A Long-Term Intercomparison of MOS and SeaWiFS

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Introduction

Since 1996, following in the success of CZCS, a fleet of space-borne 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 to extend the time-series of the global dataset. The work presented here is a long-term comparison 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 therefore has the potential to act as a consistent calibration source between the global missions, including the Japanese OCTS mission which failed 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 [2]. The SIMBIOS Project now has an archive of over two years of MOS data, with the ability to perform automated scene matching and extraction with 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 and a consistent atmospheric correction approach.

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 straylight effects, 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 Bouy (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 due to the removal 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 DLR Berlin, 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.

Table 1: Comparable MOS and SeaWiFS spectral channels

Band Number	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

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 method developed by Corsini is a superior approach in that the relative calibration is uniform from scene to scene; however, the scene-specific method developed by Franz has the potential to yield better results for any individual scene.

A comparison of the two destriping approaches is shown 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 intercalibration of MOS and SeaWiFS. The left column is the top-of-atmosphere (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, whereas 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 SIMBIOS destriper does a good job of removing the apparent striping artifacts, but the scene-wise approach is not practical for general processing as it requires a relatively homogenous scene. The comparison is provided simply to identify differences between the MOS data used in deriving the cross-calibration with SeaWiFS in 1998, and the MOS data 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.

The Cross-Calibration of MOS to 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. The cross-calibration gains derived by Wang and Franz [1,9] are presented as the dashed lines in Figure 2. 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 (actually a tight distribution of symbols) shows the gain as it would be derived 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.

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 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 Cosini 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 broad-band 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 co-locate and co-register the two datasets. The MOS data is divided into convenient square scene segments of 384 by 384 pixels. 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 prcessed to water-leaving reflectance using the Multi-Sensor Level-1 to Level-2 (MSL12) software developed by the SIMBIOS Project. 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 well. Figure 5 shows a scatter plot of the daily mean water-leaving reflectance values derived from all match-up scenes collected between February 1999 and April 2001. While the agreement is generally good, there is a significant amount of dispersion around the 1-to-1, and the characterization and minimization of these differences will be the primary focus of future work.

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. The results show that very good agreement can be obtained for particular scenes using the calibration established in 1998 and the MSL12 atmospheric correction code. 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 the broad-band 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 which have occurred in the SeaWiFS products since the cross-calibration was established in 1998. In the near future, the cross-calibration will be updated to reflect these changes.

References

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Figure 1: Destriping Results for MOS-B, Western Mediterranean, 1998 day 59.

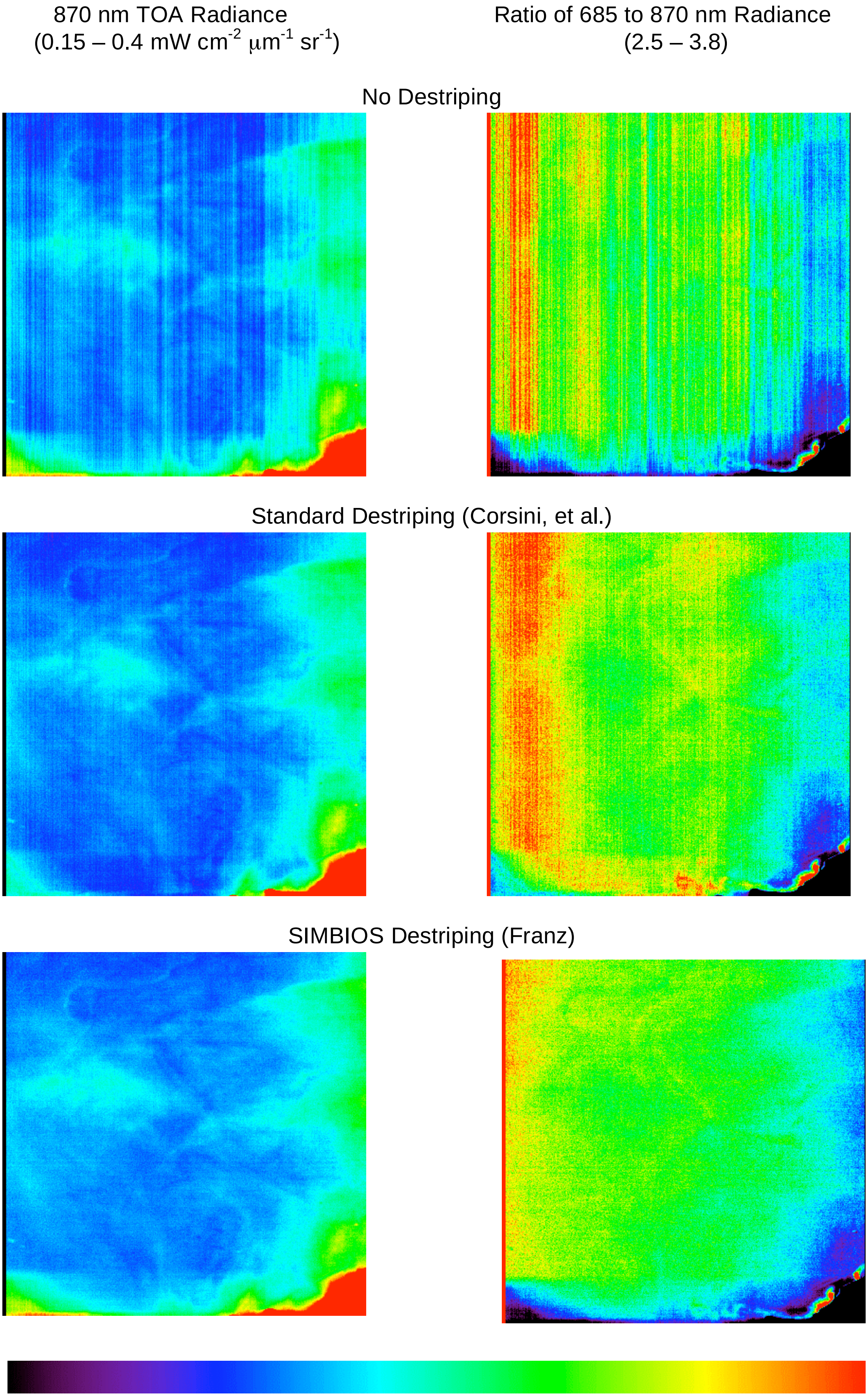

Figure 2: MOS vicarious gains derived from SeaWiFS water-leaving reflectance and aerosol type retrievals, SIMBIOS destriping.

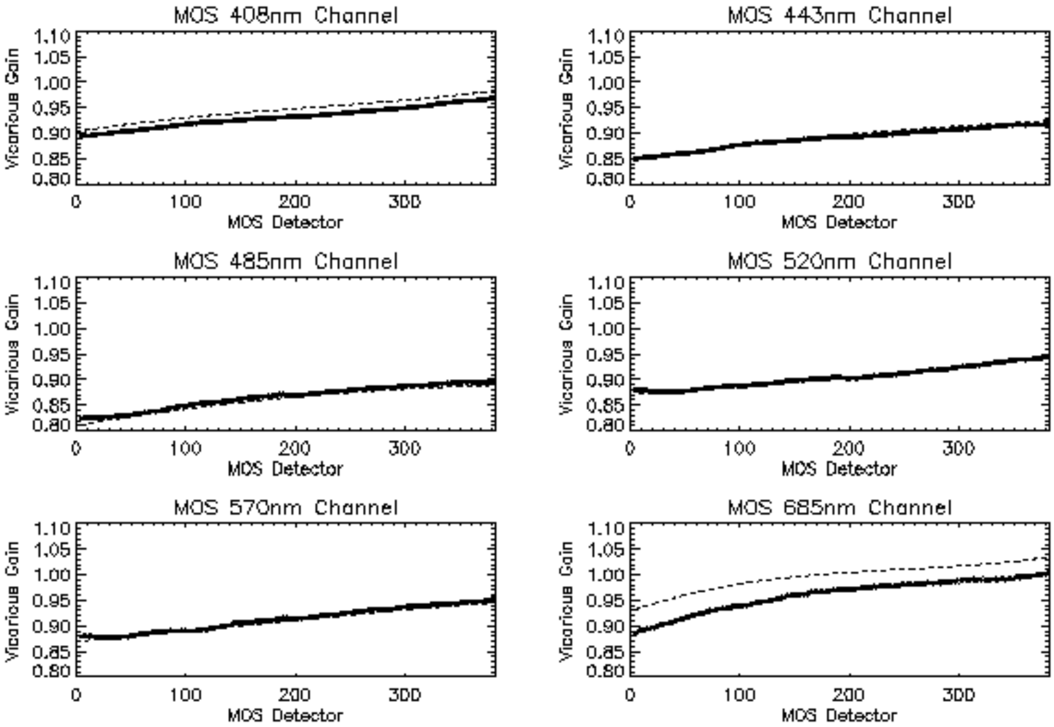

Figure 3: MOS vicarious gains derived from SeaWiFS water-leaving reflectance and aerosol type retrievals, standard destriping.

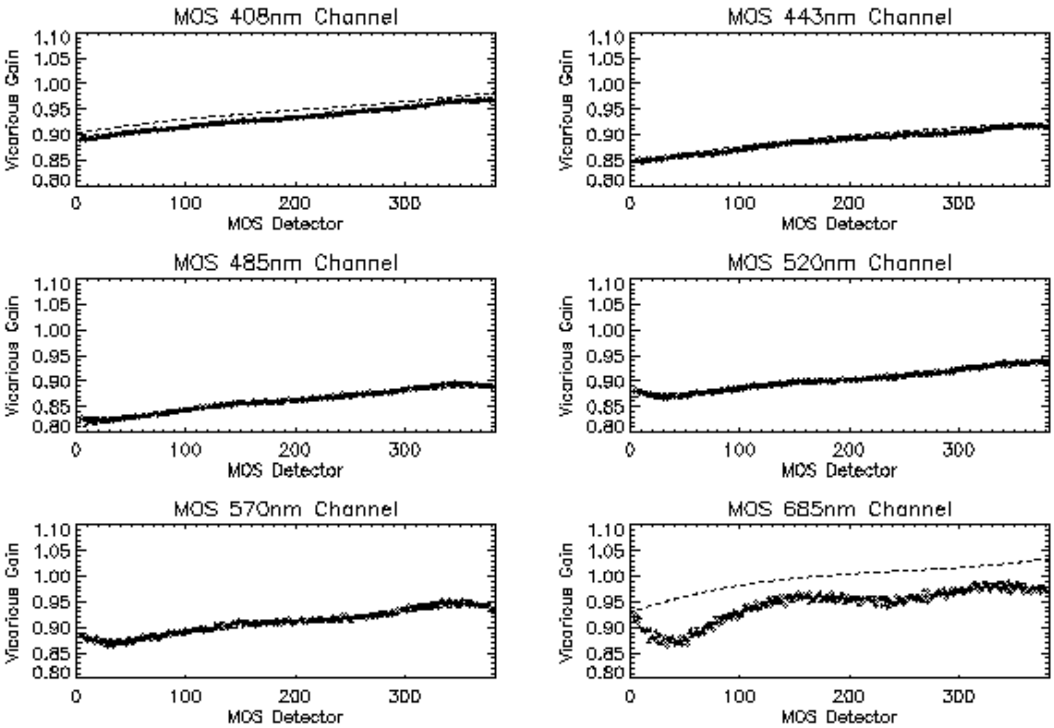

Figure 4: MOS and SeaWiFS water-leaving reflectance for one scene.
Date: 18 January 2000, Location: 88.58W, 23.70N

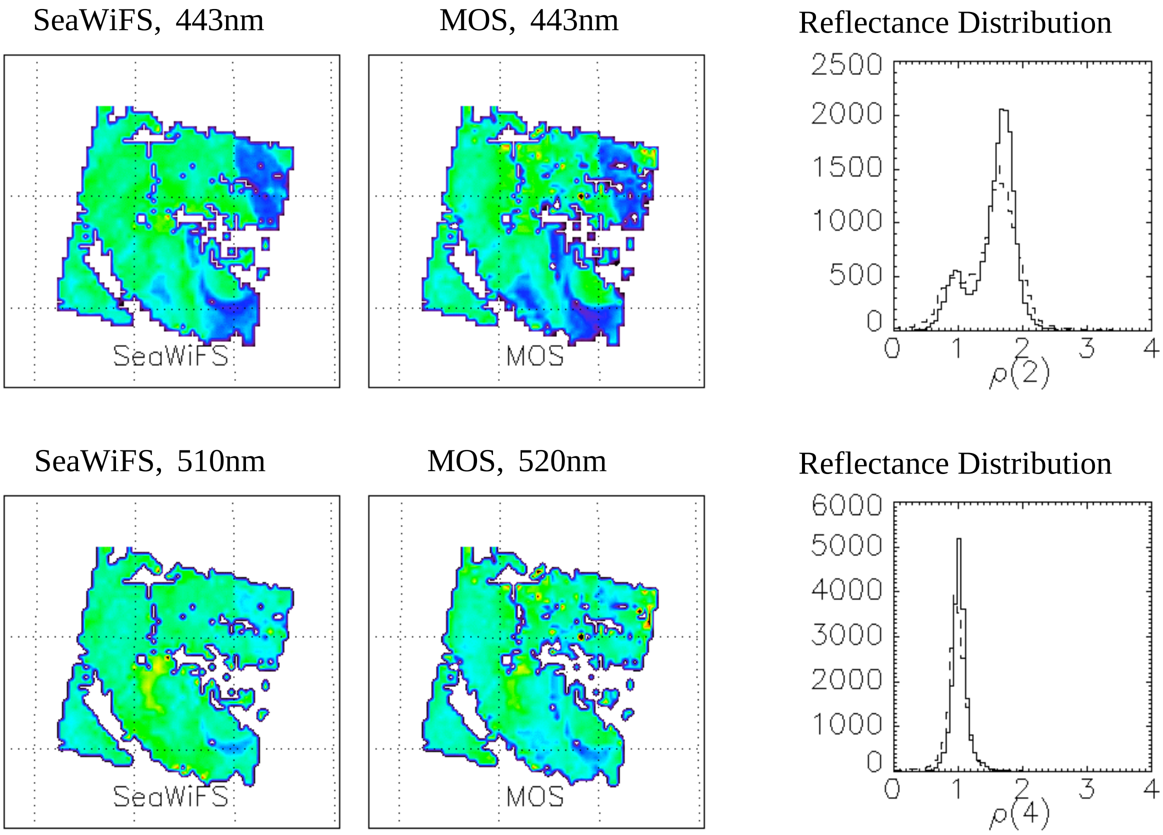

Figure 5: MOS versus SeaWiFS daily-averaged water-leaving reflectances,
Wallops data from the February 1999 through March 2001.