Assessing the Lifetime Performance of the Lightning Imaging Sensor (LIS): Implications for the Geostationary Lightning Mapper (GLM)

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ABSTRACT: The Lightning Imaging Sensor (LIS) onboard the Tropical Rainfall Measuring Mission (TRMM) satellite has been providing observations of total lightning over the Earth's Tropics for 13 years. This study examines the performance of the LIS throughout its time in orbit. Application of the Deep Convective Cloud Technique (DCCT) (Doelling et al., 2004) was performed on the LIS background pixels to assess the stability of the LIS instrument. The DCCT analysis indicates that the maximum deviation of the monthly mean radiance is within 2% of the overall mean, indicating stable performance over the period. In addition, an examination of the number of flashes detected over time similarly shows no significant trend (after adjusting for the orbit boost that occurred in August 2001). These and other results indicate that there has been no discernible change in LIS performance throughout its lifetime. A similar approach will used for monitoring the performance of the Geostationary Lightning Mapper (GLM) onboard the next generation Geostationary Operational Environmental Satellite-R (GOES-R). Since GLM is based on LIS design heritage, the LIS results indicate that GLM may also experience stable performance over its lifetime.

Doelling, D.R., L., Nguyen, and P. Minnis, 2004 : On the use of deep convective clouds to calibrate AVHRR data. Earth Observing Systems IX, W.L Barnes and J.J Butler, Eds., International Society for Optical Engineering (SPIE Proceedings, Vol. 5542), 281-289.

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ABSTRACT: The Lightning Imaging Sensor (LIS) onboard the Tropical Rainfall Measuring Mission (TRMM) satellite has been providing observations of total lightning over the Earth's Tropics for over 13 years (1998-present). This study examines the performance of the LIS throughout its time in orbit and whether degradation has occurred over time. This is important for lightning climate studies using LIS data It is also important in assessing possible performance implications of the Geostationary Lightning Mapper) GLM. In particular, we examine LIS event and flash detection to see if there are any changes through time. We also examine sensitivity changes in the LIS radiance sensitivity by utilizing the Deep Convective Cloud Technique [DCCT; Doelling et al., 2004].

The DCCT analysis indicates that the maximum deviation of the monthly mean background radiance is within 2% of the overall mean, indicating stable performance over the period. In addition, the number of monthly lightning flashes and events detected has remained stable throughout time (except for an increase attributed to the orbit boost that occurred in August 2001). These results indicate that there has been no discernible change in LIS performance throughout its lifetime and that the DCCT approach can be used monitor the performance of the Geostationary Lightning Mapper (GLM) onboard the next generation Geostationary Operational Environmental Satellite-R (GOES-R). Since GLM is based on LIS design heritage, these results indicate that GLM should provide stable performance over its lifetime.

1. INTRODUCTION

The Geostationary Lightning Mapper (GLM) is scheduled to be launched in 2015 onboard the next generation Geostationary Operational Environmental Satellite – R (GOES-R). The GLM will be the first total lightning instrument in geostationary orbit, enabling total lightning monitoring over large areas of the earth. The GLM design is based on the Lightning Imaging Sensor (LIS) and its predecessor, the Optical Transient Detector (OTD); both developed by the National Aeronautics and Space Administration (NASA). These instruments detect the optical signature of lightning using a staring CCD (Charge Coupled Device) array. Temporal, spatial, and spectral filtering allows the quickly varying signal of lightning to be observed at high

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detection efficiency both day and night [Christian et al., 1989]. The sensors employ a narrowband interference filter centered near 777.4 nm, which is near a prominent oxygen emission line triplet in the lightning spectrum. The CCD pixel array images its field of view every 2 ms. A modified frame-to-frame background subtraction is implemented at each pixel to remove the slowly varying background signal from the raw data steam. Background images are saved for navigation and cloud location purposes.

Observations from LIS are being used to produce proxy GLM datasets for use in the design and validation of the GLM instrument and algorithms. As such, it is useful to understand any changes occurring to LIS instrument sensitivity during its time in orbit. We assess the variability via two methods. The first is to examine diagnostics of the number of events and flashes observed over the LIS lifetime. The second method examines the stability of the LIS sensor by looking at the background radiance of Deep Convective Clouds (DCC).

2. LIS EVENT AND FLASH VARIABILITY

We first examine the monthly variability in LIS detected events and flashes (Fig. 1). A LIS event is a sudden increase in brightness at a pixel that exceeding a threshold. This initial determination is done onboard the LIS, reducing the amount of data that needs to be transmitted to ground. Processing of the data on the

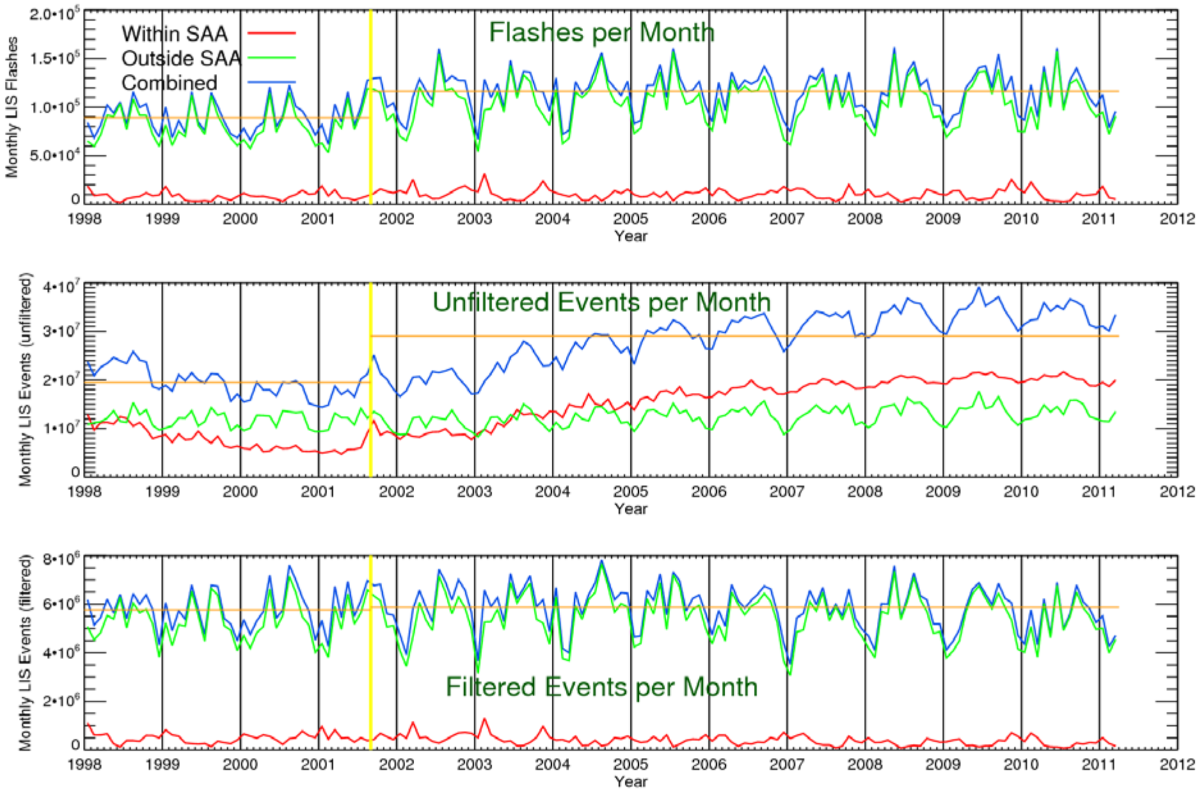

Figure 1 Monthly time series of LIS flashes (top panel), non-filtered events (middle), and filtered events (bottom). Blue lines indicate all observations; red indicates those observations within the SAA, and green for observations outside the SAA. The yellow vertical line at August 2001 shows when the orbit boost occurred. The orange lines indicate the mean monthly value of all observations, for both pre and post orbit boost.

ground identifies non-lightning events (i.e., glint, noise, high energy particles, etc.) which are then filtered out. Further processing groups the filtered events into flashes. Scaled monthly values of flashes, unfiltered events and filtered events detected by LIS are shown in Figure 1.

The top panel shows that the flashes per month increased detected by LIS increased noticeably after the orbit of the TRMM satellite was boosted to an altitude of 402 km in August 2001. However, there is no discernible trend post boost. The non-filtered monthly event time series (middle panel), however, exhibits a distinct uptrend over much of the period. Numerous false events occur over the South Atlantic Anomaly (SAA) are caused by geomagnetically trapped ionized particles [Fürst et al., 2009] impacting the LIS sensor. To examine this effect, we categorize events as occurring within or outside the SAA. The uptrend in unfiltered events is observed to be due mainly to events occurring within the SAA, and is inversely related to the 10.7 cm solar flux (Fig. 2), with some lag. The filtered monthly LIS events and flashes show no discernible trend over the period, indicating the LIS sensor and filtering techniques have been stable over the LIS lifetime.

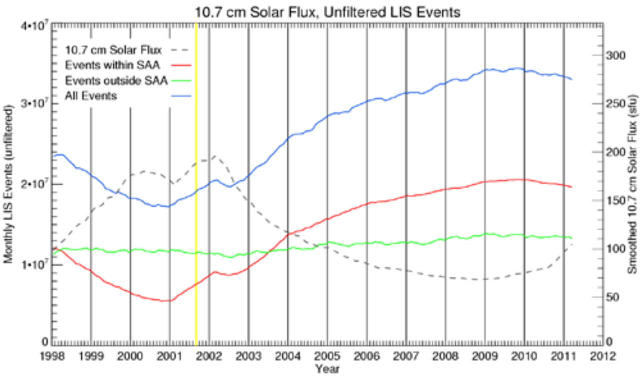

Figure 2 Time series of monthly LIS unfiltered LIS events within (red) and outside the SAA (green), and all (blue). The black dashed line indicates the monthly 10.7 cm solar flux (sfu). The vertical yellow line represents the orbit boost.

3. DEEP CONVECTIVE CLOUD TECHNIQUE (DCCT)

The Deep Convective Cloud Technique (DCCT) uses bright deep convective clouds as stable targets for calibration of solar reflective channels of satellite instruments [eg., Doelling et al., 2004]. DCCs have near uniform reflectance, as there is little intervening atmosphere to scatter or absorb radiation. The DCCT identifies DCCs, looks at the observed satellite radiances associated with the DCCs and see how they vary over time. Drifts in observed gain can be determined and applied as a correction to the observed radiances. Similarly, for the LIS, we can identify the DCCs and monitor the radiance distributions over the lifetime of LIS. Any changes in the LIS background calibration would affect event detection and thus overall flash detection efficiency. The LIS background images at 777.4 nm wavelength are within the solar reflective spectrum.

Deep convective clouds are identified as 10.8 μm brightness temperatures less than 205K measured by the Visible and Infrared Sensor (VIRS), which is collocated with LIS aboard TRMM. Both July and August data from 1998-2010 were used. Only pixels meeting the following criteria are used: 1) solar zenith angle (SZA) less than 40º, 2) viewing zenith angle (VZA) less than 40º, 3) relative azimuth angle (RAA) between 10º and 170º, and 4) the ratio of the pixel radiance divided by the standard deviation of the pixel radiance and its surrounding 8 pixel radiance is less than 0.02. Figure 3 is example of LIS background and VIRS brightness temperature images.

The LIS background radiance distribution for each two month period (July and August) analyzed are shown in Figure 4. The distributions exhibit no obvious drift with time. Figure 5 is the mean radiance for each year, plotted as a percent from the mean. The maximum deviation is 2% from the mean (364.6 W sr^{-1} m^{-2} μm^{-1}) which occurs during 2000. Otherwise, no trend in LIS background radiance is observed from 1998-2010. Thus there should be no change in event and flash detection attributable to changes in LIS radiance sensitivity.

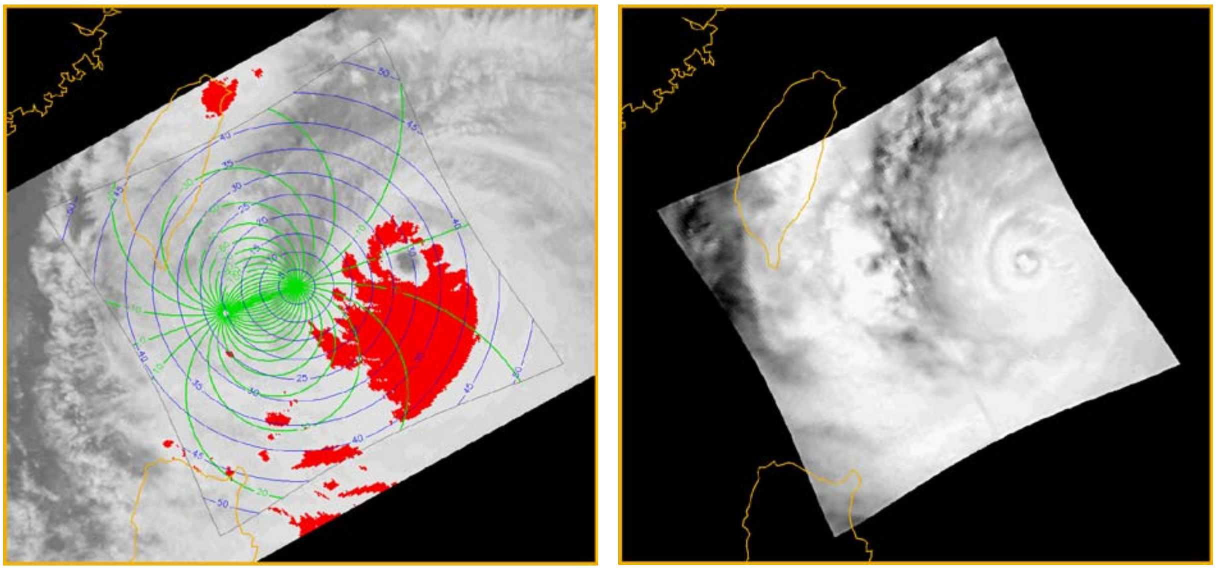

Figure 3 VIRS (left) Infrared and LIS background image of Super Typhoon Haitang. The left panel shows the location of IR temps less than 205 K (red), as well as contours of relative azimuth angle (green) and viewing zenith angle (blue).

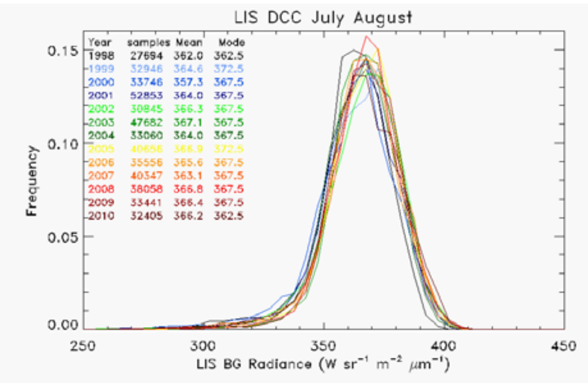

Figure 4 LIS background radiance distribution for July and August for each year 1998-2010.

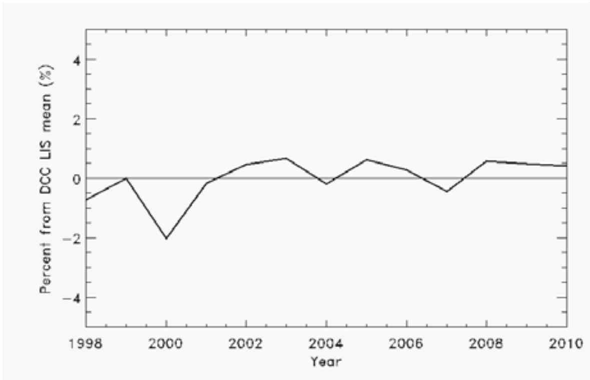

Figure 5 Variation of mean LIS background DCC radiance for each 2 month period (July and August) from 1998-2010 plotted as a percent departure from the overall mean (364.6 W sr^{-1} m^{-2} μm^{-1}).

4. CONCLUSIONS

Analyses presented here show that LIS has experienced stable performance over its lifetime in orbit. It indicates that after launch, GLM performance can be monitored by the DCCT.

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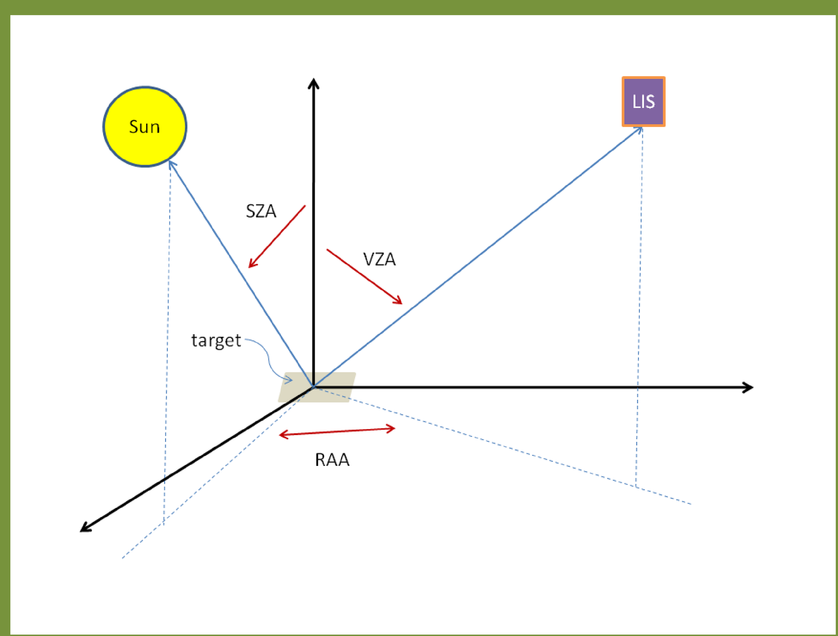
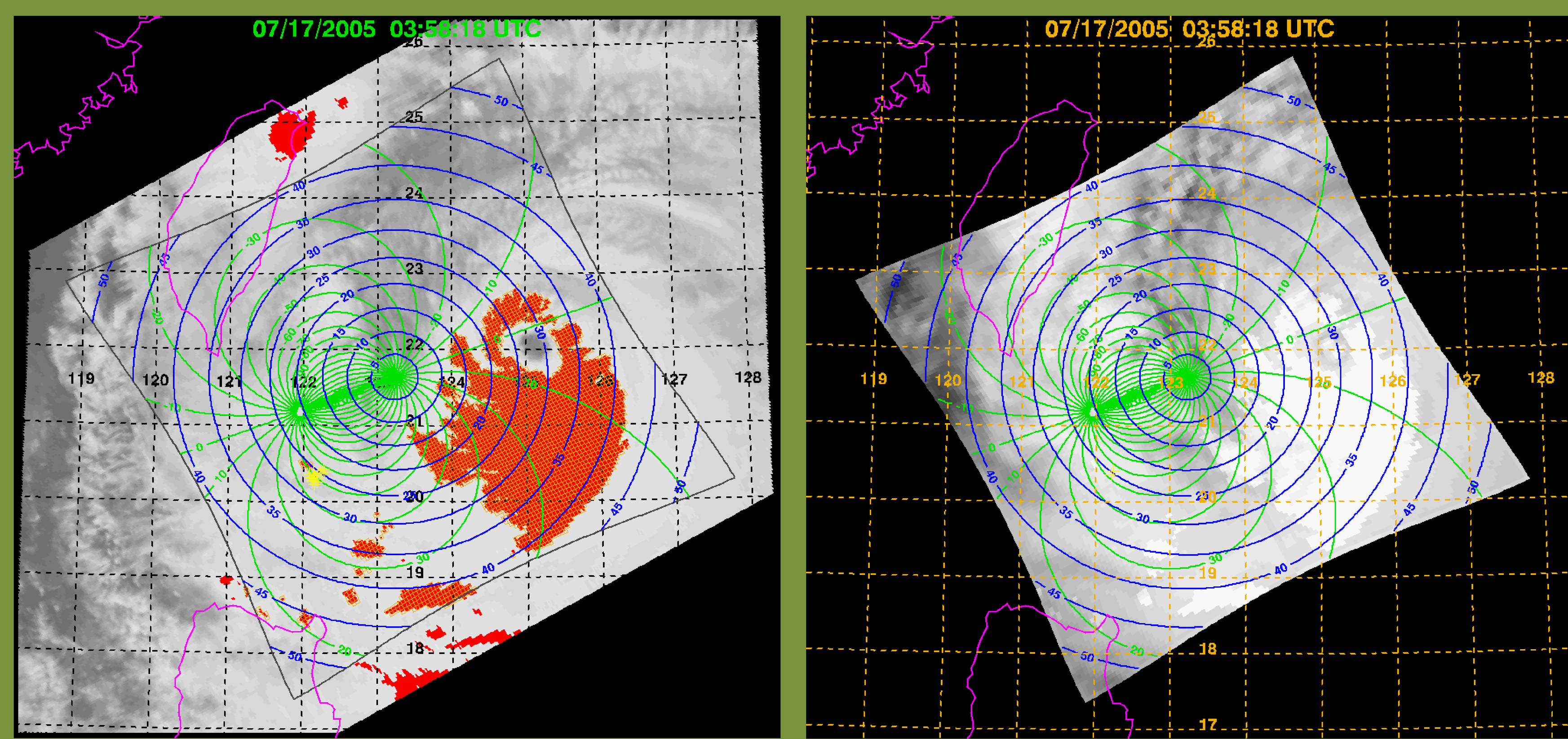
Motivation: Analyze the performance of the Lightning Imaging Sensor (LIS) over its 13 years in orbit and examine implications for the Geostationary Lightning Mapper (GLM) .

Deep Convective Cloud Technique: Deep Convective Clouds (DCC) are used as stable targets to examine the radiance of LIS background (BG) pixels over its 13 year period in orbit. DCC are identified as VIRS (Visible and Infrared Sensor) 10.8 µm channel pixels having brightness temperatures (T_b) colder than 205K . LIS background (BG) pixels co-located with the DCC pixels are used in the analysis. The LIS and VIRS are both onboard the Tropical Rainfall Measuring Mission (TRMM) satellite).



Criteria for LIS BG pixels used:

1) 10.8 µm T_b < 205K
2) Solar Zenith Angel (SZA) < 40°
3) Viewing Zenith Angle (VZA) < 40°
4) Relative Azimuth Angle (RAA) > 10° and < 170°
5) Ratio of standard deviation of pixel radiance and its 8 surrounding pixel radiances divided by the pixel radiance < 0.02

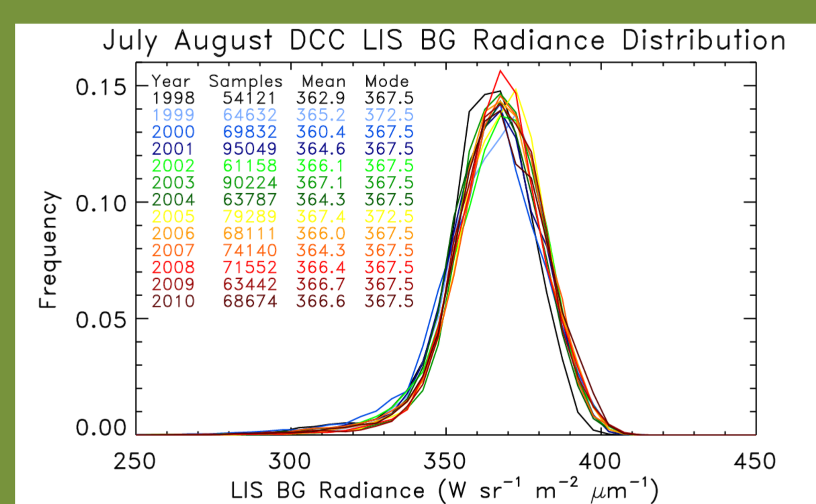


Example of VIRS IR image (left) and LIS BG image (right) for Super Typhoon Haitang
The left panel also shows the locations with VIRS 10.8 channel $T°_b$ with pixels > 205K in red.
The small orange boxes are the LIS BG pixels sizes associated with the cold VIRS pixels.
Locations of lightning events detected by LIS are also shown (yellow +). In the right panel, LIS flashes are denoted by yellow '+'. Both panels show contours of RAA (green) and VZA (blue).

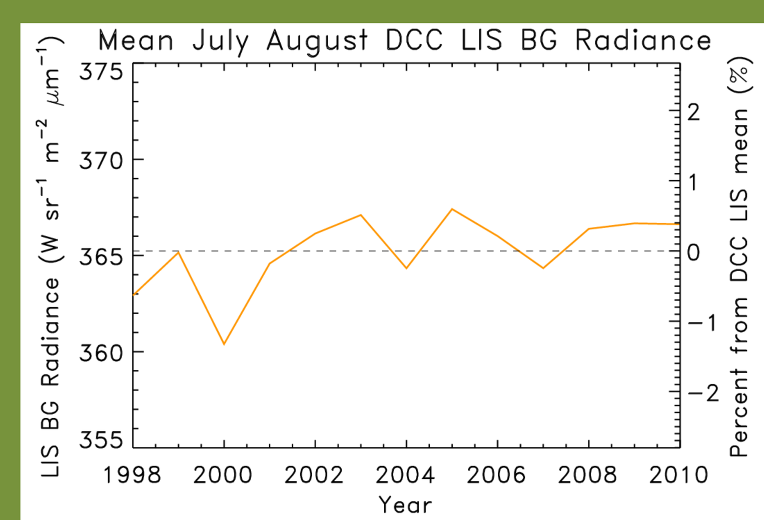
The DCC analysis was conducted on LIS BG data for each July and August from 1998 – 2010. The data were analyzed in a two month period to ensure sampling. Results shown at right illustrate that the frequency distribution was very uniform throughout the period. In addition, the mean radiance for each year deviated 2% at most from the yearly mean.

Conclusions:

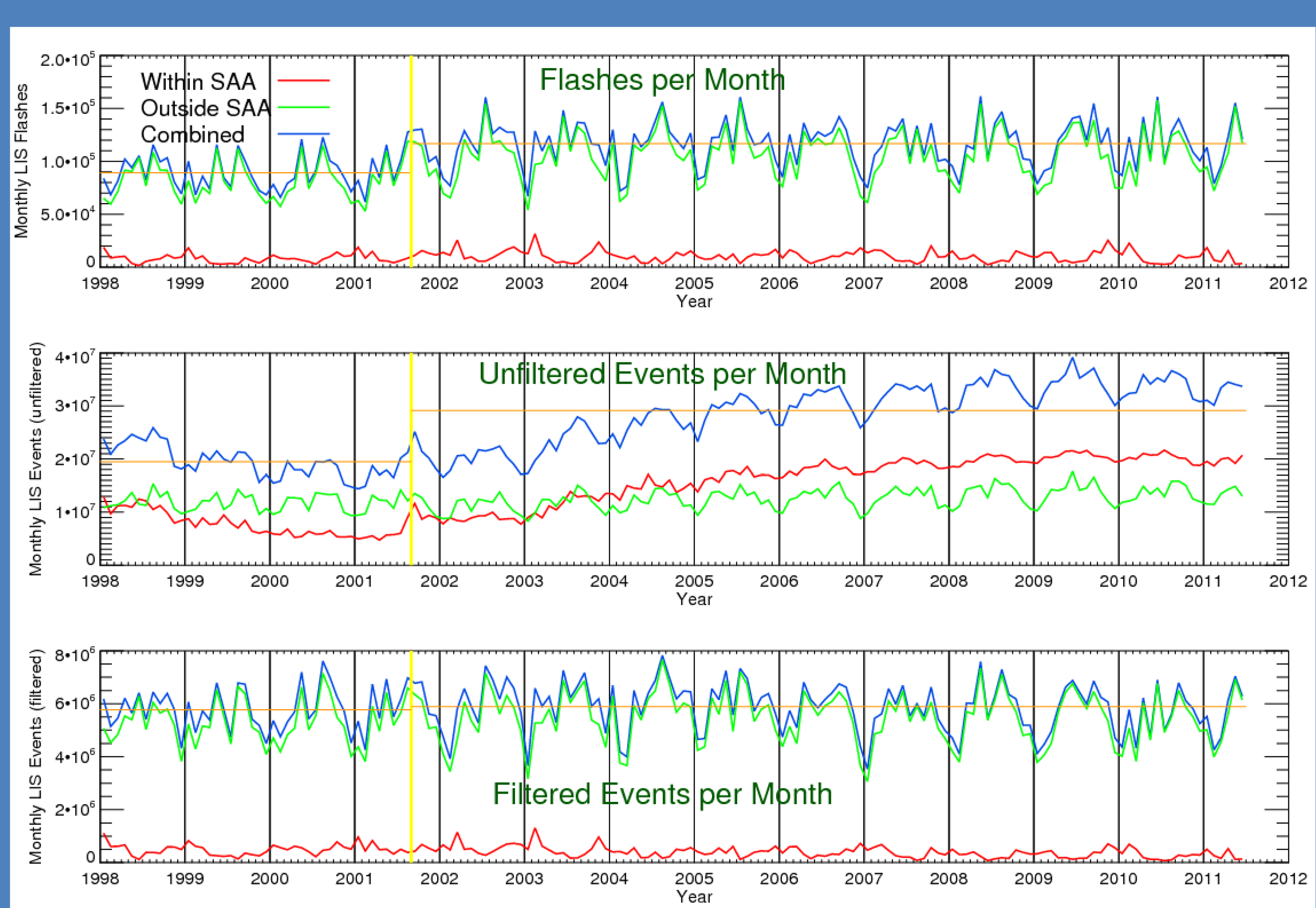
1) The DCC analysis of the LIS indicates no discernible degradation of instrument performance over its lifetime in orbit.
2) Due to its similar design, the GLM should also experience little performance degradation.
3) The DCC technique can be used to monitor GLM instrument performance once in orbit.



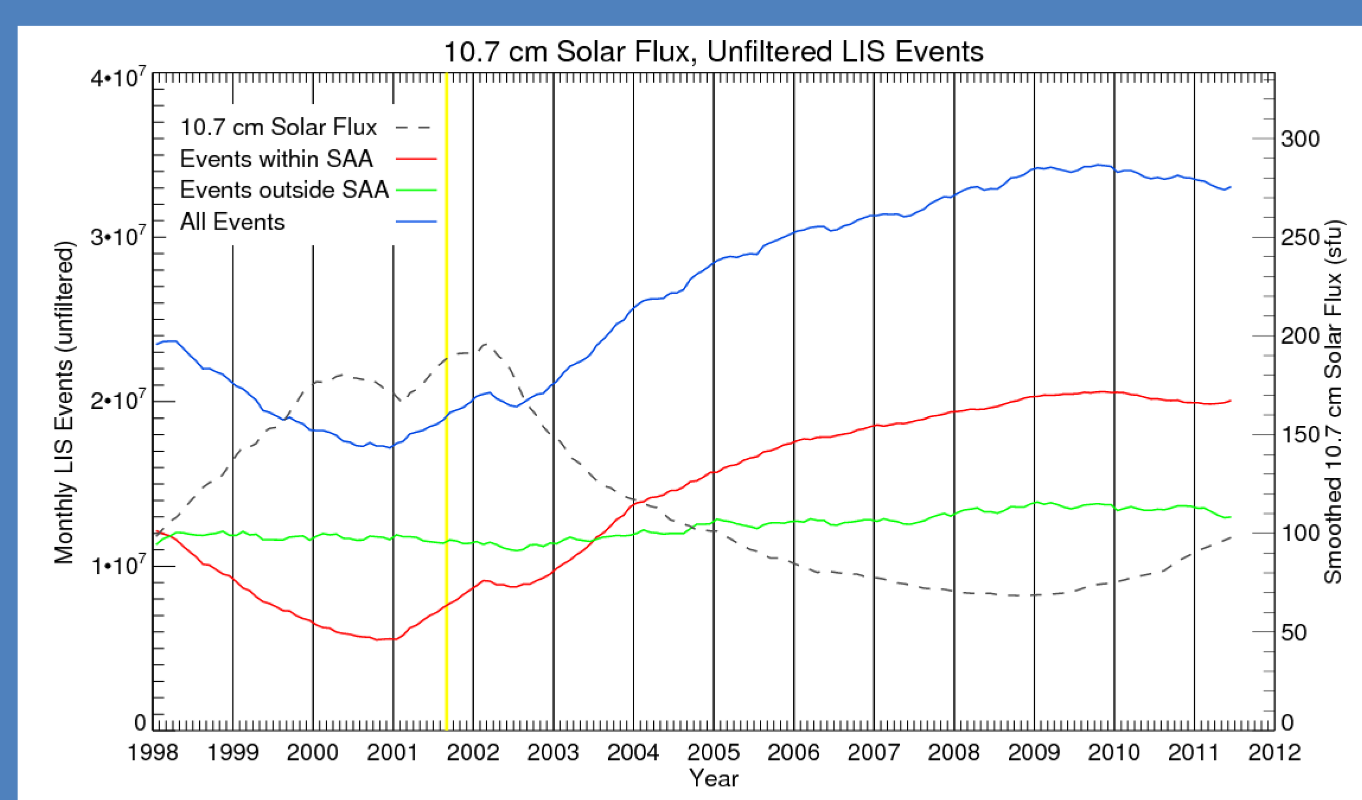
Frequency distribution of DCC LIS BG radiances for each year (1998-2010). The mean , median DCC radiance and the number of DCC LIS BG pixels for each July and August are also shown.



The mean yearly DCC LIS BG radiance for July and August. The solid horizontal line is the mean yearly value. The scale on the right indicates the yearly percentage difference from the mean.



Monthly time series of LIS flashes (top), events before filtering (middle), and after filtering (bottom). Blue indicates all observations, red are observations within the South Atlantic Anomaly (SAA), and green for observations outside the SAA. The yellow vertical line (August 2001) indicates the when the orbit was boosted from 350 km to 403 km. The orange lines are the mean of all monthly observations for pre- and post- boost periods



Time series of monthly LIS filtered and unfiltered events within (red) and outside (green) the SAA., and the combined values (green). The black line is the monthly 10.7 cm solar flux (sfu). The yellow vertical line indicates the TRMM orbit boost.

The number of flashes observed per month increased after the orbit boost, however, there is no discernible trend in monthly flashes prior to or after the boost. The unfiltered events show a distinct uptrend after the boost. Numerous false LIS events occur over the South Atlantic Anomaly (SAA) due to geomagnetically trapped ionized particles impacting the LIS sensor. The monthly unfiltered events were then partitioned as to being within or outside the SAA region. The trend in unfiltered events is seen to be due to false events occurring within the SAA and is inversely related to the 10.7 cm solar flux.

Conclusions:

1) LIS flash and event detection (after filtering) are stable over the period. This indicates GLM simulation activities using LIS data can be done using data from different years.
2) Validates the the robustness of the LIS filtering and clustering algorithms.
3) The LIS unfiltered events is inversely related to the 10.7 solar flux.