CALIBRATION COMPARISONS BETWEEN SEVIRI, MODIS, AND GOES DATA

D. R. Doelling

AS&M, Inc.
1 Enterprise Pkwy, Hampton, VA 23666 USA

L. Nguyen, and P. Minnis

NASA Langley Research Center
MS 420, Hampton, VA 23681 USA

ABSTRACT

Remote sensing of cloud and surface properties from different satellites requires consistent calibration of the instruments on each satellite. The unique spectral, spatial, and temporal resolutions of the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on the new Meteosat Second Generation, *Meteosat-8*, give it the potential for providing unprecedented scientific data, especially when combined with other satellites. In this study, five of the SEVIRI channels are intercalibrated with similar channels on other satellites to facilitate synergistic analyses and tuning of algorithms for remote sensing of surface and atmospheric components. The MODerate resolution Imaging Spectroradiometer (MODIS) on the *Terra* and *Aqua* satellites and the twelfth Geostationary Operational Environmental Satellite (GOES) imager have spectral channels similar to those on SEVIRI. A matched-ray technique combines pairs of pixel sets from each satellite at almost the same times from nearly the same angles. The gain for the 0.65-µm channel on *Meteosat-8* appears to have increased since launch. All three comparisons indicate that the gain is nearly 7% greater than the nominal value. The 0.81-µm channel gain appears to have increased by 16% as of April 2004. The 1.6-µm channel calibration differs by only 3% from the corresponding *Terra* MODIS gain. The 3.89-µm channel yields brightness temperatures that are 6-7 K too small on average compared to MODIS and *GOES-12* data at temperatures above 280 K. The large bias is apparently due to a spectral leak in the channel-4 filter. The infrared channel (10.75 µm) appears to be too warm by ~1 K compared to the other three sensors. Examination of the intercalibration results will continue with studies of the spectral differences, potential errors in the other instrument calibrations, and assessment of the calibrations in other SEVIRI channels.

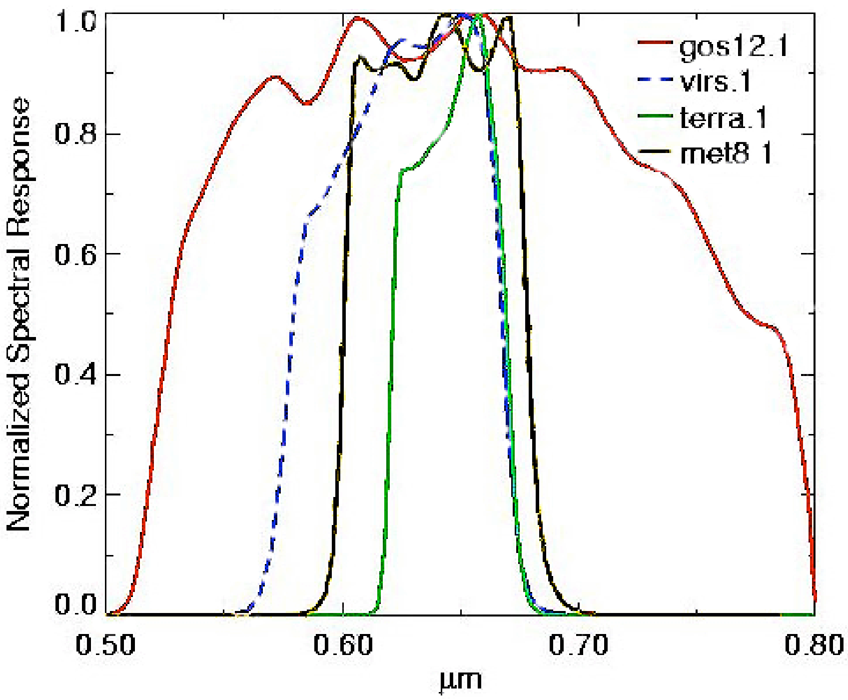
1. INTRODUCTION

Remote sensing of cloud and surface properties from different satellites requires consistent calibration of the instruments on each satellite. The unique spectral, spatial, and temporal resolutions of the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on *Meteosat-8* give it the potential for providing unprecedented scientific data, especially when combined with other satellites. In this study, a preliminary intercalibration of several SEVIRI channels is performed using similar channels on other satellites to facilitate synergistic analyses and tuning of algorithms for remote sensing of surface and atmospheric components. Two approaches are taken using similar methodologies. Data from the twelfth Geostationary Operational Environmental Satellite (*GOES-12*) imager are compared with the corresponding SEVIRI channels by matching data along the saddle line between the two satellites to ensure views from the same angles. The *GOES-12* visible channel is calibrated using the Tropical Rainfall Measuring Mission (*TRMM*) Visible Infrared Scanner (VIRS), which has an onboard infrared and visible calibration system that has been shown to be a suitable reference for other visible channel imagers. The Moderate Resolution Imaging Spectroradiometer (MODIS) on the *Terra* and *Aqua* polar-orbiting satellites has onboard calibration for all channels and is used here as direct calibration source. By calibrating against the GOES/VIRS and MODIS data, it is possible to estimate the uncertainty in the resulting calibrations by performing a third calibration between the VIRS and MODIS. The results presented here are the beginning step in an ongoing effort to continuously monitor the calibrations of the SEVIRI on *Meteosat-8*, hereafter, is referred to as *Met8*.

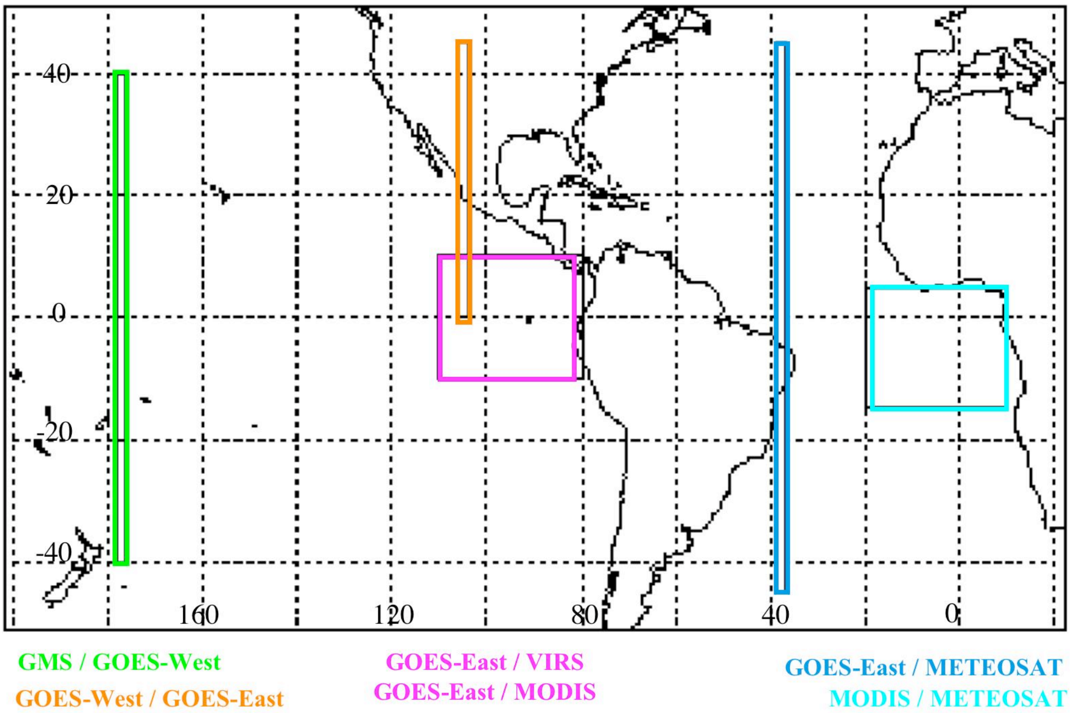
2. DATA AND METHODOLOGY

For August 2003 through February 2004, the 3-km SEVIRI data were acquired in XPIF format from the RMIB SEVIRI archive in Brussels, Belgium. SEVIRI data for April 2004 were obtained form the University of Wisconsin Space Science and Engineering Center (SSEC) in Madison, Wisconsin through their Man-computer Interactive Data Analysis System (McIDAS). *GOES-12* 4-km data for times corresponding to the SEVIRI data were also acquired from the SSEC. The 1-km MODIS data for April 2004 were accessed through the NASA Langley Distributed Active Archive System at NASA Langley Research Center in Hampton, Virginia. Only the 0.65, 0.86, 1.6, 3.9, and 10.75-µm SEVIRI channels are considered here. SEVIRI and *Met8* will be used interchangeably here to denote SEVIRI.

The corresponding channels on each satellite have slightly different spectral response functions that should be noted. For example, the spectral response functions for the visible (VIS) are all centered around 0.65 µm, but each has a different width and shape. In this initial study, only a few corrections are applied to account for differences in the responses of the solar channels. All of the VIS channel radiances are normalized to the nominal GOES solar constant used by Minnis et al. (2002a), 526.9 $Wm^{-2}\mu m^{-1}sr^{-1}$. This normalization is accomplished either by calibrating raw counts to radiance or by multiplying the observed radiance by the ratio of the solar constants in which the nominal GOES value is the numerator. To account for sampling time differences, the radiances are normalized using the ratios of the cos(SZA) where SZA is the solar zenith angle. No other corrections are applied to either the solar or infrared channels.



1. Spectral response functions for the visible channels on various satellite radiometers.



2. Regions used for intercalibrating satellite pairs.

The *GOES-12*/*Met8* calibrations are performed by averaging radiances or counts within each 1° region straddling the longitude that is equidistant between the two satellites. The box containing those regions is outlined in Figure 2 around 36°W along with the other regions used for geostationary satellite intercalibrations. These regions all have essentially the same viewing zenith angle (VZA) and SZA at all times and the same relative azimuth angles (RAZ) at local noon. Thus, the intercalibrations of the solar channels can be performed at local noon without concern for the impact of anisotropic reflectance, on average. Since the infrared channels (wavelengths exceeding 5 µm) are unaffected by solar radiation, they can be intercalibrated using data taken at any time of day over the central longitude. Only data taken within a 15-min interval are considered. *GOES-West* is calibrated against *GOES-East* (*GOES-12*) and *GMS* is calibrated against *GOES-West* in a fashion like that for *GOES-East* and *Met8*.

SEVIRI and MODIS data are matched by averaging radiances in 0.5° regions within the 20°-latitude by 30° -longitude box shown in the far right portion of Figure 2. Pairs of mean radiances are used in the calibrations if they are taken at times differing by less than 15 min and have differences in SZA, VZA, and RAZ of less than 15°, 10°, and 15°, respectively. The *GOES-East* and VIRS data are calibrated in the same manner. Thus, the VIRS calibration can be transferred from *GOES-12* to *Met8* and compared to the SEVIRI/MODIS calibration. Direct intercalibration of the MODIS and VIRS data should give the same result as the ratio of the SEVIRI/MODIS to *GOES-12*/*Met8* gains. Differences between the direct and indirect method provide an estimate of the uncertainty in the GOES-12 method. To further assess the stability of the MODIS calibrations, the SEVIRI data are compared independently to both *Aqua* and *Terra* MODIS data. If the MODIS data are accurately calibrated onboard, they should produce the same gains in the SEVIRI data.

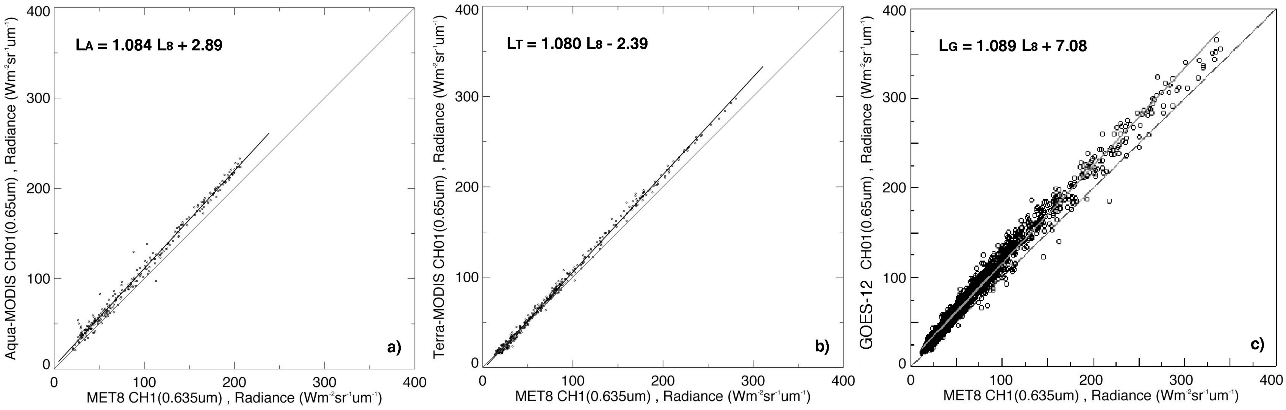
The nominal calibration of the SEVIRI VIS channel, as given by Govaerts and Clerici (2004), is

$$L_8 = 0.576\, C - 29.4, \quad (1)$$

where L is the VIS radiance and C is the 10-bit brightness count Normalizing from the SEVIRI solar constant, 515 $Wm^{-2}\mu m^{-1}sr^{-1}$., to the reference solar constant yields

$$L_8 = 0.589\, C - 30.1. \quad (2)$$

The other solar channels, 0.81 and 1.6 µm, are calibrated in a similar fashion except that the radiance is estimated directly from the SEVIRI counts and normalized to the MODIS solar constants. No comparisons with *GOES* data are possible for those two channels.



3. Regression fits for SEVIRI and (a) *Aqua*, (b) *Terra*, and (c) *GOES-12* 0.65-µm data, April 2004.

3. RESULTS

Scatter plots and linear regression fits between the SEVIRI and *Aqua* and *Terra* MODIS and *GOES-12* VIS channels for April 2004 are shown in Figures 3a, b, and c, respectively, where the radiance subscripts *A*, *T*, *G*, and *8*, refer to *Aqua*, *Terra*, *GOES-12*, and *Met8*, respectively. If the calibrations were in perfect agreement the slopes and offsets would be 1.00 and 0.0, respectively, as indicated by the line of agreement shown in each plot. The linear regression fits based on radiances (see equations in each panel) consistently show that the three reference imager VIS radiances are about 8.5% greater than their SEVIRI counterparts with some differences in offset values. The *Terra* offset compensates for some of the difference at the low end of the range but the *Aqua* and GOES-12 offsets indicate enhancement of the radiance differences beyond the 8.5% level. In terms of the count values, the average calibration based on the combined Terra and Aqua data would be

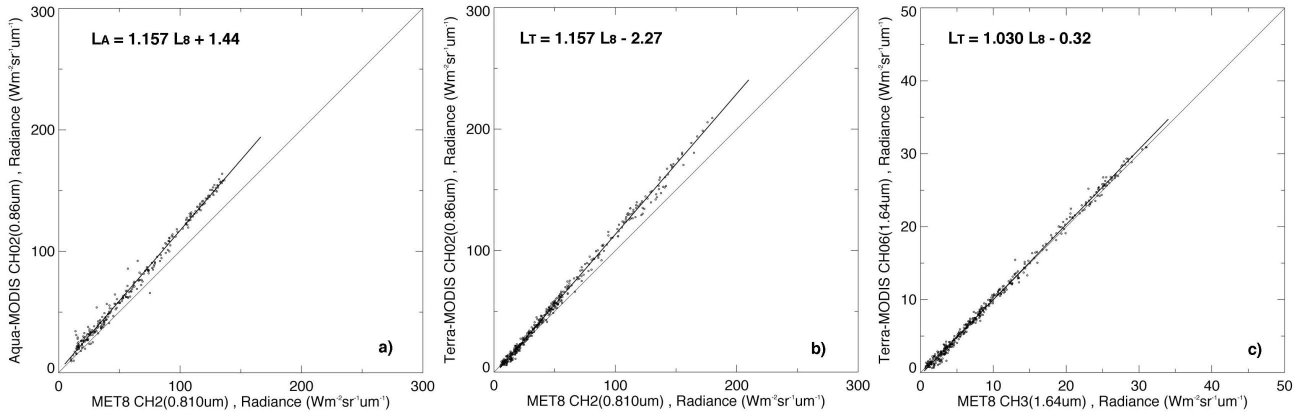
$$L = 0.630\ C - 31.9. \qquad (3)$$

The *GOES-12* scatter plot (Figure 3c) suggests that a non-linear fit might be more appropriate for GOES/SEVIRI since many of the high-value points are to the right of the linear fit. This apparent non-linearity is similar to that seen between narrowband VIS and broadband shortwave data (e.g., Minnis and Smith, 1998). In this case, the *Met8* channel is much narrower than the *GOES-12* VIS channel (Figure 1). The width of the MODIS channel (Figure 1), however, is smaller that for *Met8* and could help explain why the MODIS/SEVIRI fits are more linear than those from GOES and SEVIRI. Initial calibrations between *GOES-12* and *Met8* for 5 other months suggests a trend line in the gain of

$$g = 0.0000564\ \mathrm{DSL} + 0.592, \qquad (4)$$

where DSL is the number of days since launch on 22 August 2002. The offset slope of 0.592 is within 1% of the nominal value given by (2) indicating that (4) might provide a means for predicting the visible channel gain in the future.

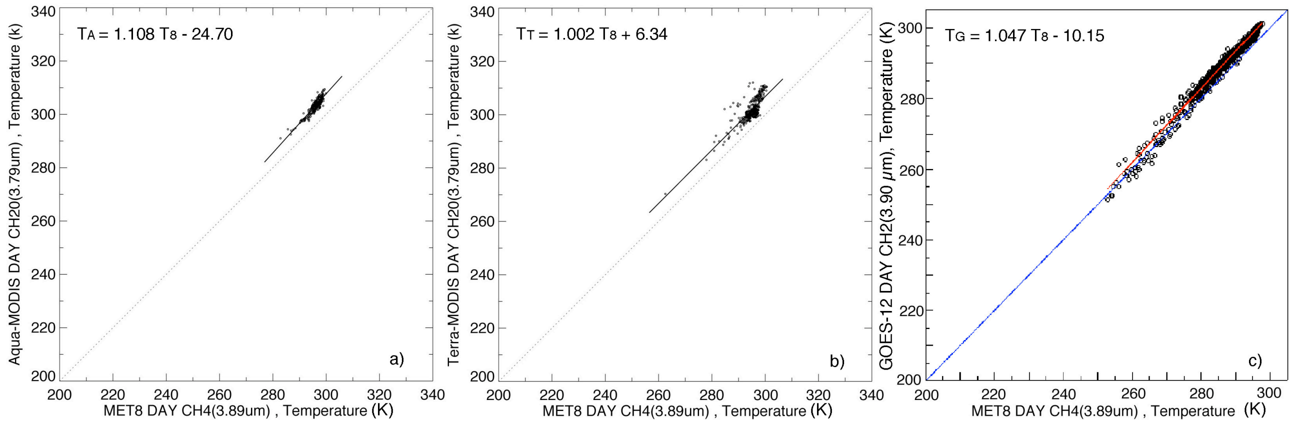
The preliminary fits between the MODIS 0.86-µm and SEVIRI 0.81-µm radiances in Figures 4a and b show a similar result for April 2004 in that the slopes are the same, but the *Terra* offset is positive while its *Aqua* counterpart is negative. In this case, the MODIS radiances are almost 16% greater than the SEVIRI values. When regressed against the SEVIRI 10-bit counts, the slopes from *Terra* and *Aqua* are 0.4771 and 0.4774, respectively, but the corresponding offsets are 23.43 and -23.0. At the *Terra* range midpoint, C = 250, the *Aqua* radiance are 3.7% greater than the *Terra* radiance. The slope and offset for the SEVIRI 1.6-µm channel counts derived from correlation with the corresponding *Terra* MODIS radiances are 0.0946 and -5.16, respectively, for April 2004. The radiance-to-radiance correlation shown in Figure 4c indicates that the *Terra* near-infrared radiances are less than or equal to those from *Met8* for dark scenes when $L_8 < 10$ Wm-^{2}. At larger values, the *Terra* radiances exceed the *Met8* values.



4. Same as Figure 3 except for (a) *Aqua* and (b) *Terra*, 0.86-µm and (c) *Terra* 1.64-µm data.

The range in the observed 3.89-µm brightness temperatures from *Aqua* (Figure 5a) and *Terra* (Figure 5b) is much smaller than that for the GOES-12 dataset in Figure 5c. In all three plots, the *Met8* temperatures are consistently less than the values from the other satellites by 5-7 K at the higher *Met8* temperatures (T_8 > 270 K). At the lower temperatures, where only *GOES-12* data are available, the two datasets tend toward agreement. The smaller range in the *Terra* and *Aqua* data yields less certainty in the regression fits (shown in each panel). However, if the two regression fits are averaged together, the resulting equation is very close to that derived from the *GOES-12* regression analysis. The large differences between the *Met8* temperatures and those form the other sensors may be due to a spectral leak in the *Met8* channel 4.

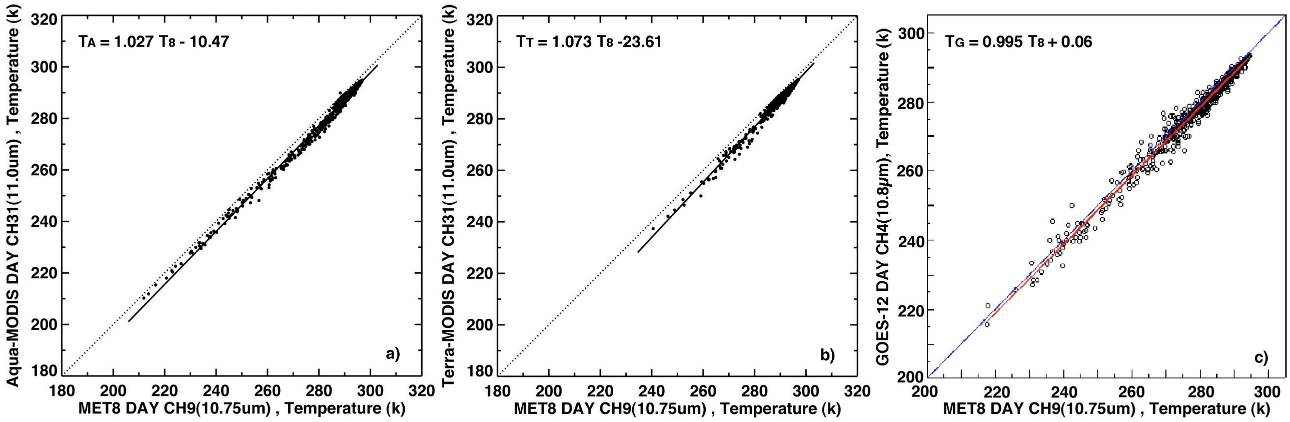
The intercalibrations between the *Met8* infrared (10.75 µm) and the other satellites (Figure 6) indicate that the *Met8* temperatures are generally too large by 1 - 4 K. Inconsistencies in the actual fits appear to be related more to the accuracy of the fits. At, the low end of the scatter plots, the *Aqua* regression line misses all of the points and would underestimate the true value. The *GOES-12* fit (Figure 6c) appears to be more realistic so that the true *Met8* overestimate would range from 1.0 to 1.5 K at 200 and 320 K, respectively.



5. Same as Figure 3 except for 3.89-µm brightness temperatures.

4. DISCUSSION

Although the MODIS and *GOES-12* visible channel regression fits paint a consistent picture in terms of gain, the results differ when considered in terms of offset. These inconsistencies suggest a level of uncertainty in the reference datasets. The *GOES-12* offset is expected to be greater than zero because of the extra Rayleigh scattering within the *GOES-12* visible band (Minnis et al. 2002a). However, the MODIS response functions should be similar enough such that their gains and offsets should be nearly identical. To further examine this uncertainty, the MODIS data were regressed directly against VIRS over the current lifetimes of the *Aqua* and *Terra* satellites. The resulting slopes (Figure 7) show no statistically significant trends for either satellite indicating that the VIRS is a stable reference. However, the mean slopes, 1.047 and 1.027 for *Aqua* and *Terra*, respectively differ by 1.9%. The corresponding mean offsets are nearly the same suggesting that the differences in the offsets seen in Figure 3 translate to differences in slopes when compared against VIRS



6. Same as Figure 5 except for 10.75-μm brightness temperatures.

data. It is not clear which of the MODIS calibrations is more accurate or relevant. The offsets from the calibrations in Figures 1a and b are nearly equidistant from zero. It is concluded that the uncertainty compared to MODIS is on the order of 2.5 $Wm^{-2}sr^{-1}\mu m^{-1}$ or ~2.5%.

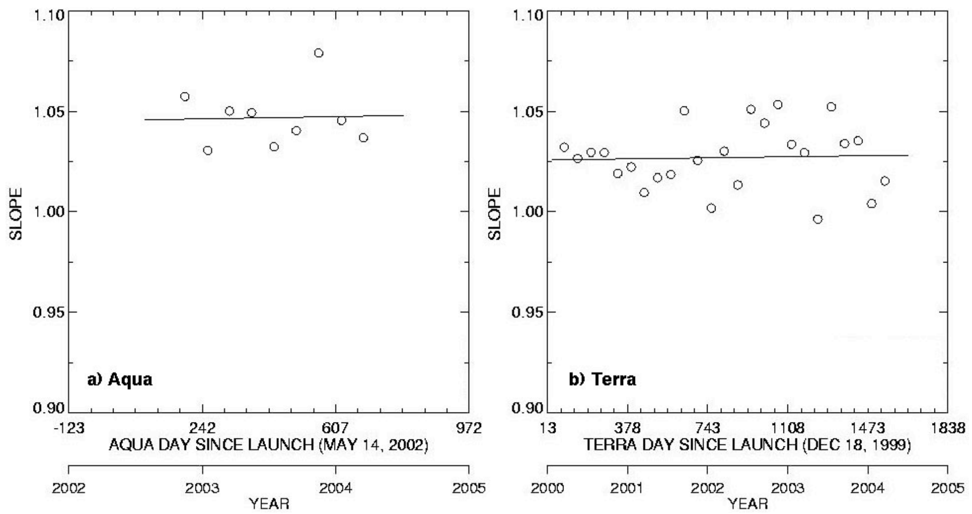
The large discrepancy between the *GOES-12* offset and that from either MODIS value is likely due to the non-linearity of the relationship between the broader GOES channel and its narrow *Met8* counterpart. A second order fit yields

$$L_G = -0.0005459\, L_8^2 + 1.221\, L_8 + 2.32. \quad (5)$$

The new offset is very close to the *Aqua* value, bringing the *GOES-12* and MODIS fits into better agreement. While the MODIS and *GOES-12* slopes in Figure 3 are all very close, the average of the *Aqua* and *Terra* slopes relative to VIRS data suggests that the *GOES-12* slope should be on the order of 3.5% smaller than the MODIS slopes. This uncertainty in the *GOES-12* slope needs additional study.

The offset differences are also observed in the 0.86-μm channel fits suggesting that there may be a fundamental difference in the offsets for all of the *Terra* and *Aqua* MODIS channels. The large slope differences between the *Met8* 0.81-μm channel and both of the MODIS 0.86-μm channels may be due, in part, to spectral response differences. However, the magnitude, 16%, of the difference is more likely a result of unresolved calibration biases in the *Met8* channel. The result in Figure 4c suggests that the 1.6-μm channel on *Met8* has an uncertainty of only 3%.

The comparisons in the solar-infrared channels (Figure 5) indicate that the cross-calibrations might be useful for correcting the spectral leak in the *Met8* channel 4 response on an average basis. However, the clustering



7. Trend in regression slopes between VIRS and (a) *Aqua* and (b) *Terra* 0.65-μm channel data.

of the points into two groups in Figures 5a and b and the bifurcation of the points in Figure 5c indicate that any fix using the cross-calibration approach is likely to be accompanied by noise on the order of 2.6 K.

Differences in the 10.8-µm brightness temperatures among VIRS, GOES, and MODIS reported by Minnis et al. (2002b) are on the order of 1 K. Unlike the results in Figure 6, the differences were not consistent from one satellite to the next. The differences were more random and some of the differences could be explained by the spectral response functions of the various instruments. It is not clear at this point if the consistent 1-K bias in the *Met8* channel is due to spectral response differences or calibration errors.

5. CONCLUDING REMARKS

The results presented here constitute the initial evaluation of the *Met8* SEVIRI calibrations using GOES and MODIS data. Much additional work is needed to fully quantify the uncertainties and develop any necessary corrections. Further comparisons should explicitly account for the differences in the spectral response functions using radiative transfer model calculations of the expected differences between the sensors. This is especially true for the 3.89-µm channel. Discrepancies between the calibrations of the *Terra* and *Aqua* MODIS channels revealed here must be resolved both for the sake of MODIS processing and future intercalibration efforts. This preliminary assessment has only considered five SEVIRI channels. In the future, additional channels will be intercalibrated with the MODIS, GOES, and VIRS sensors. Interactions with other groups studying the SEVIRI calibrations should eventually lead to an accepted set of calibration coefficients necessary for reliable physical interpretation of the these new valuable data.

Acknowledgments

This research was supported by the NASA Earth Science Enterprise Office, Code YS Radiation Sciences Branch. Many thanks to Steven Dewitte for supplying the SEVIRI data taken before April 2004 and to Marianne Koenig of EUMETSAT for developing the McIDAS server code and for providing some SEVIRI data in McIDAS format.

REFERENCES

Govaerts, Y. and M. Clerici, 2004: MSG-1/SEVIRI Solar Channels Calibration Commissioning Activity Report. *EUMETSAT Doc. EUM/MSG/TEN/04/2004*, 35 pp.

Minnis, P., L. Nguyen, D. R. Doelling, D. F. Young, W. F. Miller, and D. P. Kratz, 2002a: Rapid calibration of operational and research meteorological satellite imagers, Part I: Evaluation of research satellite visible channels as references. *J. Atmos. Oceanic Technol.,* **19**, 1250-1266

Minnis, P., L. Nguyen, D. R. Doelling, D. F. Young, W. F. Miller, and D. P. Kratz, 2002b: Rapid calibration of operational and research meteorological satellite imagers, Part II: Comparison of infrared channels. *J. Atmos. Oceanic Technol.,* **19**, 1250-1266

Minnis, P. and W. L. Smith, Jr., 1998: Cloud and radiative fields derived from GOES-8 during SUCCESS and the ARM-UAV Spring 1996 Flight Series. *Geophys. Res. Lett.*, **25**, 1113-1116.