.

Figure 6 provides a more direct indication of the temporal stability between MOS and SeaWiFS over the three-year period. Percentage differences in daily averaged water-leaving reflectance and reflectance ratio are shown, along with the best-fit line. The fits indicate that the relative stability in the derived optical properties retrieved from the two sensors is good to about 1% per year, although the day-to-day variability makes the fitting results highly uncertain. The fits also indicate that MOS retrievals are generally biased low relative to SeaWiFS.

One potential source of differences in water-leaving reflectance retrievals between the two sensors is error in the removal of aerosol path radiance. This error may be caused by the presence of particular aerosol types for which the scattering properties are not well represented within the MSL12 aerosol model suite. Alternatively, it may be that the best aerosol model is simply not being consistently identified. As mentioned earlier, the residual striping artifacts are clearly evident in the NIR band ratio, and it is this band ratio which effectively controls the aerosol model selection. Another possible source of error is a significant change in the atmospheric characteristics during the 90 minutes between the MOS and SeaWiFS overpass times. The presence of thin cirrus clouds or fog will greatly increase the uncertainty in the atmospheric correction process, and a change in such conditions will likely introduce a bias in the water-leaving reflectances between the two sensors.

Summary

The purpose of this study was to evaluate the long-term stability of the Wang and Franz cross-calibration of MOS and SeaWiFS, which was established in 1998 based on SeaWiFS reprocessing #2 products and a non-standard MOS destriping process. The results show that very good agreement with current SeaWiFS products can be obtained, for particular scenes, when the MOS data is processed through MSL12 using the standard destriping code and the 1998 cross-calibration coefficients. However, there is significant variability in the match-up results from day to day, suggesting that uncertainties in the atmospheric correction process need to be identified and reduced. One source of error is the presence of residual striping artifacts, which are clearly evident in the ratio of TOA radiances in the NIR. Improvement of the standard MOS destriping algorithm to better remove these broad stripes should reduce problems with aerosol type identification. Better methods of identifying and masking contamination by thin cirrus clouds or fog should also reduce the relative differences between the two sensors. This analysis also identified a number of changes to the SeaWiFS products since the cross-calibration was established. In the near future, the MOS vicarious calibration coefficients distributed by the SIMBIOS project will be updated to reflect these changes.

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