eMAS Solar Reflectance Band Calibration for SEAC4RS

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Abstract

eMAS inflight reflectance observations derived from laboratory calibrations have been compared with MODIS Terra/Aqua for six coordinated under-flights over the course of the SEAC4RS campaign, and to a single vicarious calibration flight conducted after the conclusion of the SEAC4RS campaign. This report describes the methodologies of the MODIS/eMAS and vicarious/eMAS comparisons, and discusses the justification for applying the vicarious/eMAS comparison results to the eMAS post-deployment laboratory calibration data to derive the final eMAS reflectance band calibration for SEAC4RS. Also discussed is an additional calibration modification to the vicarious modified lab calibration, required for the first two eMAS SEAC4RS flights (test flights out of Palmdale Ca.). Pre-flight relative calibration data suggest a 6-7% change in calibration between the second and third Palmdale pre-flight calibrations, but then little or no change for remainder of the SEAC4RS deployment, including the post deployment vicarious calibration flight. This report also discusses of some alternate calibration comparison methods and results.

Introduction

For the six coordinated under-flights of MODIS Terra/Aqua during SEAC4RS, Table I summarizes the dates, platform, MODIS overpass time, matching view zenith angle (the angle at which both eMAS and MODIS were observing the same location at the same view zenith angle), and the scene description. As noted, two of the satellite under-flights were over cloud/ocean, and the remaining four were over land and included broken cloud scenes with some limited areas of mostly clear sky. The vicarious calibration flight tracks were conducted over the Ivanpah Playa on 24 October, 2013, about 2 hrs after the coordinated Terra under-flight over marine stratus off the southwest coast of California.

Methodology of Primary eMAS and MODIS Data Comparison

Given the much higher spatial resolution of eMAS (~50 m nadir at an ER-2 altitude of 20 km) compared to MODIS (1 km nadir), two different methods were examined to make the eMAS reflectance observations more directly comparable to MODIS. In both of the methods, the MODIS data is first projected onto the eMAS grid via matching the geo-location data of each sensor. An optimal sub-region is then defined such that the across track ”width” is a few degrees wide and is centered where the view angles from each sensor match, and the along track ”length” is centered ideally within a few minutes of the overpass time; though in reality, the broken cloud conditions during the land flights necessitated eMAS data selection be mostly (or completely in some cases) before or after the overpass time.

The difference between the two methods is in how the eMAS data from within the defined box region was ultimately employed. For the *pixel aggregation method*, the eMAS data from within the defined box region was first aggregated as appropriate to simulate the coarser resolution MODIS pixels (thus producing two datasets with the same number of effective pixels). For the alternate *regional method*, the eMAS data remains at its native resolution.

Methodology of the eMAS Vicarious Calibration

Following the under-flight of Terra on 24 October, 2013, eMAS overflew the Ivanpah Playa calibration site where separate teams from JPL and the University of California-Davis were set up to measure the surface reflectance and the various atmospheric parameters needed to convert the surface values (via MODTRAN) to predicted top of atmosphere “at sensor” reflectance. The U. C. Davis group (Ustin et al.) subsequently provided predicted at sensor values for all 25 eMAS spectral channels, and the JPL team (Brugge et al.) whose primary purpose in the field was to provide measurements for AIRMISPI calibration) also provided predicted at sensor values, but only for eMAS Port 1 channels (bands 1-9), and did not include atmospheric water vapor in the MODTRAN processing. Air Force Research Laboratory (AFRL) personnel (J. van den Bosch) subsequently reprocessed the JPL data to provide at sensor radiances for all eMAS solar channels using MODTRAN radiative transfer simulations accounting for the full atmosphere, including water vapor, and including an adjustment to the aerosol optical depth. AFRL staff also conducted additional MODTRAN runs to demonstrate the sensitivity of the results to the solar spectral irradiance dataset input to MODTRAN. In addition to the WRC85 solar irradiance dataset used by the JPL team (the adopted standard for MISR processing), the additional AFRL runs used the MODTRAN default Kurucz95 solar irradiance dataset (used also by U.C. Davis) and the MODIS standard MCST dataset; note the MCST dataset has 1 nm resolution, somewhat more course than the other solar irradiance datasets. Differences between approaches are as large as 5%, but the AFRL MODTRAN processing referencing MCST solar irradiance is the most relevant for eMAS-MODIS comparison because the eMAS L1B (and MODIS L1B) processing adopt that dataset to map radiance observations into reflectance space.

Calibration Comparison Discussion and Results

Reflectance data for the six MODIS under-flights were processed using both the *pixel aggregation* and *regional* methods. Histograms of the eMAS and MODIS reflectance were generated, and adjustment ratios (MODIS/eMAS) derived that best match the means of the selected eMAS and MODIS comparison regions. Similar to what was found for the TC4 MAS/MODIS calibration comparisons, the *pixel aggregation* and *regional* methods produce similar adjustment ratios, except when the scenes include any appreciable amount of scattered/broken clouds, e.g., the four SEAC4RS land MODIS overpass scenes. Difficulties in precisely collocating the highly variable sub-MODIS pixel scale data for small bright clouds over dark land, as well as geo-location uncertainty issues, makes useful calibration comparison in such partly cloudy regions untenable. In fact, the four land cases were found to be useful only when the comparison region was limited to sub-scene sections with very little or no cloud. Even then confidence in determining calibration adjustment ratios is reduced since the clear regions; a) may still contain a small amount of cloud, b) have a reduced number of data points compared to the full overpass region, and c) have a very limited dynamic range containing only low reflectance values. This limits the usefulness of the clear sky results without inclusion of additional data of higher reflectance.

The two marine stratus cloud cases on 02 August and 24 October however provide much better calibration targets since the cloud data is much brighter and more homogeneous, thus helping to minimize any co-location issues. Unfortunately, use of the 02 August comparison data is problematic because of an apparent significant change in eMAS radiometric response sometime between the preflight calibration check on 02 August, and the preflight calibration check for the next flight on 06 August. Note, eMAS stability is monitored via preflight views of a 20-inch integrating hemisphere, and those numbers for 02 and 06 August pre-flights, suggest a calibration change comparable in magnitude to the 4-7% change noted between the eMAS pre- and post-SEAC4RS laboratory calibrations (see Figure 1).. Preflight calibration checks both prior to 02 August and for the remainder of the SEAC4RS deployment after 06 August show no significant changes (Figure 2), though after 06 August, only port 1 preflight data could be analyzed as temporary optics fogging after filling the LN_2 Port 2 dewar (in the high Houston humidity) precluded validity of those preflight hemisphere measurements. This apparent lack of radiometric calibration change during the Houston mission is supported by the consistency in the MODIS/eMAS adjustment ratios determined from the four land target calibrations (one Terra, three Aqua). Coupled with the stability of the preflight calibration checks prior to 2 August, these findings support the supposition that the change noted in the pre and post-deployment lab calibrations may well have occurred sometime between the 2 and 6 August pre-flights. Thus eMAS-MODIS adjustment ratios derived from the 2 August data are suspect since it is not known how or when the response change took place between the to two pre-flights.

The 24 October eMAS under-flight of Terra over the bright and relatively uniform marine stratus does provide an excellent calibration target that is straightforward to analyze and is presumably applicable to all eMAS data after 02 August. The reflectance based adjustment ratios for 24 October data, derived from histogram comparisons, are listed in Table II. Note however for the 1.6 and 2.1 μm bands, the adjustment ratios are gray because bandpass differences between eMAS and MODIS are significant enough that spectral cloud reflectance and the two-way atmospheric absorption transmittance differences are expected to cause at sensor reflectance differences regardless of calibration. Thus for these two channels, a correction is necessary to account for the bandpass differences. Two methods have been employed to do this. The first is to adjust (i.e., scale) the reflectance-based ratios in Table II by estimating the expected difference in top of atmosphere (TOA) reflectance values for eMAS and MODIS. The expected TOA values were derived from the cloud retrieval algorithm reflectance library look-up tables (LUTs) for eMAS and MODIS using a regional mean retrieved cloud effective radius and the retrieval code atmospheric correction LUTs. The modified adjustment ratios are listed in parenthesis next to the gray ratios. The second method involves determining, via histogram comparisons, the adjustment ratios required to best match the mean optical thickness and effective radius retrievals for the comparison regions (an approach also used for the TC4 calibration analysis). These retrieval-based adjustment ratios are listed in the adjoining column of Table II after the reflectance-based ratios. Since the retrievals use the same LUTs mentioned above, it would be expected results would be similar to the adjusted reflectance-based ratios discussed above. Interestingly the 2.1 μm reflectance and retrieval-based ratios do match well, though the 1.6 μm ratios differ somewhat.

The 24 October adjustment ratios derived from MODIS comparisons should be directly comparable to the 24 October AFRL/MCST vicarious calibration results presented in column 5 of Table II. Overall, the vicarious and MODIS-derived adjustment ratios are in good agreement. This is a particularly important result, not only because it increases the confidence in the calibration adjustment, but also because the vicarious calibration provides the only available adjustment factors for the remaining eMAS solar channels not found on MODIS. Thus the vicarious calibration results are chosen as the final adjustment ratios for all 25 SEAC4RS eMAS solar bands, though note that they are only applicable to data 06 August and later. For data prior to 06 August, the vicarious adjustment ratios are modified by the ratio of the pre and post deployment lab calibrations (to account for the aforementioned apparent calibration changed noted between the 02 and 06 August preflights). Table III lists the two sets of adjustment ratios. Note the adjustment ratio for the 1.88 μm channel in the 06 August and later data is set to the default of 1.0. This is because of high uncertainty inherent when comparing the very low eMAS measured signal, a result of strong atmospheric water vapor absorption, with the predicated at sensor radiance that is also sensitive to accurate knowledge of the column water vapor.

Additional Calibration Comparison Methods and Results

The histogram analysis methods described above use a fixed block of eMAS/MODIS data to derive the adjustment ratios. An additional method based on a less rigid target selection process was also investigated. For this method, comparison regions were selected visually from the imagery of both sensors using ENVI® region of interest (ROI) software tools. Adjustment ratios are determined using simple averages of the eMAS and MODIS ROI's, and are then averaged over all selected targets. Results for 24 October are provided in the Ames Radiance Adjustment Ratios column in Table II, and are in reasonable agreement with the above analysis, though note the ratios are in computed in radiance rather than reflectance and so do not include bandpass-dependent adjustments for solar spectral irradiance differences between eMAS and MODIS.

An additional comparison method not previously used for MAS/eMAS vs MODIS comparisons was also attempted for the 24 October case. In this “reflectance band fit” method, a linear fit of 1/eMAS reflectance as a function of the ratio of MODIS reflectance to eMAS reflectance is derived. A feature of this method is that the low reflectance values weight more heavily when taking a linear fit, such as IDL’s LADFIT function, though radiometrically flat scenes yield suspect adjustment ratios. Thus LADFIT coefficients for the 24 October stratus case that is devoid of low reflectance values don’t agree well with the reflectance based adjustment ratios unless some low reflectance values, e.g., clear sky over land, are included. For the 24 October under-flight, clear sky data observed by eMAS about 12 min before the MODIS overpass time are used; note this clear sky region is not expected to significantly change over the 12 minute eMAS-MODIS observation interval. The LADFIT scale and offset coefficients for the 24 October case that includes the low reflectance clear sky data are listed in Table II. The scale values are indeed quite close to the reflectance based adjustment ratios. The derived offset values, while small, are not zero, and their statistical significance is unclear, though they may be of concern to aerosol and land studies. Their sensitivity to reflectance uncertainty, sample size, and the dynamic range of especially the low reflectance pixels requires further study. It is worth mentioning, however, that adjusting the eMAS reflectances with the LADFIT coefficients does yield eMAS vs MODIS reflectance relationships with slopes within a percent of 1.0 and offsets that are essentially zero.

Considering the eMAS calibration appears to be stable after 02 August, it is reasonable to include data from the four clear sky/land eMAS MODIS comparisons to the 24 October data to see what effect that has on the “reflectance band fit” data. The scale and offset results are shown in the final two columns in Table II. Scale values are only minimally modified compared to those from just the 24 October data, but interestingly the offset values, while still small, reverse their sign and become negative. Future work with the aerosol community will be undertaken to investigate the relevance of these offsets.

Table I. Summary of the six eMAS under-flights of MODIS Terra and Aqua during SEAC4RS. Note the Oct 24 Terra underflight took place about four weeks after the formal end to the SEAC4RS campaign (U.S. government shutdown precluded being able to conduct a post deployment satellite comparison sooner).

Date	Satellite Platform	Overpass Time (UTC)	Matching View Zenith Angle	Scene/Surface Type
Aug 02, 2013	Terra	1840	10°	Marine stratus/ocean
Aug 21, 2013	Aqua	1908	15°	Broken cloud/land
Sept. 6, 2013	Terra	1732	0°	Broken cloud/land
Sept. 9 2013	Aqua	1938	15°	Broken cloud/land
Sept. 11, 2013	Aqua	1928	15°	Broken cloud/land
Oct. 24, 2013	Terra	1907	0°	Marine stratus/ocean

Table II. Summary of six key SEAC4RS eMAS band calibration comparisons against comparable MODIS bands. The calibration adjustment factor to be applied to SEAC4RS data, given in column 3 ("Reflectance Based Adjustment Ratio"), is the MODIS/eMAS ratio derived from the histogram method - pixel aggregation - mean value comparisons. For the 1.6 and 2.1 μm bands, the adjustment ratios have been corrected to account for spectral cloud and atmospheric transmittance effects that result from the differences in the eMAS and MODIS bandpasses (see text for further discussion). Other calibration comparison data are described in the text.

[Band #] Central Wavelength (μm) or Cloud Retrieval	Pre/Post-Deploy-ment Lab Calibration Change	Oct 24, 2013						Combination Terra/Aqua Comparisons after 02 August	
		GSFC Analysis		AFRL	Ames	GSFC		GSFC	
		Reflectance Based Adjustment Ratio (w/band correction)	Retrieval Adj. Ratio	Vicarious w/MCST Solar Spectral Irradiance	Radiance Adj. Ratio	Refl. Band Fit - Scale (w/band correction)	Refl. Band Fit - Offset (w/band correction)	Refl. Band Fit Scale (w/band correction)	Refl. Band Fit Offset (w/band correction)
[1] 0.47	-7.1%	1.07		1.06	1.05	1.06	0.0071	1.08	-0.0076
[2] 0.55	-6.6%	0.95		0.96	0.92	0.95	0.0021	0.96	-0.0043
[3] 0.65	-5.2%	0.94		0.98	0.94	0.94	-0.0008	0.94	-0.0050
[7] 0.86/$tau_{2.1}$	-6.5%	0.93	0.92	0.96	0.93	0.93	0.0034	0.94	-0.0080
[10] 1.6/$re_{1.6}$	-4.9%	0.97 (0.98)	0.89	0.95	0.98	0.96 (0.97)	0.0072 (0.0073)	0.98 (0.99)	-0.0041 (-0.0042)
[20] 2.1/$re_{2.1}$	-4.6%	0.86 (0.93)	0.91	0.94	0.86	0.86 (0.93)	-0.0015 (-0.0016)	0.86 (0.93)	-0.0034 (-0.0037)

Table III. Vicarious AFRL/MCST based adjustment ratios (predicted at sensor TOA radiance/eMAS radiance) for the 25 eMAS solar bands. These are the adjustment ratios to be applied to eMAS post-deployment laboratory calibration adjusted radiance values. Ratios for data prior to 06 August have been adjusted by the ratio of the pre-deployment and post-deployment calibrations (due to the apparent calibration change noted by the pre-flight calibration data between the flights on 02 and 06 August).

eMAS Band Number	Wavelength (µm)	Adjustment Ratio (for data 06 August 2013 and later)	Adjustment Ratio (for data prior to 06 August 2013)
1	0.47	1.061	0.991
2	0.55	0.958	0.898
3	0.65	0.980	0.931
4	0.70	1.010	0.961
5	0.74	1.002	0.947
6	0.82	0.986	0.925
7	0.87	0.958	0.899
8	0.91	1.030	0.965
9	0.95	1.136	1.060
10	1.61	0.947	0.903
11	1.66	0.991	0.944
12	1.72	1.016	0.965
13	1.77	1.102	1.049
14	1.82	0.954	0.954
15	1.88	1.0*	0.979*
16	1.93	1.003	0.976
17	1.98	1.251	1.196
18	2.03	0.974	0.927
19	2.08	0.926	0.883
20	2.12	0.938	0.897
21	2.18	0.906	0.868
22	2.22	0.881	0.845
23	2.27	0.865	0.831
24	2.32	0.862	0.835
25	2.37	0.996	0.971

* eMAS ground target signal too low (due to the strong water vapor absorption) to get reliable adjustment ratio value, therefore ratio set to default 1.0.