P4.37

INTER-COMPARISON OF GOES-8 IMAGER AND SOUNDER SKIN TEMPERATURE RETRIEVALS

Stephanie L. Haines*
University of Alabama in Huntsville
Global Hydrology and Climate Center, Huntsville, AL

Ronnie J. Suggs and Gary J. Jedlovec
Global Hydrology and Climate Center
MSFC/NASA, Huntsville, AL

1. INTRODUCTION

Skin temperature (ST) (or land surface temperature) retrievals are currently made every hour from 1145 to 2345 UTC in support of near real-time modeling applications using Geostationary Operational Environmental Satellites (GOES) data at the Global Hydrology and Climate Center (GHCC). The GOES Imager or Sounder data are used in a physical split window technique (PSW) (Suggs et al. 1998) to derive skin temperature values over much of the United States. The frequency of the retrievals allows the data to be assimilated into numerical models to improve the accuracy of their forecasts (Lapenta et al. 1999). GOES-8 is the current eastern operational satellite and provides imagery of the eastern Continental United States (CONUS) every 15 minutes. The high temporal resolution of the GOES data provides the opportunity to study the diurnal variation of measured parameters such as skin temperature.

The PSW technique uses longwave infrared (IR) window channels to simultaneously retrieve ST and total precipitable water. At least two longwave IR channels are required from the Imager or the Sounder to make retrievals. Beginning with GOES-12, the Imager will no longer have the 12 μm channel and will therefore become obsolete with respect to the PSW retrieval technique. Once GOES-12 becomes operational, the Sounder will have to provide the data for ST retrievals. GOES-11 is currently in orbit ready to replace either GOES-8 or GOES-10 and will be able to provide retrievals from both sensors. This research compares Imager to Sounder ST retrievals, in particular the spatial resolution differences, in preparation for the loss of the 12 μm channel. Comparisons between GOES-8 and GOES-11, in particular noise differences, are also studied. This paper focuses on quantifying the striping observed in GOES-8 and GOES-11 calibrated IR images and analyzing the averaging of ST retrievals from the GOES-8 Imager and Sounder. Retrievals from the GOES-8 Imager and Sounder have previously been compared to ground-truth (Suggs et al. 2000) and inter-compared (Suggs et al. 2001).

* *Corresponding author address:* Stephanie L. Haines, UAH/ Global Hydrology and Climate Center,
320 Sparkman Dr, Huntsville, AL 35805.
E-mail: haines@atmos.uah.edu

2. BACKGROUND

2.1 Infrared On-Board Calibration

Temperatures on the GOES satellites vary diurnally by tens of degrees Kelvin. These large and rapid temperature changes cause the instruments' infrared responsivities to vary significantly (Weinreb 1996). The infrared channels of the Imager and Sounder are calibrated frequently during orbit to counteract the temperature changes. To calibrate their infrared channels, the Imager and Sounder view space and warm on-board blackbodies. The Sounder views space every 2 minutes and its blackbody every 20 minutes. The Imager needs to view space as often as possible to reduce the effect of 1/f noise. For routine imaging, the Imager views space every 36.6 seconds, and during a full disk image the space look interval is 2.2 seconds. The Imager views its blackbody every 30 minutes.

2.2 Striping in Infrared Images

The GOES satellites exhibit striping in both Imager and Sounder calibrated IR images. Stripes are seen in the East-West direction as a result of multiple detectors scanning the scene. Striping occurs on uniform scenes as a result of the differences in output of the detectors in a channel (Baucom and Weinreb 1996). Baucom and Weinreb (1996) state that for GOES-8 Imager channel 4 or 5 290 K scenes striping magnitudes of several tenths of a Kelvin are common. The main cause of striping in Imager scenes is low frequency, or 1/f, noise in the calibration of the detectors (Wack and Candell 1996). The 1/f noise causes a random drift of the output of each detector during calibrations and imaging and therefore the noises exhibited in each detector are unrelated (Baucom and Weinreb 1996).

The Sounder does not suffer from 1/f-noise drifts since the Sounder performs clamps while viewing its filter wheel at a frequency of 50Hz (Weinreb 1996). The complete explanation for the striping seen in Sounder calibrated images is unknown. It is believed that the main cause for the Sounder striping is the different responses of the four detectors to the changes in background flux caused by the changes of on-board temperatures (M. Weinreb 2001, personal communication). Also, the relatively long time between space looks (2-minutes) amplifies the problem.

Instrument noise (manifested as errors in radiances and systematic striping) plays a significant role in the accuracy of surface retrievals and often requires pixel averaging to reduce the affect of random noise.

3. METHODOLOGY

Striping errors were computed for both GOES-8 and GOES-11 from three days (July 25-27, 2000) of the GOES-11 science test. For each satellite results were computed for channels 4 and 5 from the Imager, and channels 7 and 8 from the Sounder. The GOES-11 satellite was launched on May 3, 2000 and positioned at 104W during the science test conducted from June 30, 2000 through August 13, 2000.

A method to quantify the striping in GOES Imager scenes is described in Baucom and Weinreb (1996). Their method selects 4 line x 7 element uniform regions from GOES-8 Imager calibrated IR scenes. The 14 pixels for each detector are averaged and the striping is defined as the difference between the two detector averages. For this study 10 line x 18 element uniform regions were selected from Imager scenes. Because of the pixel overlap in the sampling process, a 10 x 18 pixel Imager region corresponds to a square region of approximately 40 x 40 km at nadir. For the Sounder 4 lines x 4 elements (40 km by 40 km) pixel groups were selected. A region larger than that used by Baucom and Weinreb (1996) was selected so that the Imager region would be close in size to the smallest possible square Sounder region. The Sounder region requires at least four lines because of the four detectors utilized by the IR channels of the Sounder. Detector numbering throughout the study was selected randomly, since the detector numbers of the lines of a region were unknown.

The Imager striping is defined as the difference between the average brightness temperatures of the two detectors. Sounder striping is not defined by Baucom and Weinreb (1996) and, because of the different number of detectors, there is not a Sounder method equivalent to the Imager method. The Sounder striping in this research is defined as the average of the differences between brightness temperatures of adjacent detectors. The largest difference between adjacent detectors is also given.

Regions uniform with respect to the IR window brightness temperature values were selected manually and only those with standard deviations less than 1 K were retained. The standard deviation limit ensures that the chosen sectors have near constant brightness temperatures, with variation due to noise only. For each satellite sensor four regions were selected at three different times, giving a total of twelve regions for each channel. For each time, the root mean square (RMS) of the four striping errors was computed. Over the three images, the RMS error was averaged. This method is adapted from the method described by Wack and Candell (1996).

Retrieval statistics for GOES-8 Imager and Sounder were computed for a case study over a region covering much of the CONUS for a primarily clear-sky day on April 25, 2001. The standard deviations of the Imager and Sounder skin temperatures were computed for single pixel and 3x3 pixel averaging (with single pixel spacing) retrievals. The Imager and Sounder single pixel retrievals have 4 km and 10 km nominal spatial resolution, respectively.

4. RESULTS

4.1 Striping Comparisons

Visual inspection of calibrated IR GOES-8 and GOES-11 images reveals striping in the scenes from both satellites, with GOES-8 tending to exhibit a larger amount of striping. An exception to this general observation is the Imager channel 5 from GOES-11. For several, but not all, of the Imager channel 5 images viewed and analyzed during this research the GOES-11 striping was seen to be equal to or larger than the GOES-8 striping. This observation correlates to the findings presented by Wack and Candell (1996) that state that the channel 5 striping for GOES-11 can be expected to be similar to GOES-8 striping. The calculated GOES-11 Sounder channel-8 noise level is slightly higher than the noise level for the same channel on GOES-8 (Bachmeier et al. 2001), therefore Sounder channel 8 striping improvements should be expected to be negligible.

The computed average striping errors for the Imager and the Sounder instruments are presented in Tables 1 and 2, respectively. The Sounder striping errors are presented as the average of the differences between adjacent lines (error 1), and as the largest difference between adjacent lines (error 2). The average striping errors show improvement for GOES-11, with an average improvement factor of 1.4 from GOES-8 to GOES-11. The smallest improvement of a factor of 1.2, for the Imager channel 5, correlates well to previous observations. For the Sounder, channel 8 shows the smallest improvement factor, with a value of 1.3 (for both error computation methods) compared to channel 7 with improvement factors of 1.8 and 1.6 for striping errors 1 and 2, respectively.

Table 1. GOES-8 and GOES-11 Imager average striping errors.

Satellite	Band	Average Striping Error (K)
GOES-8	4	0.207
GOES-8	5	0.239
GOES-11	4	0.130
GOES-11	5	0.207

Table 2. GOES-8 and GOES-11 Sounder average striping errors.

Satellite	Band	Average Striping Error1 (K) (average of differences)	Average Striping Error2 (K) (largest difference)
GOES-8	7	0.250	0.389
GOES-8	8	0.177	0.316
GOES-11	7	0.138	0.243
GOES-11	8	0.137	0.246

Comparing the Imager average striping errors to the Sounder errors computed using the average differences indicates the striping is similar for the two instruments. However, comparing the Imager striping to the Sounder striping computed using the largest difference between adjacent detectors reveals larger Sounder striping. The largest difference between adjacent lines may be the best indication of striping within an image because this is the striping visually noticed. These results may indicate larger striping exhibited by the Sounder than the Imager, although the Imager striping is computed by averaging over several lines, and no averaging is performed during the Sounder computations. Even if the striping in the Sounder is less than in the Imager, the Sounder is at a disadvantage because of its coarser resolution.

Striping is known to increase with decreasing temperature and the Baucom and Weinreb (1996) study presents striping as a function of temperature. In general, the regions sampled for this case study had brightness temperatures in the range 290-300 K. Baucom and Weinreb (1996) study striping in terms of GVAR counts for GOES-8 imager channel 4 only, and they conclude that the mean GOES-8 Imager channel 4 striping for scenes at 300 K is between 0.11 and 0.18 K. Wack and Candell (1996) estimate GOES-8 Imager channel 4 striping at 0.14 K and channel 5 striping at 0.21 K. Comparisons of these published striping values to those presented in Tables 1 and 2 indicate that the striping values computed during this case study are larger than the published values. However, this case study was for a small sample of regions, and for a larger sector size. As the size of the sector increases, the probability of variations between detectors increases because of surface variations. The results from this case study display the same trends as the published results, with the Imager channel 5 having the larger striping value, and the GOES-11 Sounder exhibiting the expecting improvement.

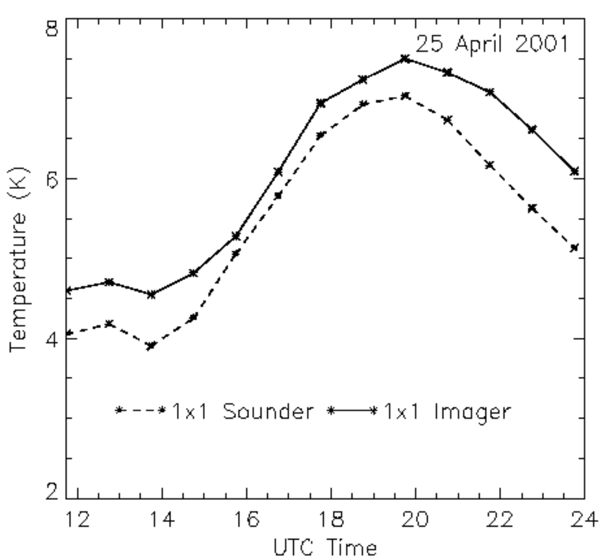

Figure 1. Standard deviation of single pixel ST retrievals from the GOES-8 Imager and Sounder over the CONUS domain.

4.2 GOES-8 Comparisons

Noise and striping within GOES images often requires averaging of retrievals. However, averaging reduces the spatial resolution of the retrievals and finer details of the natural variation are lost. It is therefore of interest to study the spatial variation of retrievals with varying degrees of pixel averaging. The standard deviation (SD) of ST within a domain reflects both the noise and natural variation. Figures 1, 2 and 3 show the SD of ST within a large subsection of the CONUS region for single pixel retrievals, Sounder single pixel retrievals and Imager 3x3 pixel averaged retrievals (with single pixel spacing), and 3x3 pixel averaged retrievals for both instruments, respectively.

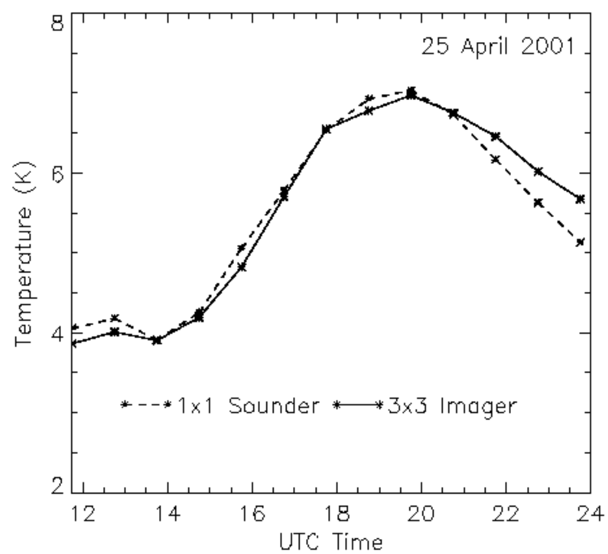

Figure 2. Standard deviation of GOES-8 Imager (3x3 pixel averaged retrievals) and Sounder (single pixel retrievals) ST over the CONUS domain.

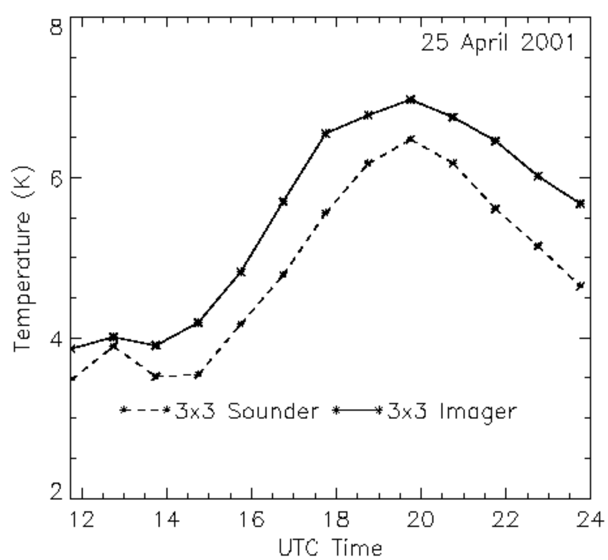

Figure 3. Standard deviation of 3x3 pixel averaged ST retrievals from the GOES-8 Imager and Sounder over the CONUS domain.

Comparing the SD of single pixel retrievals from the Imager and Sounder in Figure 1 reveals larger values for the Imager retrievals. This suggests that the Imager is detecting a higher degree of natural variation of ST across the region. Larger SD values for the Imager are expected because of the Imager's finer spatial resolution (4 km compared to the Sounder's 8 km resolution) and the 100% coverage by the Imager compared to only approximately 64% coverage by the Sounder. The Sounder has a field of view resolution of 8 km but samples only every 10 km, therefore only 64% of the pixel is sampled. Also, the Imager statistics are computed from a much larger number of pixels than the Sounder. The SD values from both instruments contain a noise component, and averaged retrievals can be expected to remove most of this noise.

Figure 2 shows the SD of ST sampled by the Imager and Sounder at similar sampled spatial resolutions. The Imager retrievals are still at single pixel spacing, but each pixel is the average of its surrounding 3x3 pixel box. The Imager retrievals are averaged and therefore both noise and natural variation components are reduced. The Imager and Sounder SD values are very close, with the only significant difference during the late afternoon hours. This observation suggests that for the same sampled spatial resolution single pixel Sounder retrievals detect a similar degree of natural variability as 3x3 pixel averaged Imager retrievals. However, the Sounder values still contain a striping and random noise component and therefore the natural variability detected by the Sounder should be less than that indicated in Figure 2.

Figure 3 shows the SD of ST for both Imager and Sounder averaged retrievals. As expected, the Sounder SD values have decreased from the single pixel results because of decreased components of both noise and natural variability. Also, the Imager again has the larger SD values for the same reasons as for those stated for Figure 1. Both Imager and Sounder 3x3 pixel averaged SD values have decreased by approximately 0.5 K from their single pixel SD values.

Retaining the 4 km spatial resolution of the Imager retrievals but performing averaging appears to reduce to striping and noise but preserve much of the natural variability of ST. At single pixel spacing, the Imager has approximately 15 pixels for every one Sounder pixel. The much higher number of pixels and the 100% coverage of the Imager are significant advantages over the Sounder. Statistics computed (not shown) for the same case study but with only the closest Imager pixel selected for each Sounder pixel (i.e. the Imager and Sounder statistics are computed using the same number of pixels) reveal similar SDs for 3x3 averaged retrievals. Therefore, the Imager's advantage is only retained at single pixel spacing. Images of retrievals produced using single pixel Sounder data often exhibit striping. Therefore averaging of Sounder retrievals is necessary to eliminate striping, but the sampled spatial resolution may be too coarse for some applications.

5. CONCLUSIONS

Current ST retrievals are produced using GOES-8 Imager data and assimilated into a forecast model. GOES-8 has passed it expected lifetime of five years and will be replaced soon by GOES-11 or GOES-12. Retrievals made from GOES-12 will need to be made using the Sounder because of the loss of the 12 μm channel from the Imager.

Comparisons of striping between GOES-8 and GOES-11 reveal decreased striping in some, but not all, cases from the newer satellite. The reduced striping will decrease the need for averaged retrievals, but it appears that striping will still be apparent.

Evaluations of the variability of ST across a region reveal components from both natural changes and noise. To reduce the striping noise, averaging of the retrievals is performed. Comparisons of GOES-8 Imager and Sounder SDs of ST reveal that the Imager retains the same variability with 3x3 pixel averaged retrievals as the single pixel Sounder retrievals. Single pixel Sounder retrievals contain noise from line-to-line striping, but averaged Sounder retrievals have a coarse resolution.

Acknowledgments. This work was partially supported under the GOES Improved Measurements and Products Assessment Plan (GIMPAP). GOES-11 data were supplied by Jaime Daniels at NOAA/NESDIS.

6. REFERENCES

Bachmeier S., M. Gunshor, J. Nelson, T. Schmit, T. Schreiner, D. Stettner, and G. Wade, cited 2001: CIMSS GOES-11 Science Test. [Available online from http://cimss.ssec.wisc.edu/goes/g11_report.]

Baucom, J.G. and M. Weinreb, 1996: Characteristics of E/W stripes in infrared images from the GOES-8 imager. *GOES 8 and Beyond*, E.R. Washwell, ed., Proc. SPIE 2812, 587-595.

Lapenta, W.M., R.J. Suggs, G.J. Jedlovec, and R.T. McNider, 1999: Impact of Assimilating GOES-Derived Land Surface Variables into the PSU/NCAR MM5. *Preprints, Workshop on Land-Surface Modeling and Applications to Mesoscale Models*, NCAR, Boulder, CO, 65-68.

Suggs, R.J., G.J. Jedlovec, and A.R. Guillory, 1998: Retrieval of geophysical parameters from GOES: evaluation of a split window retrieval technique. *J. Appl. Meteor.,* **37**, 1205-1227.

Suggs, R.J., G.J. Jedlovec, W.M. Lapenta, and S.L. Haines, 2000: Evaluation of skin temperatures retrieved from GOES-8. *Preprints, 10th Conf. On Satellite Meteorology and Oceanography*, January 9-14, 2000, Long Beach, CA, 137-140.

Suggs, R.J., W.M. Lapenta, G.J. Jedlovec, and S.L. Haines, 2001: Intercomparison of GOES-8 Imager and Sounder Land Surface Temperature Retrievals. *Preprints, 11th Symposium on Meteorological Observations and Instrumentation*, January 14-19, 2001, Albuquerque, NM, 362-365.

Wack, E.C. and L.M. Candell, 1996: Simulation of GOES 8 Imager IR striping due to 1/f noise. *GOES 8 and Beyond*, E.R. Washwell, ed., Proc. SPIE 2812, 608-613.

Weinreb, M. 1996: Real-world calibration of GOES-8 and –9 sensors. *GOES 8 and Beyond*, E.R. Washwell, ed., Proc. SPIE 2812, 572-585.