The Geostationary Lightning Mapper – Theoretical and Predicted Performance Lightning Detection Techniques

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Abstract

The design and characteristics of the Geostationary Lightning Mapper (GLM), which is scheduled for launch in early 2016, have been well documented over the last several years including discussions of required / anticipated detection efficiencies (DE). In this presentation, we discuss the bases of these predictions, why high DE is important and some of the built-in features that are designed to enable the GLM to achieve and exceed its theoretical performance limits.

The theoretical performance is based on the predicted strength of the optical signal arriving at geostationary orbit and the radiative transfer characteristics and sensitivity of the GLM sensor. The GLM was designed to detect 90% of lightning flashes within its field of view assuming signal strengths based on U-2 and LIS observations, a cloud background with an 80% albedo and a signal to noise ratio of 5.4 that would limit false events to an acceptable level.

As built versions of instruments typically fail to achieve theoretical performance. Real world implementations of complex technologies usually fall short of design goals. The GLM pushed a number of technologies including the interference filters and the focal plane. As a consequence, we expect the GLM to miss the 90% performance goal, but to far exceed the 70% DE requirement. The predicted performance is based on laboratory-based calibrations. Based on these calibrations, we predict that the GLM will just miss the 90% DE performance goal but will easily exceed the 80% DE of the LIS.

However, the GLM has a number of resources that were not available for LIS, the most important of which is a telemetry bandwidth increase from 8 Kbit/sec. to 8 Mbits/sec. This increased bandwidth enables the instrument detection thresholds to be set to lower values, which introduces more false events that are then removed during ground-based processing. Another feature of the GLM is that amplitude and background information is transmitted for each event. This enables more sophisticated coherency based event filtering than was possible with LIS.

The overall operational concept of the GLM is discussed with a focus on how the design optimizes detection efficiency. Finally, arguments are presented for why high detection efficiency is a critical feature of the GLM and how this feature will support operations and enable research that has been underemphasized to date.

Introduction

The Geostationary Lightning Mapper (GLM) is being built by Lockheed Martin to be an operational instrument on the next generation of Geostationary Operational Environmental Satellites (GOES-R). It will be flown on all future GOES satellites, thus providing coverage from both GOES-east and GOES-west. The expected coverage is shown in figure one.

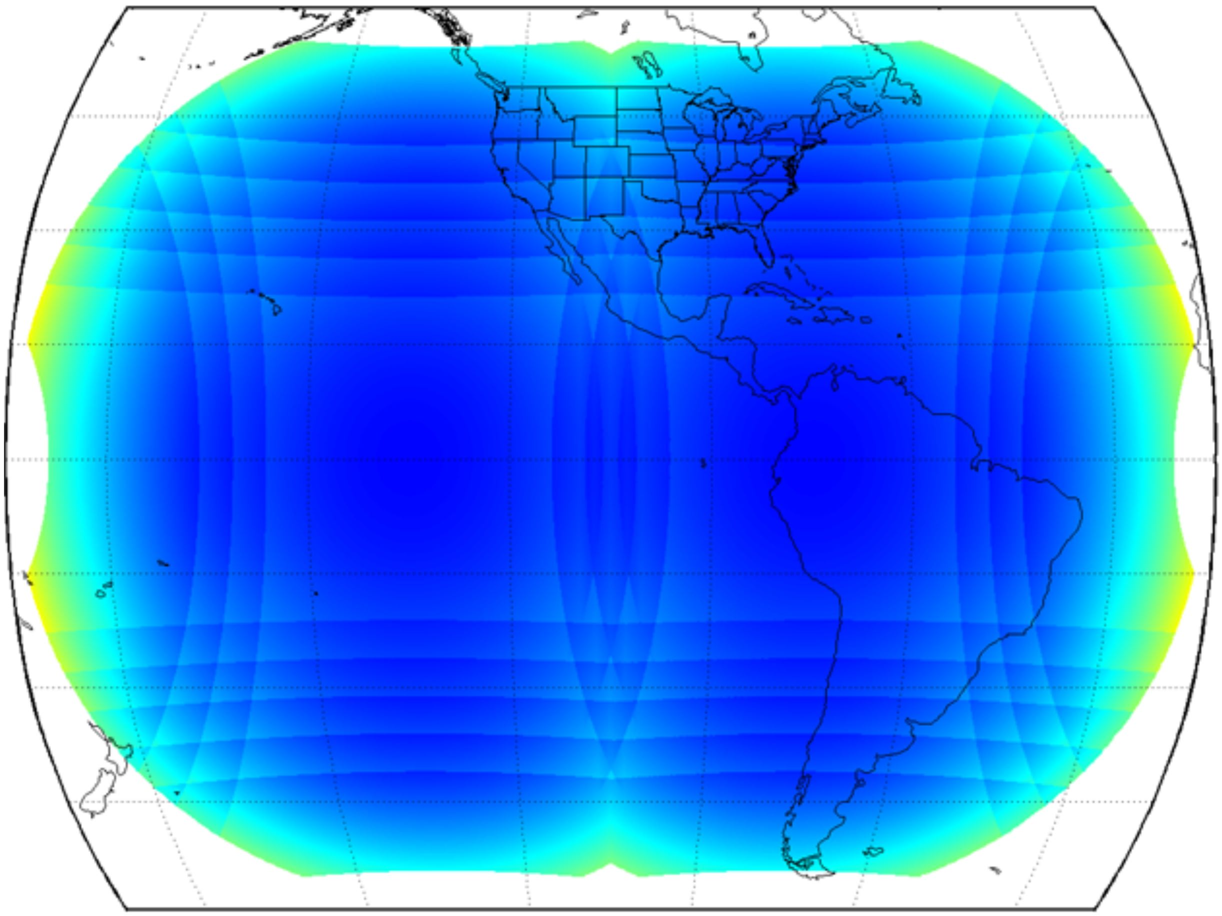

Figure 1. Field of view coverage from GOES-E and Goes-W

The GLM will provide the first large area, continuous monitoring of total lightning activity with high detection efficiency and storm scale spatial resolution. It will enjoy significant advantages over many ground based systems such as essentially constant detection efficiency (DE) over its entire field of view including both continents and oceans, consistent performance over decade long periods, and the ability to detect individual stokes and their intensity.

Some of the scientific applications that will be realized with the Mapper include:

Improved warning times for severe weather – doubling present Doppler radar based warning

Decreased false alarm rates for severe weather – halving the present Doppler radar based false alarm rates

Virtual radar – in areas with limited radar coverage, total lightning can be used to track thunderstorm development, propagation and evolution.

Quantitative ice-phase precipitation estimation – total lightning activity is quantitatively related to the total ice production in a thunderstorm which in turn is related to the total precipitation for deep convective storms. These types of storms often produce very high rain rates and can result in flash floods.

Climate change monitoring – the Lightning Imaging Sensor (LIS) on the Tropical Rainfall Measuring Mission (TRMM) has maintained a consistent lightning detection efficiency and radiometric sensitivity over its sixteen years on orbit thus providing a reliable measure of global lightning activity. Lightning activity is highly sensitive to temperature and it is theorized that small increases in temperature could produce large increases in lightning making lightning activity a good indicator of temperature changes.

Design and Performance

The challenge for optical detection of lightning from space is daytime detection when sunlight reflecting from cloud tops can be more then an order of magnitude brighter than the lightning signal. The GLM uses the same basic detection approaches as were proven with the Optical Transient Detector (OTD) and the Lightning Imaging Sensor (LIS): high speed imaging (500 frames per second), narrow band detection (1nm wide interference filter center on the 777.4 nm oxygen emission line) and on-orbit signal processing to convert the image data into event data (RTEP). For the GLM, 56 parallel, pipelined Real Time Event Processors (RTEP) are used instead of one and they are implemented in a pure digital design as opposed to an analog-digital hybrid. The RTEPs essentially reduce the required telemetry bandwidth from over 10^{10} bps for image data by over four orders of magnitude. For the GLM, a higher than required telemetry bandwidth has been allocated so that so that threshold levels can be set to lower values, thus enabling the detection of weaker lightning events. Lower threshold settings in turn produce a higher number of false events due to shot noise. These false events are removed by ground processing which is improved over both LIS and OTD because both the event amplitude and the five most significant bits of the background are transmitted for each event detected. These parameters enable a more capable statistically based coherency filter to be implemented for GLM ground processing than is possible for the LIS.

The GLM is designed to have approximately a 10% radiometric throughput advantage over LIS. This in combination with enhanced telemetry bandwidth and improved ground processing algorithms, would theoretically result in an significant performance advantage for the GLM. The theoretical DE performance for the GLM is shown in figure 2.

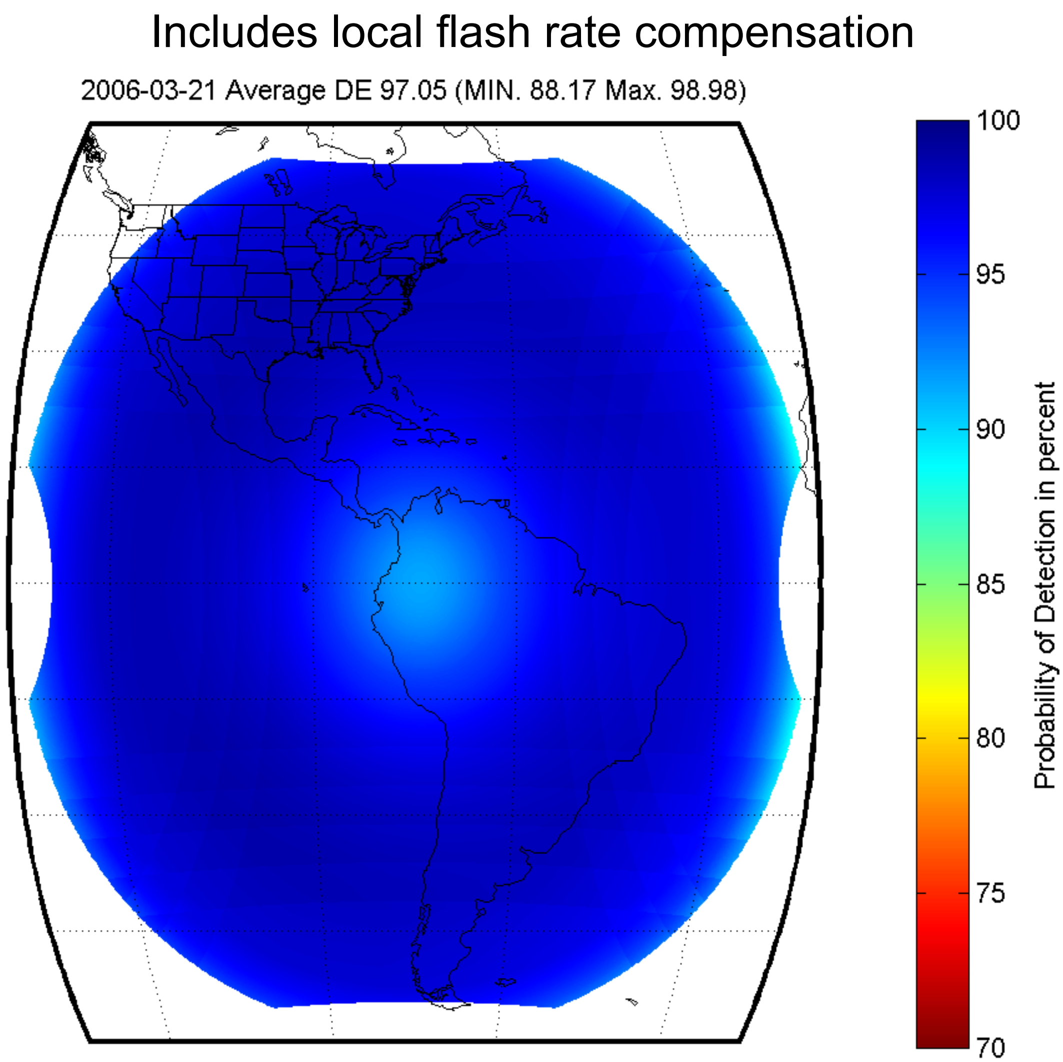

Figure 2. Radiometrically-based Predicted Detection Efficiency

Of course, as built instruments rarely meet theoretical performance and the GLM is no exception. The GLM is a complex instrument and has pushed the state of the art in a number of areas including a large CCD that must process 10^9 pixels per second each with a well depth of almost $2*10^6$ electrons. This was a very challenging development and has resulted in an instrument that will easily meet performance requirements but with higher than predicted electronics noise. Overall, we anticipate the the GLM will detect slightly less than 90% of the lightning flashes that occur within its field of view.

The GLM includes two unique design features. Because the field of view is required to cover a half angle of incidence of eight degrees and a 1 nm wide interference filter can only tolerate a five degree incidence angle and still pass the 777.4 nm oxygen emission lines, the 1 nm wide filter must be located an a collimated region near the center of the telescope. Two additional filters are located in the front of the telescope, in object space. One filter is a high and low pass filter called the solar blocking filter and the other is an additional interference filter with a 2.6 nm band pass. These filter are shown in figure 3.

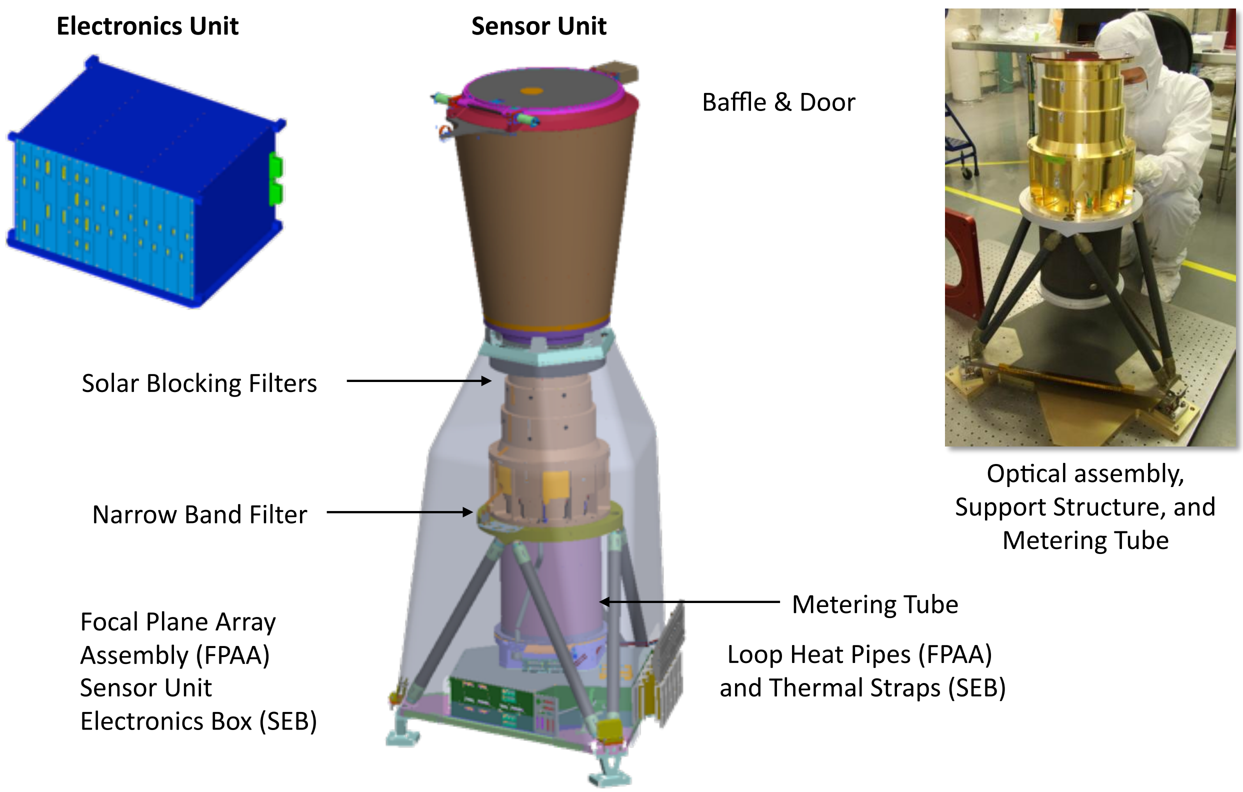

Figure 3. GLM Instrument Overview

Because the angle of incidence on the 2.6 nm is steeper than the angle on the 1 nm filter, the passband wavelength shifts faster through this filter with the net result that no incident radiation at an angle greater than 12 degrees can pass through the 1 nm filter. Hence the system acts like a very long sun shade and the GLM can maintain near maximum performance during solar eclipses. Another unique feature is a variable pitch focal plane in which the CCD pixel sizes vary across the field of view. This variance enables the GLM to maintain a near constant foot print across the filed of view and thus enabling location independent performance.

Conclusions

The GLM will provide significantly enhanced capabilities to the US's observation satellite systems. These new capabilities will directly contribute to improving severe weather monitoring as well as to scientific research. Further, the GLM should help lay the foundation for adding additional lightning mappers in geostationary orbit with the hope for eventual continual global coverage of all lightning activity.