8.2 SIMULATION AND ANALYSIS OF GOES-R GEOSTATIONARY LIGHTNING MAPPER DETECTION ALGORITHM PERFORMANCE

Loren SadewaClark[1], Tom Dixon[2], Pete Armstrong[3], Ruth Cholvibul[4], Jared Clarke[5], Peter Silverglate[6], Donald Chu[7]

1. INTRODUCTION

The Geostationary Lightning Mapper (GLM) is to fly on the upcoming Geostationary Operational Environmental Satellite (GOES-R) to be launched in late 2015. It is being built by Lockheed Martin Advanced Technology Center (LMATC) in Palo Alto, California and RYCO in Huntsville, Alabama. GLM takes pictures of the Earth at a rate of 500 frames per second with a nadir resolution of 8 kilometers (km). It subtracts the average background of each pixel in the image to leave transient signals which are downlinked if they exceed background-dependent threshold levels.

In ground processing, these signals are tested for coherency, i.e. having a predecessor in the same pixel in the recent past and being strong enough such that the probability of the current signal and its predecessor being noise is below a certain level. If so, the current signal is passed along as a lightning event. The goal here is to show that this approach gives at least 70% detection efficiency with less than 5% false alarms. Assuming an average flash rate of 20 per second within the GLM field-of-view [Christian (2003)] makes this a false alarm rate of 1 per second.

[1] Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

[2] NASA GSFC, Code 417.0, 8800 Greenbelt Road, Greenbelt, MD 20771

[3] MIT/LL, 244 Wood Street, Lexington, MA 02420-9108

[4] Orbital Sciences Corporation, 7500 Greenway Center Drive, Greenbelt, MD 20770

[5] IAI, 15020 Conference Center Drive, Chantilly, VA 20151

[6] Chesapeake Aerospace, 63 Prospect Bay Drive W, Grasonville, MD 21638

[7] Chesapeake Aerospace, **Corresponding author address:* Donald Chu, NASA GSFC, 8800 Greenbelt Road, Greenbelt, MD 20771; e-mail: donald.chu-1@nasa.gov

We have full-disk images from the current generation GOES N-P spacecraft [Chesters (2013)], lightning statistics from the low-Earth orbiting Lightning Imaging Sensor (LIS) [Grandell (2010), Buechler (2012)] plus GLM optical and detector parameters from the design and testing. We also know how the instrument applies signal thresholds onboard to limit the data sent to the ground and how the ground filters work. By simulating GLM frames and applying the onboard and ground processing, it should be possible to get an idea of how well GLM will work and to gain experience tuning the processing parameters.

The simulation of GLM lightning detection is divided into data generation and detection proper, i.e. the space and ground segments. Data generation starts with LIS lightning phenomenology statistics. Signal levels are then predicted based on GLM instrument parameters, e.g. aperture size, throughput and onboard electronics processing. The detection procedure implements a coherency filter which requires at least two events (signals that exceed threshold) in the same pixel within a certain time span in order to detect a lightning flash. There is also the probability test to eliminate weak signals that meet the first two criteria, i.e. space and time proximity.

The output of the data generation (space segment) program includes simulated event frame number, row, column, amplitude, background and flash number or false event type. The actual instrument outputs include only the first five of these quantities, but the last one is useful for verification. The output of the detection proper (ground segment) program includes detected event frame number, row, column, amplitude and detected flash number. The level 1b ground processing algorithm does not identify flashes, but doing so is useful for determining false alarm rate in the simulation.

2. SIMULATION DESIGN

The simulation is divided into three independent programs. The first models the space segment, i.e. instrument, and produces the event data for ground processing. The second models the ground segment and throws out false events. The third evaluates the ground processing results against the truth.

2.1 Space Segment (Data Generation)

1. Steps through time (frame by frame) updating the average background, adding false events due to radiation and system noise, adding lightning events, detecting events that break threshold and updating the tracked background. Backgrounds are derived from GOES 1 km resolution images to which glint has been added. They are resampled to 8 km resolution and rotated according to a simulated attitude history.

2. Adds radiation events to the image based on an isotropic influx of protons and heavy ions onto the focal plane with a Linear Energy Transfer (LET) distribution as given in the GOES-R radiation report [Barth, (2006)]. The lenses and spacecraft block particles from impinging at close to normal incidence. Particles are assumed to traverse the focal plane instantaneously.

3. Adds lightning flashes to the image with probability chosen to give an average of 20 flashes per second. For daytime simulation, flashes are initiated preferentially over bright background pixels. Pulses are added to active flashes with probability to give the average time between pulses. To control the number of pulses per flash, a fraction of those pulses are randomly tagged as the terminal pulse. Pulses execute a random walk with parameters chosen to give the observed average flash area assuming 8 km square pulses. Amplitude mean and standard deviation are controlled by drawing them from a pool of log-normal variates.

4. Adds noise and detects events – Noise is computed for every pixel and assumes Poisson statistics with levels based on the current image plus an assumed electronics noise level. Events are detected by subtracting the tracked background image computed below from the current image and comparing the difference to user-chosen background-dependent threshold levels. Those thresholds are set to give about ten thousand noise events per second corresponding to how the instrument is tentatively to be operated.

5. Tracks background – Background is tracked by computing a weighted average of the current image I_n with the tracked background T_n

$$T_{n+1} = \frac{I_n + (k-1)\cdot T_n}{k} \quad (1)$$

   Changes are limited by clamp values, and detected events can optionally be omitted from the current image before updating.

Figure 1 shows the lightning and various false events, i.e. noise, radiation and jitter, simulated for a 1 second time span. The top row shows the amplitude distribution for each. The second row shows the temporal distribution, and the third row shows all the events together plotted as a function of time.

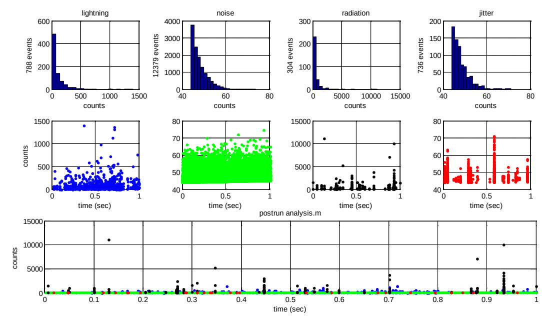

Figure1. Input Events

Some things left out of the space segment program include forking, blooming, charge transfer smearing and hot pixels. To simulate forking, the program could provide for multiple simultaneous pulses per flash. Both blooming and charge transfer smearing are both single frame phenomena and by themselves would be rejected by the coherency filter. If they are close in time and space to other false events, however, they would contribute to false alarm rate. Hot pixels could be added by allowing for different electronic noise standard deviations in each pixel.

2.2 Ground Segment

The ground segment (detection proper) program steps through the simulated events frame by frame. Filtering and flash detection use three arrays the size of the image. They are the flash number array, the lifetime array and the probability array.

1. Flash Number Array – When there is an event not close in space and time to a

preceding event, it is given an ID number which is inserted into the Flash Number Array. Most events are noise and time out without being corroborated by a second event, but those that are share their ID number with their child events. When a flash times out without new pulses, its flash number is removed from the array.

2. Active Pixel Array – This array tracks the lifetime left to an event, i.e. how many more pulse-less frames can go by before the flash ends. Whenever there is an event, the maximum gap between pulses is inserted into the corresponding element of the array. With each subsequent frame, the values are decremented by one until they reach zero. The snapshot in Figure 2 shows the active pixels as green dots and the current events as red x's. The plot on the right shows the two nearly coincident events that passed.

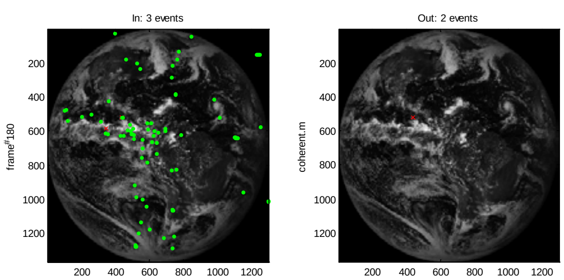

Figure 2. Active Pixel (Lifetime) Test

3. False Event Probability Array – Two weak events may be coherent but be noise rather than lightning. To avoid this, events are rejected if the probability of their both being false is greater than a user-chosen value. This array holds the probabilities of past events being false P_{fe} and is computed from their signal amplitude s and noise standard deviation σ_n assuming Gaussian statistics

$$P_{fe} = \frac{1}{\sigma_n\sqrt{2\pi}}\int_s^\infty e^{-\frac{x^2}{2\sigma_n^2}}\,dx \qquad (2)$$

To be declared a lightning event,

1. the event has to be in an active pixel, i.e. one having positive remaining lifetime
2. the joint probability of the event and its predecessor both being false has to be less than some maximum value $P_{fe}(max)$

The joint probability is computed by multiplying the probability of the event in question being false P_{fe2} by the probability that its predecessor was false P_{fe1} times the number of intervening frames n

$$P_{fe} = n \cdot P_{fe1} \cdot P_{fe2} < P_{fe}(max) \qquad (3))$$

2.3 Evaluation

The principle performance metrics for GLM are detection efficiency and false alarm rate. Detection efficiency is computed as the number of flashes detected n_d divided by the total number of flashes n_F

$$p_d = n_d/n_F \qquad (4)$$

If even one event in a flash passes through all event filters, the flash is detected. To determine which flashes were detected, we retrieved the *true* flash number of every detected event. We then found the unique ones and counted them to get n_d.

False alarm rate is computed as the number of false flashes n_f divided the time span Δt

$$far = n_f/\Delta t \qquad (5)$$

False flashes are taken to be those that do not include any lightning events. To determine which flashes were false, we went through all detected events flags and threw out the true ones. We retrieved the *detected* flash number for each of these false events, took the unique ones and counted them to get n_f. Then we divided by the time span to get the false alarm rate far. We did this to avoid assuming that each false event detected generated a false flash.

3. RESULTS

Figure 3 shows the input events at top, i.e. 17451 false events (red) and 384 true events (green), plotted against time. The plot at the bottom shows the filtered events. Although only 187 of the 384 lightning events were detected, 88% of flashes were detected with zero false alarms. To get rid of all the false events in this example, it was necessary to raise the lowest threshold from 64 to 72 counts. If detector noise is lower than expected, this threshold can be lowered which should increase detection probability.

This is a simple simulation, but it captures most features of the instrument and ground algorithms. As such it avoids the need for overly crude and controversial approximations to make back-of-the-envelope performance estimates. Initial results suggest that the GLM system will meet its detection and false alarm requirements. In the coming months, we hope to continue exercising and improving the simulation to test the ground software and gain insight into how the system will work on orbit.

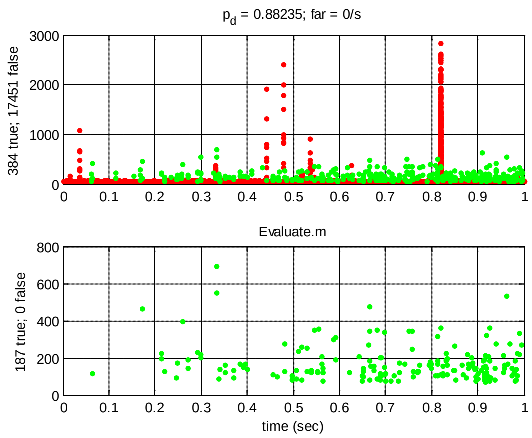

Figure 3. Detection Results

4. REFERENCES

Barth, J., 2006: *The Radiation Environment for Electronic Devices on the GOES-R Series Satellites*, 417-R0RPT-0027

Buechler, D., 2012: personal communication, UAH/NSSTC, Huntsville, AL

Chesters, D., 2013: http://goes.gsfc.nasa.gov/text/goes.fulldisk.html

Christian, H.J. et al., 2003: Global Frequency and Distribution of Lightning, *JGR*, vol. 108, no. D1, 4005, doi: 10.1029/2002JD002347

Grandell, J., 2010: Flash statistics from LIS 1999-2008, EUM/MTG/VWG/10/0029