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# POST-LAUNCH CALIBRATION OF AVHRR AND GOES SOLAR CHANNELS

## Summary and Purpose of Document

This paper summarizes the current NOAA/NESDIS in orbit visible calibration procedures for geo and leo instruments. It is submitted in response to Action 30.19.

Action Requested: None

**POST-LAUNCH CALIBRATION OF AVHRR AND GOES SOLAR CHANNELS**

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## 1. INTRODUCTION

Current Advanced Very High Resolution Radiometer (AVHRR) has three channels in the visible (0.58-0.68 µm) and near infrared (0.725-1.0 and 1.58-1.64 µm) parts of the spectrum. The Geostationary Operational Environmental Satellite (GOES) Imager carries a single visible channel at 0.55-0.75 µm. These channels do not have on-board calibration devices. Post-launch instrument degradation will therefore make the pre-launch calibration obsolete in time. The only remedy is to calibrate these channels on orbit with vicarious techniques, i.e., using external references.

There are four broad categories of external references that are commonly used in vicarious calibration of satellite instruments. These are stable Earth targets, celestial targets, calibrated radiometers, and modeled radiances. The first three approaches are employed at NESDIS to calibrate the solar channels of the AVHRR and the GOES Imager. This report summarizes the methodology of each method, current status and results of their applications to the AVHRR and GOES Imager, and future directions.

## 2. AVHRR

### 2.1. Calibration from Stable Earth Target

This technique, elaborated by Rao and Chen (1995, 1999) with ongoing refinement, is the primary method for the operational calibration of the AVHRR solar channels. The fundamental assumption is the existence of earth targets whose top of the atmosphere reflectances are stable and known. One recent modification is the recognition that the reflectance of the selected earth targets (e.g., Libyan Desert), while stable inter-annually, may vary intra-annually due to the bi-directional reflectance distribution of the surface and the annual variation of the local solar zenith angle. Work is also being undertaken to eliminate cloud contamination, to account for the non-homogeneity of the surface reflectance, and to reconfirm the value of the reflectance of the target (absolute calibration). Eventually this technique will be applied to stable earth targets at other geographic locations and of different reflectances to minimize the atmospheric (ozone, aerosol, water vapor) and instrument (dual slope) effects on calibration.

Figure 1 is a plot of NOAA-16 AVHRR reflectances over the Libyan Desert (21°N -23°N, 28°E-29°E) as a function of time. The horizontal line in each panel is the reference reflectance for the channel, determined by Rao and Chen (1995, 1999) for Channels 1 & 2 from aircraft measurements over the White Sand Desert and by Heidinger et al (2002) for Channel 3A from Terra MODIS measurements over Arctic. The plus signs (+) are the derived reflectances from pre-launch calibration coefficients, corrected for solar zenith angle and earth-sun distance at the time of observation. The curve is the least-squares fit of the data to a model of linear degradation superimposed with a sinusoidal annual variation. The asterisks (*) are the reflectances with the linear trend removed. This figure shows that, for the NOAA-16 AVHRR Channel 1, the pre-launch calibration initially over-estimates the reflectance by less than one percent, and the ensuing degradation (1.2%±0.1% per year) has been moderate. For Channel 2, the pre-launch calibration initially under-estimates the reflectance by a few percent ("the post-launch drop-off") and the degradation (2.4%±0.2% per year) is close to normal. For channel 3A, the degradation (0.2%±0.2% per year) is hardly noticeable.

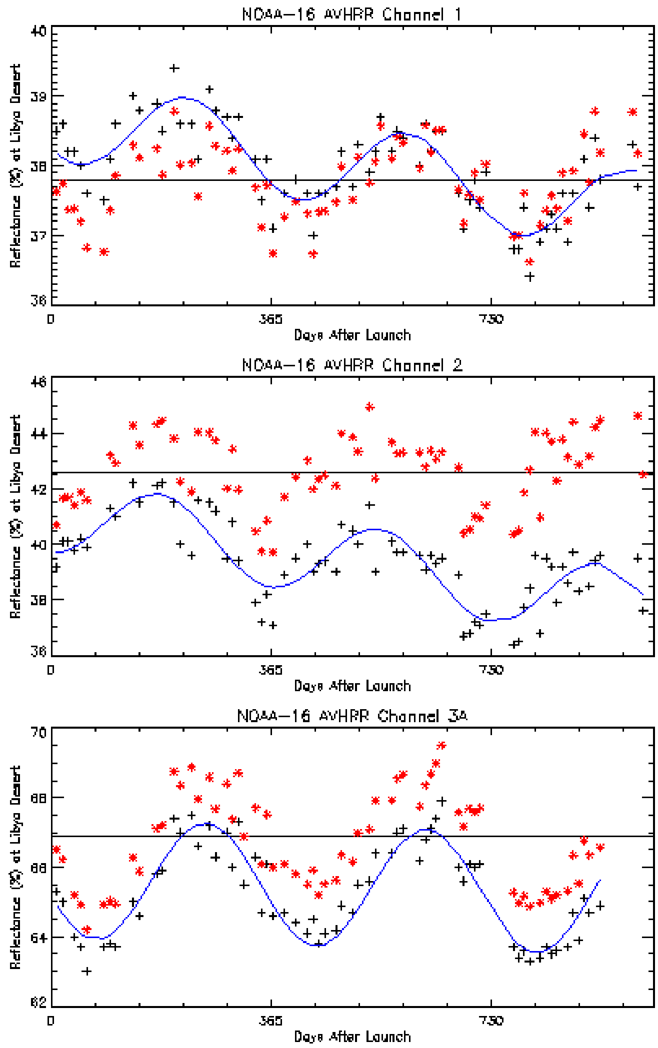


Figure 1: **Pre-launch and vicariously calibrated reflectances of NOAA-16 AVHRR over Libyan Desert as a function of days after launch.**

The operational calibration coefficients for the NOAA-16 AVHRR have been updated monthly since February 2003 with this type of analysis. This technique has also been applied to the NOAA-17 AVHRR. Preliminary results indicate similar trends, i.e., the pre-launch calibration over-estimates the reflectances in channel 1 and under-estimates those in channels 2 and 3A by a few percent. Degradation rates cannot be estimated until at least one year's data have been analyzed.

### 2.2. Calibration from Celestial Target

This technique has not been applied to the AVHRR, as the AVHRR does not actively seek views of celestial bodies during its normal operation. We leave it for future research to ascertain whether the AVHRR observations of the moon, in terms of frequency, filling the AVHRR's field of view, and the moon phase, are adequate as a source of calibration.

## 2.3. Calibration from Calibrated Radiometer (MODIS)

This technique, pioneered by Heidinger et al. (2002), employs co-located observations by the AVHRR and a reference radiometer such as the MODIS on EOS/Terra satellite. In this case, what the AVHRR should measure is known from the MODIS, so the measurements can be used to calibrate the AVHRR. The orbit characteristics of NOAA-16 and Terra dictate that the co-location of the two satellites typically occurs near local noon at 70°N and near local midnight at 70°S. While this does not constrain the infrared comparisons, it leaves only the northern summer months with the necessary solar illumination for visible calibration. It is also desirable for the scene to contain wide range of reflectance values, e.g., land or sea surface not covered by snow or ice. This further narrows the window of calibration. Because of these constraints, this technique is not used as the primary method for operational calibration.

Nevertheless, the MODIS-based calibration continues at NESDIS as it offers several unique advantages to improve some key aspects of calibration. In July 2003, data in channel 3A of the NOAA-16 AVHRR were collected for five scenes co-located with MODIS/Terra, specifically for the purposes of calibration. (The NOAA-16 AVHRR Channel 3A has been deactivated from routine operation since May 1, 2003.) This type of data collection has been planned for the following years and results will be reported to CGMS in the future. Inter-satellite calibrations involving EOS/Aqua and NOAA-17 will be studied in future.

# 3. GOES IMAGER

## 3.1. Calibration from Calibrated Radiometer (MODIS)

This technique, described by Wu (2003), is a close analogy to Heidinger et al (2002). Unlike the AVHRR, the GOES and Terra orbits intersect approximately every nine days, making it suitable for update year round. On the other hand, it has been difficult to obtain precisely concurrent GOES Imager and MODIS measurements. Typically, the time difference between GOES and MODIS images (up to ten minutes) is an order of magnitude longer than that between AVHRR and MODIS (about one minute). To alleviate this problem, we match the histograms of the two images (instead of matching the two images pixel-by-pixel) to be more tolerant to uncertainties in navigation and cloud movement between the imaging times.

Figure 2 is an illustration of the procedure. In the upper panel, the lower curve of “GOES-8 Prelaunch” is a portion of the histogram of GOES-8 Imager reflectance for a scene using pre-launch calibration. The “MODIS Estimate” is the MODIS counterpart (similar channel corrected for spectral difference) for the same scene. The mismatch between the two curves is significant, and the task is to find the calibration coefficient that minimizes this mismatch. In the lower panel, the mismatch between GOES and MODIS is plotted as a function of calibration coefficient, which has a minimum value around 1.75. The histogram of GOES reflectance using the optimal calibration coefficient is again plotted in the upper panel as “GOES-8 Match”.

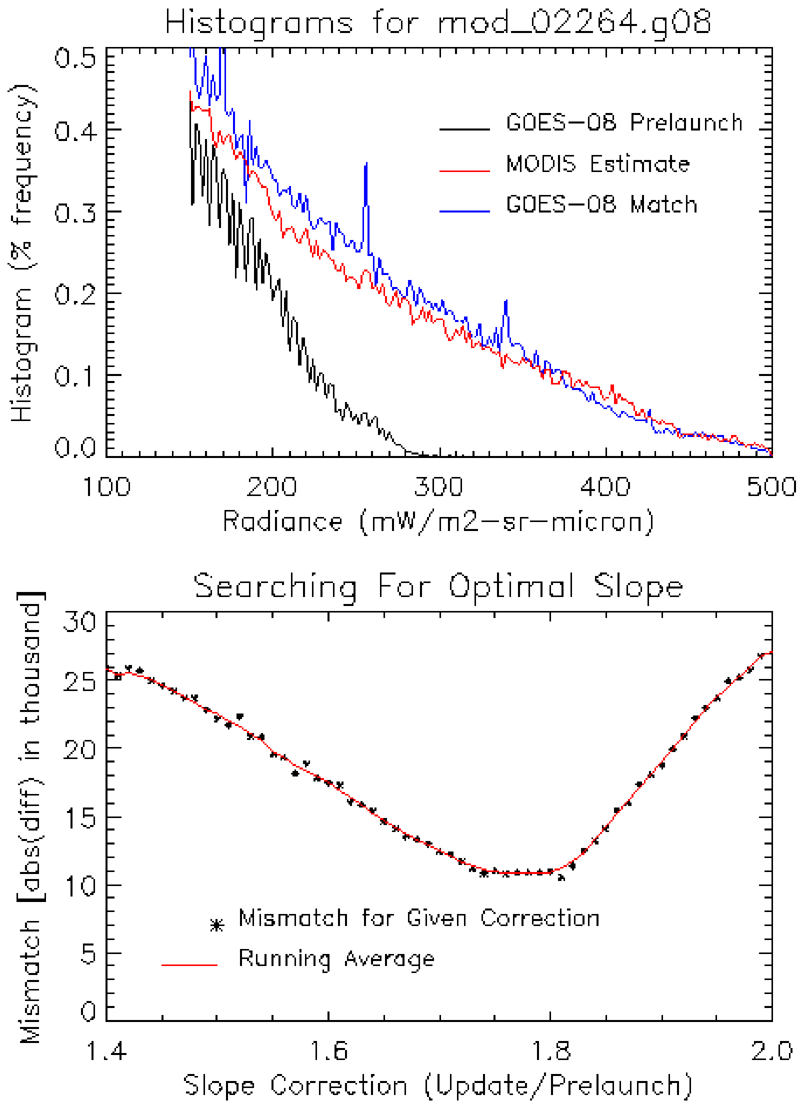


Figure 2: **Vicarious calibration of GOES Imager visible channel from MODIS measurements.**

This technique provides instant updates of absolute calibration, whereas other techniques typically require data collection for more than one year and give only the relative degradation. Although MODIS is currently used, the technique does not necessarily depend on a particular instrument, in fact using multiple calibrated instruments (ATSR on ERS-2 and ENVISAT, VIIRS on NPP and NPOESS) should be beneficial and has been planned for future. We have obtained (but not applied to the GVAR) the updated calibration coefficients for GOES-8, -10, and -12 Imager visible channels using this technique.

This technique is not yet mature for operation, though. The mismatch in time between GOES and MODIS observations, occasionally long enough for cloud edge to move across a few pixels, remains a major source of error. Solution to this problem may be sought in two ways – to reduce the mismatch time by working around the GOES Imager scan schedules (e.g., north to south for GOES-8/12 and south to north for GOES-10), and to better account for the mismatch time by weighting the images accordingly. Another problem is that the GOES Imager visible channel (0.55-0.75 μm) is spectrally wider than that of the AVHRR (0.58-0.68 μm) and (especially) MODIS (0.62-0.67 μm). Consequently, spectral correction is more difficult between GOES and MODIS due to vegetation reflection on the long wave side and aerosol scattering on the short wave side. We have limited the comparisons to the cloudy scenes only. Other options are being investigated.

### 3.2. Calibration from stable Earth target

This technique is similar to that of Rao and Chen (1995, 1999). Since there is no suitable Earth target near the GOES nadir, the Grand Desert in Sonora, Mexico (32°21'N, 114°39'W) has been used, from where the local zenith angle of the GOES East & West is 57° and 43°, respectively. The reflectance of the Grand Desert has been determined by the NOAA-9 AVHRR at nadir. Among other issues, it is unclear how much the nadir reflectance differs from that at ~50°. Figure 3 shows eight years of observations from the visible channel of the GOES-8 Imager, from which we estimated the degradation rate as 5.8% per year for the 8-year period. The plot shows a drop around 1200 to 1300 days after launch, corresponding to the later half year of 1997, and reduced degradation thereafter. This was likely caused by the increased precipitation and vegetation activities in the area after the strong 1997 El Niño event (Smith et al 2002). Although this technique has a number of limitations, we plan to continue to provide comparison with results from other techniques.

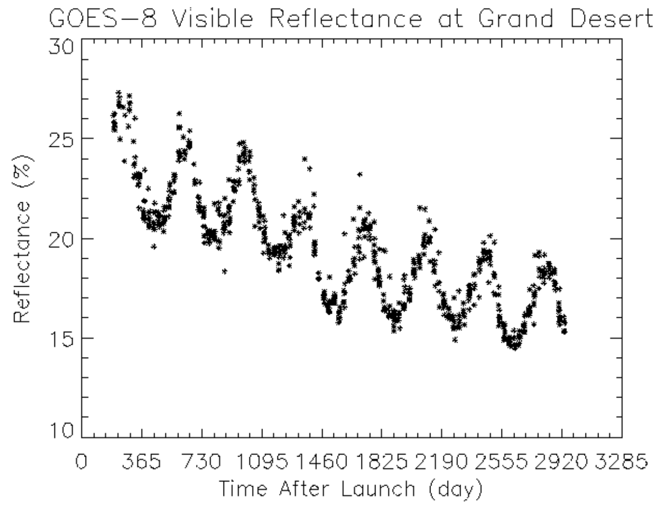


Figure 3: **Vicarious calibration of GOES Imager visible channel from stable Earth target.**

### 3.3. Calibration from celestial target

The celestial technique for determining the rate of degradation of the responsivity in the visible channel of the GOES Imager exploits observations of stars that are routinely made for another purpose – to determine the attitude and orbit of the GOES. The principles underlying the use of star observations to infer GOES visible channel responsivity degradation are described in Bremer et al. (1998). The basic idea is that for a star whose brightness is invariant with time, any change in amplitude of the Imager's output on viewing the star must represent a change in the Imager's responsivity. Figure 4 is an example of a time series of observations of signal amplitude from one star.

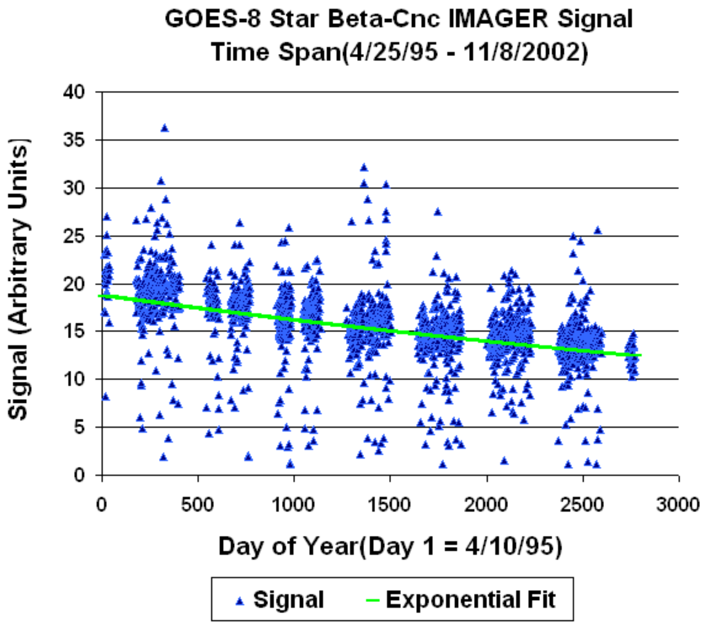


Figure 4: **Vicarious calibration of GOES Imager visible channel from star observations.** From such data from 40 stars, we determined that the degradation rates through June 2003 for the GOES-8 and GOES-10 Imager visible channels were 5.0%/yr ∀0.1%/yr and 6.4%/yr ∀ 0.1%/yr, respectively. (The quoted uncertainties are only the statistical uncertainties; any difficulties in the technique itself will increase the total uncertainty.) Work is currently underway to improve the technique by reducing the scatter in the observations. Complete up-to-date results can be viewed at http://www.oso.noaa.gov/goes/goes-calibration/visible-channel.htm.

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