On-Orbit Characterization of the GOES Imager Channel-to-Channel Co-Registration and Correction Algorithm Evaluation

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Introduction

The field of view (FOV) of the four infrared (IR) channels on the Imager instrument of the Geostationary Operational Environmental Satellite (GOES) should be co-registered (distance between pixel centers) within 50% of the pixel width. With few exceptions (Wu et al 1996), this has rarely been verified.

In May of 2012, the Space Science and Engineering Center (SSEC) at the University of Wisconsin – Madison discovered that the co-registration error along the scan (East-West) direction between GOES-13 Imager Channel 4 (10.7 μm) and Channel 2 (3.9 μm) was much more than 50% of the pixel width. In one incident (0945 UTC on May 14, 2012), this led to the false detection of fog along rivers and the east shore of lakes (Figure 1), when Ch2 measurements are more affected by the cold land to the east while Ch4 by the warm water in the river or lake. This difference in brightness temperatures was misinterpreted as signal from fog (lower emissivity at Ch2). After the Ch4 image was manually shifted by one pixel, most of the false detection disappeared.

In response to the discovery, the NOAA/NESDIS Center for Satellite Applications and Research (STAR) characterized the co-registration error between the other infrared channels, amongst other GOES, and temporally (Grotenhuis et al 2012). Some of the results and methodology are presented here. To mitigate the effects of the erroneous co-registration error, the NOAA/NESDIS Office of Satellite and Product Operations (OSPO) has developed a data resampling method to be operationally applied to GOES-13 (Li et al 2013). STAR has evaluated the method spatially and statistically, and the results are presented here.

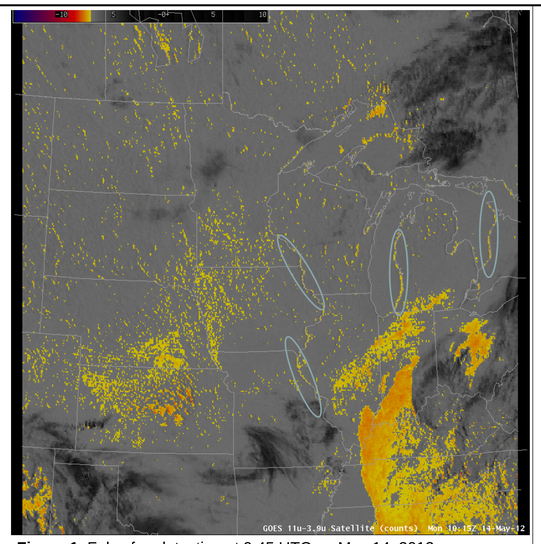

Figure 1. False fog detection at 9:45 UTC on May 14, 2012. *Courtesy of the University of Wisconsin-Madison Space Science and Engineering Center (SSEC).*

Co-Registration Error Characterization Methodology

Wu et al. (1996) observed correlation between the spatial and spectral gradients of brightness temperatures of two GOES Imager channels, shown as the slanted orientation in the histogram (Figure 2, left). From that they inferred co-registration error between these channels (Figure 2, right). It was found recently that the co-registration error can be further characterized and corrected by incrementally interpolating the radiance of one image spatially until the correlation, measured by the chi-squared error to a linear fit, is minimized (Grotenhuis et al 2012).

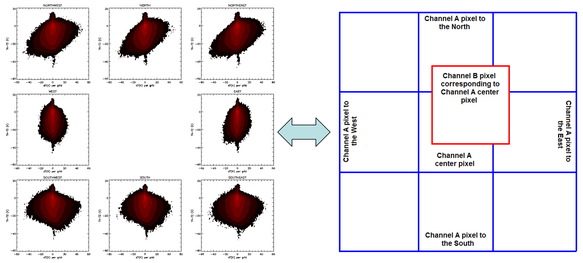

Figure 2. Spatial/spectral brightness temperature gradient histograms (left) and associated registration geometry (right).

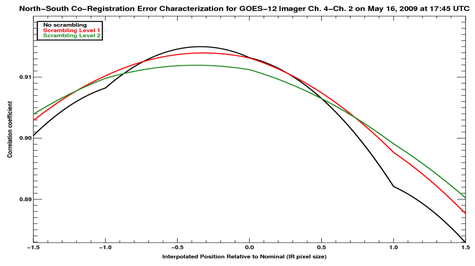

Figure 3. GOES Imager Channel 4/Channel 2 brightness temperature correlation coefficient vs. interpolated position, used to find co-registration error.

The co-registration error can also be characterized by the interpolated distance that yields the greatest brightness temperature statistical correlation, calculated from the sample Pearson correlation coefficient (Figure 3). The spatial interpolation is performed on one channel's radiance image prior to the conversion to brightness temperature. This is similar to previous work performed by NASA for the ADAR 5500 sensor system functional flight test (Blonski et al 2000). Data scrambling reduces systematic errors due to varying interpolation error (note the "kinks" in the plot to the right).

Co-Registration Error Characterization Results

The co-registration error was characterized amongst different GOES (Figure 4, left), between all the IR channels (Figure 4, middle), seasonally (Figure 4, right), yearly (not shown), and in the long-term (not shown). This was done in both the East-West and North-South directions.

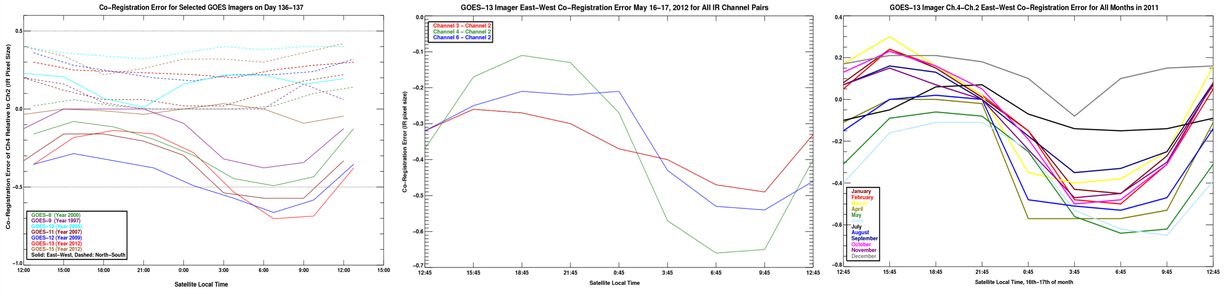

Figure 4. GOES Imager co-registration characterization amongst different GOES (left), between all IR channels (middle), and seasonally (right).

Resampling Evaluation by STAR

To reduce the negative effects on GOES products due to the co-registration error, the NOAA/NESDIS Office of Satellite and Product Operations (OSPO) has developed a data resampling method (Li et al 2013) to be operationally applied to GOES-13 Channel 2 so that its registration better matches the other IR channels. STAR evaluated the resampling both spatially and statistically.

The OSPO provided several images that had been resampled to correct the co-registration error, and STAR measured significantly less co-registration error after resampling (Figure 5). OSPO also created a series of resampled images from the same original image where the correction had been applied in varying amounts. The sum of the amount of correction applied and the measured remaining error was roughly constant (Figure 6).

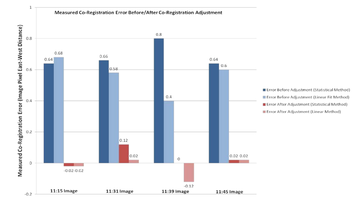

Figure 5. GOES-13 Channel 2 to Channel 4 measured co-registration error before and after resampling.

Figure 6. GOES-13 Channel 2 to Channel 4 measured co-registration error before and after resampling.

The resampling is Fourier-based, and it can be shown mathematically that the Modulation Transfer Function (MTF), a measure of imaging quality, does not change in the resampling process. This was confirmed empirically by comparing the frequency of gradients between the original and resampled images for all gradient magnitudes (Figure 7).

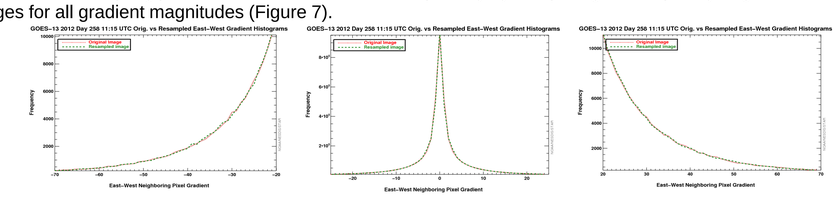

Figure 7. GOES-13 Imager Channel 4 east-west gradient histograms before and after resampling.

The original and resampled images were compared statistically. Regardless of the amount of shift applied, the average GOES VARiable format (GVAR) value of the shifted images was within 0.01% of the average GVAR value of the original image. Also, the median GVAR value of the shifted image was always identical to that of the original. GVAR count histograms were similar (Figure 8) and a histogram of the difference in GVAR counts between the two images is a symmetric function centered at zero (Figure 9).

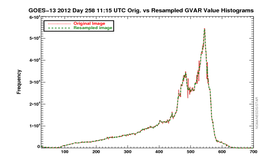

Figure 8. GOES-13 Imager Channel 4 GVAR count histograms before and after resampling.

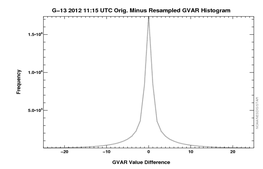

Figure 9. GOES-13 Imager Channel 4 original image GVAR counts minus resampled image GVAR counts.

Conclusions

- The co-registration should be closely monitored, beginning with the GOES post-launch test (PLT) and throughout the mission life.
- The tools used in this study can be developed for the GOES-R Advanced Baseline Imager (ABI). Experience gained from this study will benefit the cal/val of GOES-R ABI when launched.
- The resampling used to correct the co-registration error properly reduces the error while maintaining image quality and GVAR count statistics.
- STAR, SSEC, and others are working with OSPO for a possible operational implementation of the resampling correction before GVAR generation.

References

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