Calibration Comparisons Between SEVIRI, MODIS and GOES Data

David R. Doelling[(1)], Patrick Minnis[(2)], Louis Nguyen[(2)]

[(1)] *AS&M, Inc., 1 Enterprise Parkway, Hampton, VA, 23666, USA; email: d.r.doelling@larc.nasa.gov*
[(2)] *NASA-Langley Research Center, MS 420, Hampton, VA, 23681, USA; email: p.minis@larc.nasa.gov*

ABSTRACT

In this study, five of the Spinning Enhanced Visible and Infrared Imager (SEVIRI) channels are inter-calibrated with similar channels on MODerate resolution Imaging Spectroradiometer (MODIS) and Geostationary Operational Environmental Satellite (GOES)-12/ Visible Infrared Scanner (VIRS). A ray-matching technique combines pairs of pixel sets from each satellite at almost the same times from nearly the same angles. The MODIS and VIRS derived SEVIRI 0.635 and 0.810µm gains indicate to have increased since launch. Monthly gains computed from April to August of 2004 establish that the SEVIRI visible channels are quite stable during this time period. The SEVIRI 3.9µm temperature is colder than the corresponding MODIS and GOES-12 temperatures. However the SEVIRI 11.7µm temperatures are warmer.

1. INTRODUCTION

Calibrated radiances are necessary to compute proper and consistent cloud, radiation and other environmental products from various platforms. Consistent products are obtained by using the same algorithm on various satellites. This requires radiances that are calibrated against a reference calibration. Geostationary derived products are essential in operational forecasting, aviation, as well as diurnal studies. Many products are directly dependent on the calibration. The SEVIRI instrument has expanded capabilities compared with its predecessor. However, the SEVIRI visible channels do not have onboard calibration. In order to make full use of the 4 visible channels they need to have accurate and stable calibration over time. In this study, MODIS and VIRS via GOES-8 visible calibrations are transferred to SEVIRI. The transfer is performed using a ray-matching technique. The MODIS derived calibrations are compared with the EUMETSAT and pre-launch calibrations. The SEVIRI calibration has been monitored for 5 months to track any apparent drift, but the time span is not long enough to remove any long-term drift. The SEVIRI IR channels have onboard blackbodies and are calibrated. IR comparisons are made between SEVIRI and MODIS to determine the similarity of the corresponding 3.9 and 11.7µm channels. This study is a continuation of [1].

2. METHODOLOGY

2.1 Data

SEVIRI 3-km pixel level visible channel digital counts (DC) in the XPIF format during August of 2003 to February of 2004 were obtain from Royal Meteorological Institute of Belgium (RMIB) archive, available on the web at http://gerb.oma.be. SEVIRI pixel level radiances beginning in April 2004 were obtained from Space Science and Engineering Center (SSEC) at the University of Wisconsin (http://www.ssec.wisc.edu) in Man computer Interactive Data Analysis System (McIDAS) format as well as the GOES-12 4-km radiances. The Terra and Aqua MODIS 2-km sub-sampled from 1-km pixel radiances were obtained in 5-minute granule files at the Langley Distributed Active Archive Center (DAAC) (http://eosweb.larc.nasa.gov) in the MOD02 for Terra or MYD02 for Aqua format. The VIRS 2-km pixel level radiances were also obtained at the Langley DAAC and are in the 1B01 format.

2.2 Ray-matching Technique

The ray-matching technique uses coincident, co-angled, and co-located pixel radiances to transfer the calibration of a reference satellite to another. VIRS and MODIS have onboard calibration, by use of solar diffusers and can be used as a reference, since they are well calibrated and have long term stability [2]. Aqua and Terra MODIS radiances are ray-matched by collocating 0.5° latitude by longitude gridded radiances from MODIS and SEVIRI. The ray-matching domain (30° longitude by 20° longitude) was slightly off-centered from the Meteosat-8 sub-satellite point (3°W, 0°N) to include as much ocean as possible and was centered at 5°W and 5°S. Only ocean regions are used, since the spectral reflections over land are unpredictable. The solar, viewing and azimuth angles were matched within 5°, 10° and 15°, respectively. The time difference was less than 15 minutes. Ray-matched gridded SEVIRI DCs were regressed against MODIS radiances on a monthly basis.

The MODIS radiances were normalized with the corresponding SEVIRI channel solar constant. The time difference is accounted for by normalizing the MODIS radiance with the SEVIRI cosine of the solar zenith angle. No spectral corrections were made based on the

individual channel spectral response functions. The solar constants used for SEVIRI, 0.635, 0.810, 1.640 µm channels are 515.03, 354.28, 73.28 $Wm^{-2}sr^{-1}um^{-1}$, respectively and provided by EUMETSAT [3]. The Terra-MODIS corresponding solar constants are 508.83, 316.84, 75.05 $Wm^{-2}sr^{-1}um^{-1}$, respectively. The Terra solar constants were also used for Aqua, since they differed by less than 0.2%. The Iqbal [4] solar spectral irradiances and the published normalized spectral response functions were used to compute the MODIS solar constants. This study relies on the MODIS radiances as absolute truth. Then the ratio of SEVIRI and MODIS solar constants and cosine solar zenith angles are applied. Various solar constant ratios were computed using Iqbal [4], Wehrli [5], and Kurucz [6] solar spectral irradiances. The ratios differed by 0.3, 1.6, and 1.3% for the 0.635, 0.810, 1.640 µm channels, respectively. Most of the solar constant ratio difference comes from the computation of the bandwidth.

The same ray-matching technique is applied to transfer the calibration from VIRS to the GOES-12 visible channel. The GOES-12/VIRS radiances are regressed against the SEVIRI DCs using ray-matched gridded 1° regions centered at the bisecting longitude at solar noon. Solar noon ensures matched solar, view and azimuth angles. The solar constants based on Iqbal are 531.7, 517.3 and 515.03 for VIRS, GOES-12, and SEVIRI, respectively.

In order to determine the stability of the visible channels the monthly gains are plotted as a function of time. Since the offset is inversely correlated with the gain, the mean offset during the given time period is computed. The monthly gains in the trend-line are derived using the mean offset. The SEVIRI instrument has a deep space look, implying the offset is stable over time. Ray-matching technique needs at least a complete seasonal cycle and three years to determine long term degradation trends, since angular matches are not random and depend on the solar zenith angle near the equator.

3. RESULTS

3.1 The 0.635 µm channel results

Monthly Terra and Aqua MODIS/SEVIRI regressions were performed from April to August of 2004 and for GOES-12/SEVIRI from August 2003 to August 2004. The August 2004 regressions are shown in Fig. 1. The standard error of the estimate is 3.3, 3.5, and 9.5 $Wm^{-2}sr^{-1}um^{-1}$ for Terra, Aqua and GOES-12, respectively, for August 2004. Since the GOES-12 was first calibrated against VIRS and then SEVIRI, the standard error was expected to be greater than the MODIS/SEVIRI cases. The mean offset was computed for each set of regressions and are shown in the first row of Table 1. The SEVIRI operational (pre-launch) offset is 51 [7]. A EUMETSAT SEVIRI calibration validation performed during August 4-8, 2003 (Table 4 in [7]) indicates a retrieved offset of 51. The Aqua-MODIS offset was also 51.The Terra and GOES-12 had a mean offset of 55 and 46, respectively, which are within 10% of the nominal offset.

The 0.635µm gain trends are shown in Fig. 2. The mean of the gains during the period of analysis are shown in Table 2. The solid line reveals the gain trend. The SEVIRI 0.635µm gain appears quite stable and no short term drift is detected. The GOES-12 derived gains reveal a slight upward trend, but is probably due to noise. 3 years of gains is usually needed to detect any long-term degradation. The mean of the gains are given in Table 2. The gains in this study are within 3% of each other and are greater by more than 10% compared with the nominal and August 2003 published gains. It is uncertain what could account for the difference. The SEVIRI images used in this study were not in the preferred EUMETSAT native format and a possible calibration factor may have been overlooked. For this reason the results are considered preliminary. Other possible explanations include which offset is used, the computation of the solar constant, the ray-matching method used to transfer calibration, and differences in the spectral response function between MODIS and SEVIRI. If the offset of 51 is used the gains are 0.617, 0.647, and 0.669 for Terra, Aqua and GOES-12, respectively. The uncertainty in the solar constant ratio was 1.3 % (see 2.1). The geostationary ray-matching technique has been validated to be within 1% [8]. Since Terra and Aqua MODIS are absolutely calibrated, the ray-matching technique should be as good as the 2.3% difference between the two gains. Ozone and water vapor absorption unique to each spectral band could account for differences in the computed gain. The 0.635µm spectral response functions are shown in Fig 3a. SEVIRI has a greater bandwidth than MODIS, but smaller than VIRS or GOES-1. This suggests if there were a strong absorption band outside of the MODIS bandwidth it would also manifest itself in the VIRS/GOES-12 gain.

3.2 The 0.810 and 1.64 µm channel results

The 0.810 and 1.64 µm SEVIRI mean offsets are given in Table 1. It is interesting that the offsets derived from Terra and Aqua MODIS are consistent for all channels. MODIS uses the same solar diffuser plate for all visible channels. The Aqua 1.64µm channel failed and GOES-12 has a single 0.65µm channel in the visible. The mean gains from April to August 2004 are stated in Table 2. The MODIS derived 0.810 µm gains are within 3% of each other and 12% greater than the August 2003 gain

[7]. If the gain of 51 is used the Terra-MODIS derived gain is 4% lower. The MODIS derived gains are significantly greater than the August 2003 or the nominal. The gain difference arguments discussed in 2.2 are valid in this case. The 0.810/0.635µm ratio for the gains derived from MODIS and those from August 2003 are 0.80 and 0.83, respectively and are similar. This implies that the vegetation indexes derived from SEVIRI and MODIS should not be significantly different. Fig. 4a and 4b show the gain trend lines for the 0.810µm channel. There is greater noise than for the 0.635µm channel, and the trend lines are insignificant. The 0.810µm drift cannot be determined from this study.

The 1.64µm MODIS derived gain and offset from April to August 2004 is given in Table 2 and 1, respectively. The Terra MODIS and August 2003 gains are within 1% and if 51 were used as the offset, the Terra MODIS gain would be 2.5% less than the gain shown in Table 2. This matches the EUMETSAT gain and is significantly different than the nominal gain. In this case the SEVIRI bandwidth is 3 times greater than the MODIS (Fig. 3c).

3.3 The 3.9 and 11.7 µm channel results

The SEVIRI instrument has onboard calibration in the IR channels. Atmospheric absorption in the spectral bands is much greater than in the visible wavelengths. IR temperature differences between satellites are usually more of a function of bandwidth and placement than calibration anomalies. Absolute IR calibration uncertainty is usually less than 1° K [9]. However to retrieve consistent cloud properties the IR channels differences need to be known. Temperature differences between SEVIRI and MODIS or GOES-12 are compared.

The SEVIRI temperatures were regressed against Terra, Aqua MODIS, and GOES-12 temperatures. The difference (SEVIRI-reference) is given in Table 3. For the 3.9 and 11.7 µm channel the mean SEVIRI temperature is ~ 293° and 287° K, respectively. The dynamic range of the 3.9µm channel was insufficient to compute the slope of the regression. The slope of the 10.7µm was within 1% of unity. The 3.9µm temperature difference in Table 3 indicates significantly colder temperatures in the SEVIRI. The regression was performed during daylight and the radiance includes both shortwave and longwave components. It is uncertain what impact the greater SEVIRI bandwidth and possible spectral leak. Note that the temperature difference is less between GOES-12 and that its central wavelength is closer to that of SEVIRI than is MODIS. The 11.7µm temperature differences are given in Table 3. The SEVIRI temperature is warmer than MODIS or GOES-12. MODIS has a smaller bandwidth (Fig 5b) than either GOES-12 or SEVIRI. However, the GOES-12 and SEVIRI 10.7µm filter are similar (Fig 5b) and the difference is ~1°. The temperature difference between Terra and Aqua is 0.2°K, confirming that noise in the ray-matching technique is not the cause.

4. Conclusions

Terra and Aqua MODIS were cross-calibrated with SEVIRI using a ray-matching technique. The VIRS calibration was transferred first to GOES-12 and then to SEVIRI. The MODIS and VIRS derived gains were compared with the nominal and EUMETSAT, validated in August 2003 [7], gains. For the SEVIRI 0.635µm channel the MODIS and VIRS derived gains were within 3% of each other and 10% greater than the EUMETSAT gain. The use of the nominal offset, the ratio of the solar constants, atmospheric absorption, or the uncertainty in the ray-matching technique, could not explain the difference. The short analysis period precludes the unraveling of any significant long-term gain trends. Aqua and Terra MODIS derived SEVIRI gains, between April to August 2004, were stable for all channels. Similar results were observed for the SEVIRI 0.810µm channel. The MODIS derived gains were within 3% and 12% greater than the EUMETSAT gain. The Terra MODIS derived 1.64µm gain was similar to the EUMETSAT gain. Daytime SEVIRI 3.9µm temperatures were colder by 6.7° and 3.3°K, respectively, compared with MODIS and GOES-12. The 11.7µm SEVIRI temperatures were warmer by ~1.5°. Corresponding channel spectral differences may explain some of the discrepancy. The results are an initial evaluation and considered preliminary.

5. Acknowledgments

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6. References

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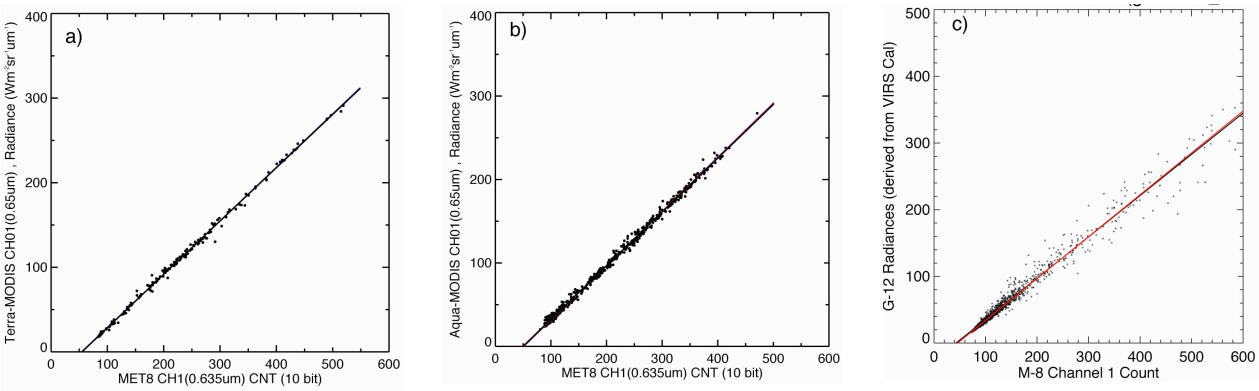

Fig.1 August 2004 regressions of SEVIRI 0.635µm DC against (a) Terra-MODIS, (b) Aqua-MODIS, and (c) GOES-12 derived from VIRS radiances ($Wm^{-2}sr^{-1}um^{-1}$)

(µm)	Terra	Aqua	G-12/ VIRS	Pre-launch	Aug 2003
0.64	55	51	46	51	51
0.81	56	51		51	52
1.64	55			51	53

Table 1. SEVIRI visible channel DC offsets

(µm)	Terra	Aqua	G-12/ VIRS	Pre-launch	Aug 2003
0.635	0.632	0.647	0.630	0.578	0.564
0.810	0.529	0.515		0.397	0.467
1.640	0.089			0.081	0.088

Table 2. SEVIRI visible channel gains ($Wm^{-2}sr^{-1}um^{-1}$/DC)

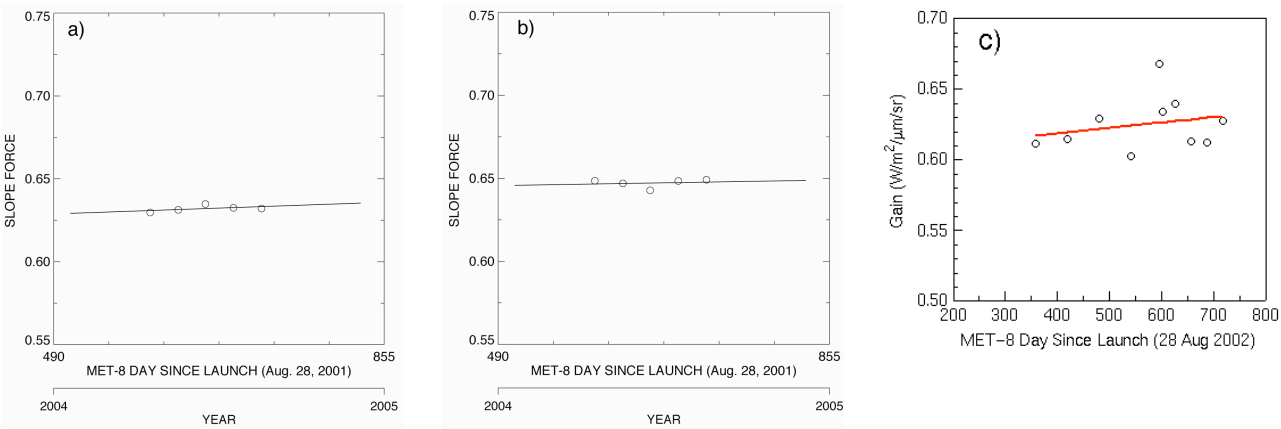

Fig 2 SEVIRI 0.635µm gain trends based on (a) Terra MODIS, (b) Aqua-MODIS, and (c) GOES-12 derived from VIRS. The gain trend lines are also shown.

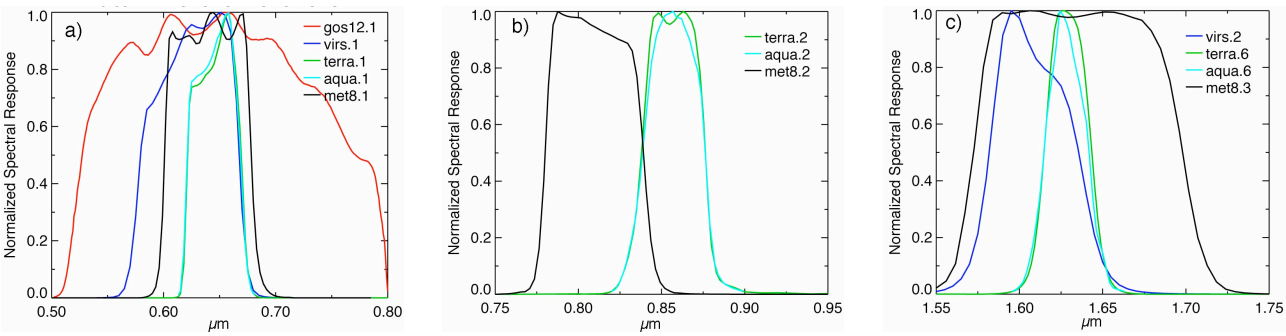

Fig. 3. The SEVIRI [met-8], MODIS [terra, aqua], VIRS, and GOES-12 normalized spectral response functions for the (a) 0.635µm, (b) 0.810µm, and (c) 1.640µm visible channels.

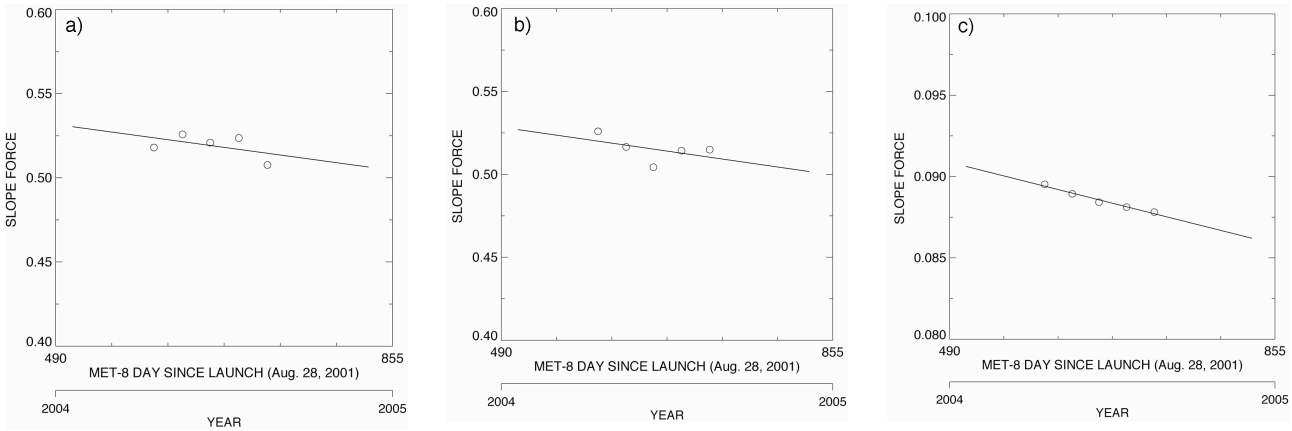

Figure 4. SEVIRI 0.810µm gain trends based on (a) Terra MODIS, (b) Aqua MODIS, and 1.640µm gain trend based on Terra MODIS. The gain trend lines are also shown.

(µm)	Terra	Aqua	GOES-12
3.9	-6.7	-6.8	-3.3
11.7	1.9	1.7	1.2

Table 3. SEVIRI minus Terra MODIS, Aqua MODIS, and GOES-12 temperature differences (°K) for the 3.9 and 11.7µm channels.

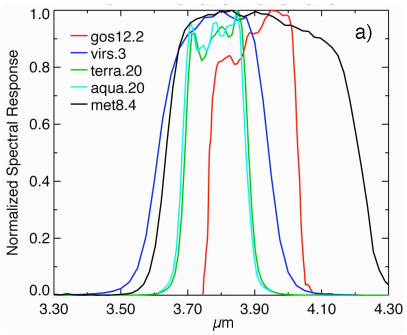

Fig. 5 (a). Fig. 3. The SEVIRI [met-8], MODIS [terra, aqua], VIRS, and GOES-12 normalized spectral response functions for the 3.9µm channels

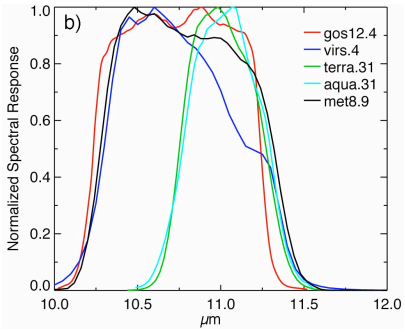

Fig. 5 (b). Fig. 3. The SEVIRI [met-8], MODIS [terra, aqua], VIRS, and GOES-12 normalized spectral response functions for the 10.7µm channels

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