P2.35 INTERCALIBRATION OF GEOSTATIONARY AND POLAR SATELLITE IMAGER DATA USING AVHRR, VIRS, AND ATSR-2 DATA

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1. INTRODUCTION

Cloud and radiative property retrievals from operational satellite imager data require accurate calibration of the satellite imaging radiometers. The lack of consistent calibration between the various satellites minimizes their utility in climate monitoring. While such intercalibrations between satellites have been performed for projects such as the International Satellite Cloud Climatology Project (ISCCP), the lengthy delay between data and calibration acquisitions precludes timely, accurate analyses of the operational datasets.

Efforts to maintain an up-to-date set of calibration coefficients for quantitative analyses have generally been limited to onboard calibrations of the thermal infrared (IR) channels on most satellites. In addition to the on-board IR-channel calibrations, the solar channels on imagers like the Visible and Infrared Scanner (VIRS) and Along Track Scanning Radiometer (ATSR-2) on research satellites use well-characterized onboard calibrators. The only imager currently on an operational meteorological satellite that is calibrated in a timely fashion is the NOAA-14 Advanced Very High Resolution Radiometer (AVHRR; see Rao and Chen 1996).

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This paper presents the results of a technique that has been developed to rapidly intercalibrate the visible and infrared channels on all geostationary and Sun-synchronous satellites such as the Geostationary Operational Environmental Satellite (GOES), Geostationary Meteorological Satellite (GMS), Meteosat, NOAA-12 and NOAA-15 satellites. The technique relies on the availability of one or more satellites having a well-maintained set of calibrations.

2. METHODOLOGY

The general approach taken here is similar to the Desormeaux et al. (1993) method except that the data-matching constraints are less stringent and a single geostationary (GEO) satellite, once calibrated against the reference sensor, is used as a primary reference for the other satellites. Reflectance is the parameter of interest for the visible (VIS; 0.65 µm) channel. VIS reflectance is defined as

$$\rho = \frac{L_v(\theta_o,\theta,\phi)}{E_o cos\theta_o \delta(day)}. \qquad (2)$$

The solar and viewing zenith and relative azimuth angles are θ_o, θ, and ϕ , respectively, and δ is the Earth-Sun distance correction factor. A value of

526.9 $Wm^{-2}sr^{-1}\mu m^{-1}$ is assumed to be the nominal VIS solar constant E_o. This value is used as a common scaling factor for all of the data. The VIS channel on the NOAA-14 AVHRR is used as the reference calibration here, so its radiances are normalized to the reference solar constant by multiplying by the ratio of the nominal-to-NOAA-14 solar constants. Although the VIS channel on each imager has a unique filter function, the bandpass for most of the instruments is between 0.55 and 0.75 µm.

The intercalibrations are effected by least squares regression analysis between spatially and temporally matched averages of the data in corresponding channels of two satellites. Additionally, the data are only selected if they have nearly the same values of θ and ϕ. For the

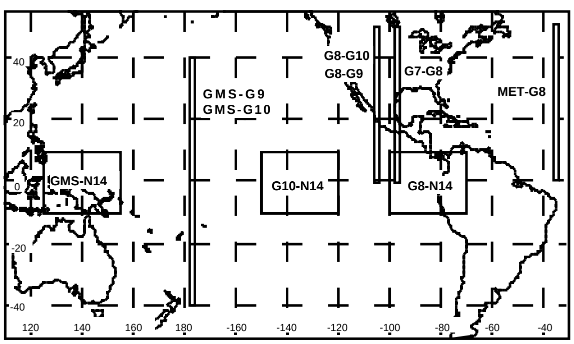

Fig. 1. Regions for satellite intercalibration.

calibration of a GEO to a NOAA satellite, the GEO data must be taken within 15 min of the NOAA radiances and must have values of θ and ϕ within 15° of the Sun-synchronous data. Data taken in possible sunglint conditions are filtered out of the datasets and the NOAA radiance is normalized the GEO solar zenith angle. The radiances are averaged on a 0.5° grid to yield a pair of data points for each grid box. Similarly, GEO satellites are also intercalibrated with each other. Very close matches in time and space are possible because of the fixed views and regular imaging schedules. The GEO data are taken at local noon or midnight at the bisecting longitude between the two satellites. Local noon insures that all of the angles are nearly identical. The GEO data are matched to within 2 min. Because reflectance anisotropy may not be entirely symmetrical, average radiances at each 1-2° of latitude are computed for two 1-2° boxes that straddle the bisecting longitude. The regions used to cross-calibrate many of the various satellites are shown in Fig. 1.

In addition to the GEO-to-GEO matches, the GEO satellites are used to cross-calibrate with other imagers like the VIRS on the Tropical Rainfall Measuring Mission (TRMM) satellite. Because TRMM is in a 35°-inclined orbit, it rarely has any close matches with Sun-synchronous satellites. But it can be collocated and bore-sighted with GEO data. Thus, GEOs can serve as calibration sources for other satelllites. Calibrations between Sun-synchronous satellites follow the approach of Loeb (1997) who used the frequent polar overpasses of such orbiters to obtain well-matched data. Data were averaged on a 0.5° grid for the last two calibration methods.

While the calibrations are performed for all channels that are spectrally similar, this report focuses on the infrared window (IR, ~11 µm) and VIS channels. The VIS brightness counts are regressed against the reference radiances L_{VR}, where the starting reference is the NOAA-14:

$$L_{vR} = L_{VA} = a(C - C_o) \qquad (2)$$

where a is the gain, C is the observed brightness count or squared count, and C_o is the space count. The VIS regression forces the lines through the space count for the particular calibration satellite. The IR temperature is

$$T = T_A = b_1 T_G + b_o, \qquad (3)$$

where b_i and b_o are the regression coefficients. The mean IR temperatures for each data point are computed in radiance and converted to T with the appropriate Planck function. Despite the spectral differences between the various IR channels, it is assumed that the equivalent blackbody temperatures should be the same for all of the sensors.

3. DATA

Matched geostationary and NOAA AVHRR data were selected for several days and times for 1994 through 1998. Table 1 shows an example of the sampling used for some of the satellites. Other datasets used include GOES-10, Meteosat-5-7, GMS-5, and VIRS. All data were converted for processing in the Man-computer Interactive Data Analysis System (McIDAS).

3.1 AVHRR

The initial reference data comprise 4-km resolution Global Area Coverage (GAC) AVHRR channel-1 visible (VIS; ~0.67 µm) and channel-4 infrared (IR; ~10.8 µm) measurements from NOAA-14. NOAA-14 was launched into a near Sun-synchronous orbit on December 30, 1994. It has a nominal equatorial crossing time of 1430 local time (LT).

The NOAA-14 AVHRR VIS radiance is

$$L_{VA} = (0.000069d + 0.566)(C_{10} - 41) \qquad (4)$$

(Rao and Chen, 1996; and 1998 update), where C_{10} is the 10-bit count and d is the number of days since launch of the satellite. The value of E_o is 510 $Wm^{-2}sr^{-1}\mu m^{-1}$. The IR temperature is

$$T_A = B^{-1}(L_{IR}), \qquad (5)$$

where B^{-1} is the inverse Planck function integrated over the filter function of the channel and L_{IR} is the measured radiance which is nominally linear with count. A correction for nonlinearity in the response is applied to obtain an accurate radiance.

NOAA-12 has an equatorial crossing time of 0700 LT. Although channel 1 is calibrated before launch, the NOAA-12 VIS calibration is not updated and no trend like (4) is available.

3.2 GOES-7

GOES-7 was located at 108.5°W during April 1994, at 98°W during the summer and fall of 1994 and then moved to 135°W in January 1995. It was operational until January 1996. The GOES-7 Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) VIS channel is centered at 0.65 µm and the radiance is based on a squared relationship to VIS count.

3.3 GMS-5

The GMS VISSR has a nominal 1.25-km resolution VIS channel and a 5-km IR channel. Matched data are obtained by computing the 5-km VIS rms average corresponding to a given IR pixel. The IR temperature conversion uses a nonlinear lookup table. GMS-5, at 140°E, has provided data since June 1995.

3.4 GOES-8, 9, 10

GOES-8 has been at 75°W since September 1994. GOES-9 was initially located at 90°W during September 1995 and operated at 135°W from January 1996 to December 1997. GOES-10 The GOES-8 and 9 imagers have 1-km VIS (~0.62µm) and 4-km IR (10.8 µm) channels (Menzel et al., 1994) with data taken at a 10-bit resolution.

Month	N14-G8	N14-N12	G8-G7	G8-G9
Jan	98, 99	98		98
Feb	96,97,98		95	96,97,98
Mar				96,98
Apr	95,97,98			96,97
May	95,96			
Jun		97,98	95	
Jul	95,97,98			96
Aug	95,96,98			96
Sep	97			96,97
Oct	97,98		94,95	97
Nov				
Dec	97,98	96,98	94	97

Table 1. Monthly satellite calibration data by year.

Simple averaging is used to degrade the VIS resolution to 4-km.

3.5 VIRS

The VIRS has been operating since December 1997 at a 2-km resolution. The solar constant for channel 1 (VIS) is 531.7 $Wm^{-2}sr^{-1}\mu m^{-1}$.

4. RESULTS

The scatterplot for GOES-8 during the October 1997 is shown in Fig. 2 with the regression fit forced through the space count, 28.5. The correlation is excellent with the forced fit centered in the data over the full range. The IR fit for the same period is close to the line of perfect agreement between GOES-8 and NOAA-14 and is typical for the 4 years. The differences between the two temperatures are negligible. Figure 3 shows that the visible channel gain for GOES-8 increases linearly with time consistent with steady degradation of the instrument optics. For a given satellite, the radiance normalized to the reference solar constant is

$$L_{vis} = (\Delta g\ d + g_o)(C - C_o), \qquad (6)$$

Where g_o is the initial gain, Δg is the trend, d is the days since the reference date, and C_o is the offset count. Preliminary results for several

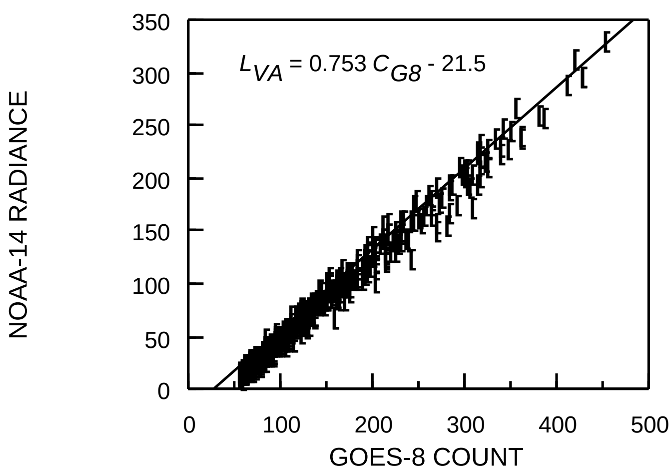

Fig. 2. GOES-8 VIS calibration, October 1997.

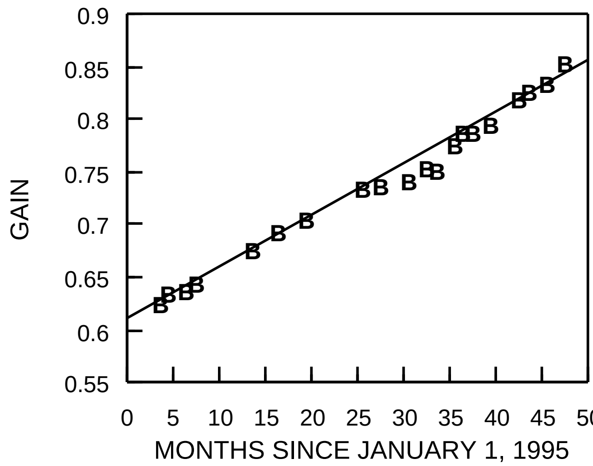

Fig. 3. GOES-8 VIS channel gain trend, where GAIN is in $Wm^{-2}sr^{-1}\mu m^{-1}$.

satellites are given in Table 2. The value of Δg for GOES-8 at the 95% confidence level is 0.000169 $\pm$ 0.000018. The GMS VIS calibration, where C is squared counts, for March 1998 indicates that a zero radiance cannot occur even when there is no signal. Thus, the GMS data should be used carefully in low sun or shadowed conditions.

Calibrations were also performed with GOES-10 via GOES-8 and via NOAA-14 directly to test the GEO-to-GEO technique. The resulting slope between the two calibrations is 0.999 indicating that the method is extremely accurate.

In this study, the NOAA-14 VIS channel has served as the reference. Because it has an onboard calibration system, the VIRS can also serve as a standard. The GOES-8 VIS radiances calibrated against NOAA-14 were compared with the corresponding VIRS radiances for January

Satellite	g_o	Δg x10^4	C_o	Ref Date
NOAA14	0.585	0.7120	41.0	12/30/94
NOAA12	0.554	0. 5390	41.0	5/14/91
GOES-8	0.609	1.6000	28.5	1/1/95
GOES-9	0.547	1.0948	29.0	1/1/96
GMS-5	0.00753	0.0204		3/15/95

Table 2. Parameters for (6). g_o and Δg in $Wm^{-2}sr^{-1}\mu m^{-1}$.

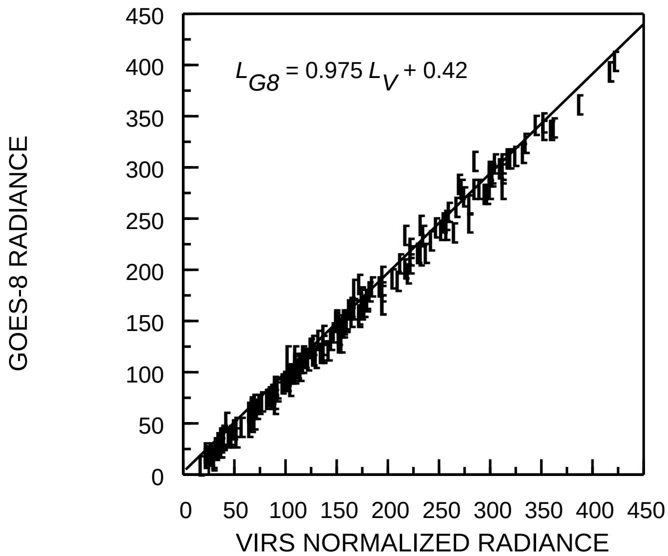

Fig. 4. Regression of VIRS and GOES-8 VIS channels for January 1998. Radiances given in $Wm^{-2}sr^{-1}\mu m^{-1}$.

analysis.

The scatter is minimal with a squared correlation coefficient of 0.999. The fit shown in Fig. 4 reveals that the GOES-8 radiance is roughly 2% less than the VIRS. Reversal of the axes yields a similar result suggesting that the NOAA-14 AVHRR trend may not be steep enough.

5. CONCLUSIONS

The method presented here provides a means for accurately calibrating satellite VIS channels in a timely fashion. This approach assumes that the AVHRR sensors are well calibrated. Thus, any errors in the AVHRR calibrations will be transferred to the other satellites. Independent validation of these results is an important part of this effort. Other satellites and sensors will be examined and the validation of the VIS channels will be continued. Other channels such as the 3.7 and 1.6-µm channels on the NOAA satellites will also be intercalibrated. These calibrations provide the basis for consistent retrievals of cloud and surface properties and radiative fluxes from all of the different satellites used for climate monitoring. These techniques also permit rapid evaluation of the geostationary satellite data, thus paving the way for a near-real time analysis of radiative properties from these satellites.

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