OPTICAL DETECTION OF LIGHTNING FROM SPACE

Dennis J. Boccippio
Hugh J. Christian

Global Hydrology and Climate Center
Marshall Space Flight Center, AL 35806

1 INTRODUCTION

Optical sensors have been developed to detect lightning from space during both day and night. These sensors have been fielded in two existing satellite missions and may be included on a third mission in 2002.

Satellite-hosted, optically-based lightning detection offers three unique capabilities: (1) the ability to reliably detect lightning over large, often remote, spatial regions, (2) the ability to sample all (IC and CG) lightning, and (3) the ability to detect lightning with uniform (i.e., not range-dependent) sensitivity or detection efficiency. These represent significant departures from conventional RF-based detection techniques, which typically have strong range dependencies (biases) or range limitations in their detection capabilities.

The atmospheric electricity team of the NASA / Marshall Space Flight Center's Global Hydrology and Climate Center has implemented a three-step satellite lightning research program which includes three phases: proof-of-concept/climatology, science algorithm development, and operational application.

The first instrument in the program, the Optical Transient Detector (OTD), is deployed on a low-earth orbit (LEO) satellite with near-polar inclination, yielding global coverage. The sensor has a 1300x1300 km^2 field of view (FOV), moderate detection efficiency, moderate localization accuracy, and little data bias. The OTD is a proof-of-concept instrument and its mission is primarily a global lightning climatology. The limited spatial accuracy of this instrument makes it suboptimal for use in case studies, although significant science knowledge has been gained from the instrument as deployed.

The second instrument in the program, the Lightning Imaging Sensor (LIS), is deployed on a low-earth orbit (LEO) satellite with tropical inclination (the Tropical Rainfall Measurement Mission, or TRMM, platform). The sensor has a 600x600 km^2 FOV, even higher detection efficiency than the OTD, very high localization accuracy, and little data bias. Co-located with the TRMM Microwave Imager (TMI), Precipitation Radar (PR) and Visible/IR Sensor (VIRS), the primary mission of the LIS is the development of science application algorithms in which lightning data is used to augment – and in some cases proxy – conventional (microwave and IR) storm remote sensing data. While the LIS sensor is tasked with the construction of a tropical lightning climatology, its primary usefulness is in individual storm case-studies.

The third instrument in the program, the Lightning Mapping Sensor (LMS), is hoped to be flown aboard a future geostationary platform. The LMS would thus have a fixed, hemispheric FOV and provide complete life-cycle coverage of each observed storm. Using science algorithms developed during the LIS mission, and extending storm coverage beyond scene "snapshots", the LMS would represent the final step in the sensor development process and pave the way for future routine, operational application of space-based lightning detection data.

This paper discusses the operational characteristics of the presently deployed sensors (OTD and LIS), presents preliminary validation statistics, outlines key early science results, and describes the OTD and LIS dataset availability from the Global Hydrology and Climate Center.

2 THE OTD

2.1 SENSOR DESCRIPTION

The OTD was launched on 3 April 1995 into a near circular orbit of 740 km with a 70° inclination, providing an instantaneous field of view of 1300x1300 km^2. Since that time, it has been detecting lightning activity over most parts of the world, with approximately 10 km spatial resolution and better than 50% detection efficiency for both cloud to ground and intracloud lightning under all orbital conditions.

The instrument detects lightning by looking for small transient changes in light intensity. This measurement is particularly difficult during daytime because sunlight reflecting off cloud tops is much brighter than the lightning. In order to work in daytime, the OTD uses a very narrow band interference filter (1 nm), takes 500 images a second and utilizes a real time event processor (RTEP) to discriminate lightning events from the background scene. The onboard processing helps reduce the data rate from 100 Mbps to less than 8 Kbps, while preserving the lightning activity.

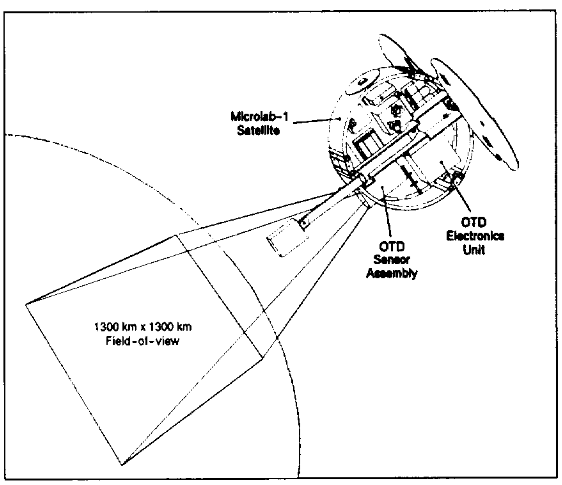

Fig 1 : The Microlab-1 satellite and OTD sensor

2.2 NOISE AND SAMPLING

Even with the onboard real-time processing, much of the data transmitted to earth are false events as opposed to actual lightning and require significant ground processing. With the OTD, most of the noise occurs from high-energy particle impacts of the sensor CCD array itself. While this noise source can be software filtered (based on its streaklike appearance when appearing at angles oblique to the sensor array, or its random scatter when appearing at angles acute to the sensor array), it does have other effects on sensor performance. An extreme example of this is the South Atlantic Anomaly, a large and natural feature of the Earth's electromagnetic environment. Fig. 2 shows the distribution of noise rejected by the OTD software filters, which clearly peaks in the South Atlantic region near Sao Paulo, Brazil. In the highest noise rate environments, the OTD data buffers periodically fill with noise and temporarily "blind" the instrument while the buffers empty. This translates to a significant (and documented) reduction in total OTD viewtime over the region, as shown in Fig 3. The practical result of SAA-related noise is an increase in the variance of regional flash rate estimates over the region (due to the reduced viewtime) and a decreased sensitivity over the region (due to the more aggressive behavior of the adaptive software noise filters which remove SAA-related noise).

Outside of the SAA, the sampling characteristics of the OTD are comparatively uniform. Ground locations will be seen for a maximum of three minutes (depending on the square CCD array's orientation, or yaw, at the time of the overpass). Ground locations in high latitudes are of course seen more frequently than ground locations in low latitudes, and the satellite orbit includes a slow precession; thus, over a suitably long sampling window (55 days), the entire local diurnal lightning cycle will be sampled. Because of the strong modulation of lightning activity on diurnal time scales, this effectively means that the OTD should *not* be used to investigate meteorological phenomena with shorter than 55 day periods (e.g., the Madden Julian Oscillation), and all long term measurements should be averaged over 55 day windows.

2.3 PERFORMANCE

The OTD has been operational since 1995 and continues to collect global lightning data. Once per 55-day cycle, the precession of the Microlab-1 satellite orbit takes it into a low "solar beta angle" regime where the onboard temperature drops dramatically and sensor performance is severely impacted. While these dropouts were relatively minor early in the mission, their duration is increasing as the satellite and sensor age. As such, the

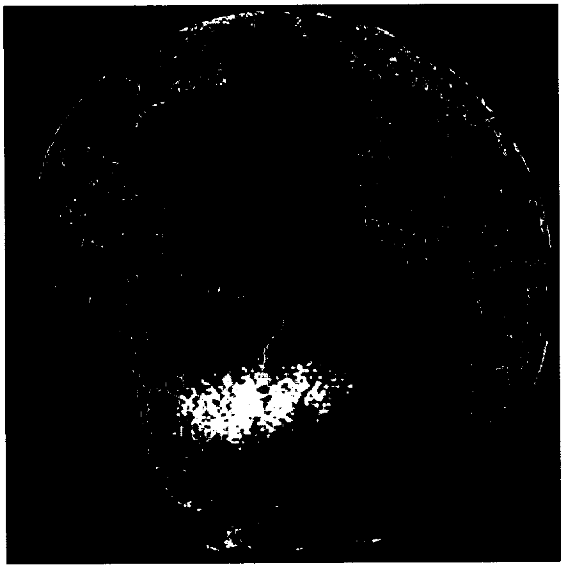

Fig. 2 : Noise rejected by the Optical Transient Detector production software. Radiation noise from the South Atlantic Anomaly (SAA) dominates.

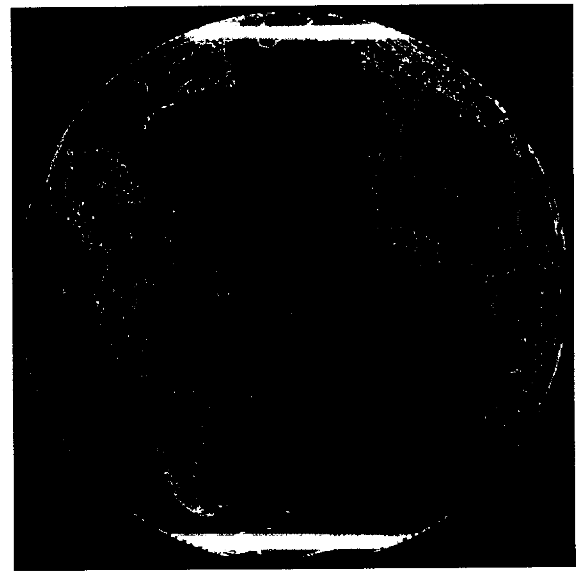

Fig 3 : Total Optical Transient Detector viewtime during the first two years of operation. Note the significant SAA-related reduction in viewtime.

first two years of OTD data are of highest quality for use in climatological studies, and inclusion of data beyond that time should carefully account for cold-sensor dropouts. Also, since these dropouts can include significant portions of the diurnal lightning cycle, it is safest to increase the temporal averaging window to 110 days (two cycles) to ensure even coverage and reduce diurnal cycle biases in climatological results. Note that even without considering cold-sensor dropout windows, the OTD dataset is *less* diurnally biased than any previous satellite-based study (e.g., DMSP/OLS, ISS-b).

3 THE LIS

3.1 SENSOR DESCRIPTION

The LIS was launched into low-earth orbit aboard the TRMM satellite on 28 Nov 1997. The TRMM orbit is at a 35 deg (tropical) inclination at an altitude of 350 km. The LIS sensor is functionally identical to the OTD sensor (albeit with several hardware improvements), and at this lower orbital altitude the LIS thus has a total FOV of about 600x600 km2 and a much improved nadir pixel resolution of 4 km. The LIS swath width is about the same as the TRMM TMI and about twice that of the TRMM PR, and thus provides complete coverage for any storms seen by either of these two co-located sensors.

The LIS was designed to improve upon the OTD's sensitivity, with a target flash detection efficiency of 90%. In addition, the sensor optical gain was adjusted to provide greater radiance resolution at the low end of optical pulse amplitudes, a key factor in gauging the sensor's effective detection efficiency. The sensor also is now capable of using "variable thresholding", in which the noise threshold for bright daytime scenes is automatically adjusted upward to reduce optical (cloud-

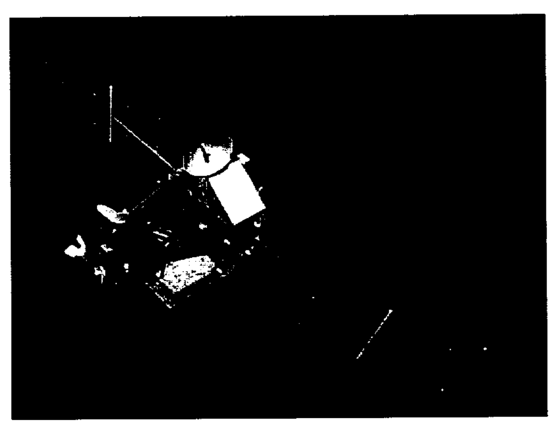

Fig 4 : The TRMM satellite. Sensors mounted on the satellite base include the LIS, a microwave imager (TMI), precipitation radar (PR) , visible/IR instrument (VIRS) and multispectral sensor (CERES)

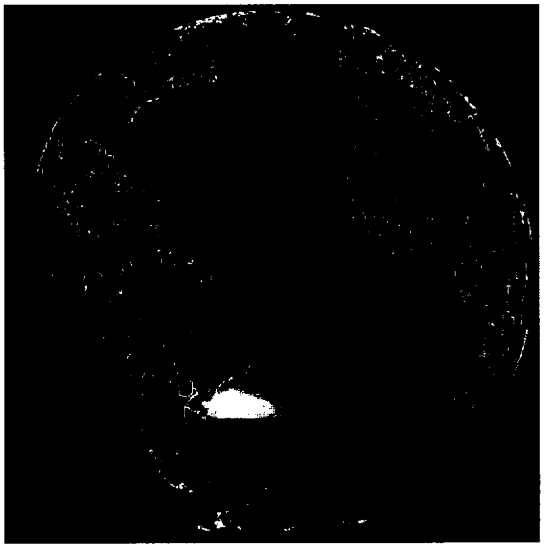

Fig 5 : Optical and radiation noise rejected by the LIS production software. Note the reduced SAA effect.

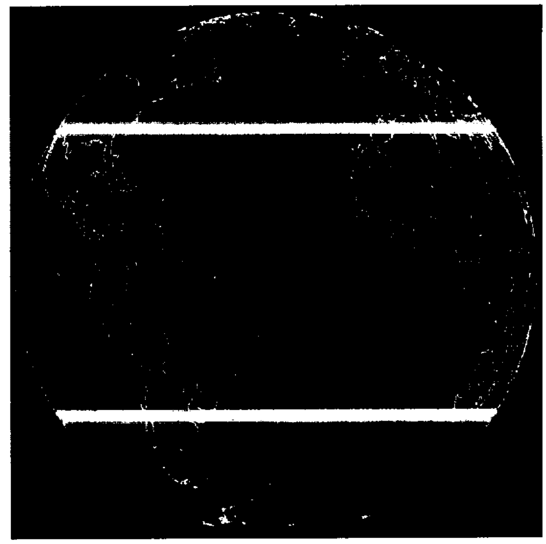

Fig 6 : Total LIS viewtime during the first 10 months of operation. Note tha unlike OTD, there are no significant reductions associated with the SAA.

edge) noise. These features, combined with the vastly improved navigation and timing information available from the TRMM satellite, make the LIS an instrument optimally suited for detailed case study analysis.

3.2 NOISE AND SAMPLING

Typical LIS viewtime of individual storms is 80 seconds, adequate to gauge the most interesting ranges of storm flash rates. The TRMM satellite typically flies in an "X-forward" (fixed yaw) direction, and thus the relative orientation of the sensor is not a factor and the 80 second viewtime is obtained across the LIS FOV.

The lower orbital altitude of this sensor yields a considerable reduction in the impact of SAA-related raidation. Fig 5 shows that the area affected by SAA radiation covers about a quarter the spatial extent as that impacted with the OTD. Most importantly, the key South American tropical continental region is mostly free of SAA contamination. Also, from Fig 6 it can be seen that the intensity of SAA-related noise as seen by LIS is reduced enough that the data buffers do not routinely fill in this region, and there is no appreciable "blinding" of the sensor by the SAA. LIS coverage is zonally uniform, and indeed quite high at the "top of the orbit" over the southern United States, a convenience which bodes well for ground truth studies.

3.3 PERFORMANCE

With the exception of very infrequent "cold cal" roll maneuvers for the benefit of the other TRMM sensors, and occasional "delta-V" (altitude correction) maneuvers, the LIS has nearly a 100% active duty cycle with few appreciable data dropouts. The exception is occasional filling of the data buffers by actual lightning *data* (rather than noise) in the very highest flash rate storms. This is an unexpected result of the vastly increased number of optical pulses seen by the LIS due to its doubled resolution (a fourfold increase in pixel data) and dramatically improved sensitivity. Buffer-filling storms are rare, and are fully tagged in the distributed LIS datasets. The appropriately reduced viewtime data are stored in the LIS orbit files to allow accurate calculation of storm flash rates in these rare cases.

4 SENSOR VALIDATION

4.1 OTD/NLDN COMPARISONS

The earliest empirical validation of the OTD sensor was conducted by cross-comparison with the GAI National Lightning Detection Network (NLDN). This study attempted to pair observed NLDN and OTD flashes based on their spatial and temporal separations, and hence yield an OTD CG detection efficiency (Boccippio et al, 1998). It was assumed that OTD IC detection efficiencies would be comparable. The DE estimates were by necessity probabilistic, given the known limitations in OTD timing and navigation accuracy (the sensor being designed for climatological, not case study, purposes). These estimates spanned a low end (i.e., resulting from relatively stringent space/time separation criteria or acceptable errors of 300 ms and 200 km) and a high end (from more realistic space/time criteria of 600 ms and 200 km). The high end of these estimates agreed fairly closely with prelaunch laboratory calibration of the sensor and U2-based optical pulse statistics collected previously by Christian and Goodman (1987). The DE estimates for the two most commonly applied OTD threshold settings ("15" and "17") are shown in Table 1, along with estimates of the IC:CG ratio, bias by preferentially detected positive CG flashes, and bias by slightly higher nighttime sensitivity.

Thresh	DE	IC:CG	+/- Bias	N/D Bias
15	55-70%	3.0-5.2	12-14%	6%
17	50-66%	2.7-5.1	12-13%	11%

Table 1 : OTD CG detection efficiency estimates derived from ##,### possible flash coincidences, day-night and positive-negative DE biases, and inferred IC:CG ratio

The combined dataset of jointly observed OTD and NLDN CGs, and the remaining dataset of non-NLDN observed OTD flashes (assumed IC) was investigated to determine if the OTD data could be used with any skill to *a priori* identify IC and CG flashes from their optical signatures. Using a category-based discriminant analysis approach, it was determined that while the three populations of intracloud, negative CG and positive CG flashes had statistically significant differences in the distributions of their optical characteristics (cloud-top radiance, footprint and duration), the magnitude of these differences and the spread of the distributions precluded any predictive use of the optical properties to determine flash type (beyond the rare cases of long continuing current signatures). The NLDN thus remains the most reliable tool for robust identification of ground flashes.

4.2 LIS/LDAR COMPARISONS

The greatly improved spatial accuracy of the LIS/TRMM sensor and platform now allows direct intercomparison with ground-based time-of-arrival (TOA) lightning channel mapping sensors, such as the Kennedy Space Center LDAR and the similar, portable TOA system constructed by New Mexico Tech and recently deployed in Oklahoma (summer 1998). Analysis of these joint datasets during TRMM overpasses allows us for the first time to confidently assess LIS IC detection efficiency, as well as characterize the specific types of flash morphology which OTD and LIS best detect, and the channel processes they are most sensitive to. Preliminary investigation has used the Oklahoma data from 11 June 1998, in collaboration with Ron Thomas and Paul Krehbiel of NMT. The investigation is currently being extended to the KSC LDAR system.

The preliminary analysis includes 160 flashes within 200 km of the OK LDAR system and within the LIS FOV, manually isolated by their spatial and temporal characteristics. Using the first-release version of the LIS noise filters, we find a total LIS lightning flash detection efficiency of greater than 80% (relative to the LDAR) during this single nighttime pass. The raw (unfiltered) LIS data is currently being examined to determine if low-information content real flashes (i.e., single LIS pixel illuminations) are being incorrectly filtered out of the LIS dataset; if so, the actual DE will be higher and the noise filters will be tuned to retain the incorrectly rejected flashes.

The (x,y,z,t) characteristics of one of the 160 analyzed flashes (an IC) are shown in Fig. 7, with LDAR sources and LIS optical pulses overlaid. From this comparison, it is evident that the LIS clearly sees the upper portion of the channel structure. The combined dataset is currently being analyzed to quantitatively assess the degree of optical attenuation with depth from cloud top.

These preliminary LDAR results are also very relevant for the early OTD/NLDN CG-based detection efficiency study. There is now a suggestion that the OTD/LIS IC detection efficiencies may be somewhat higher than their CG detection efficiencies. Further, some low-altitude CG flashes mapped by the LDAR system were seen by the LIS, but only quite late in the flash – occasionally up to 800 ms into the flash. In the OTD

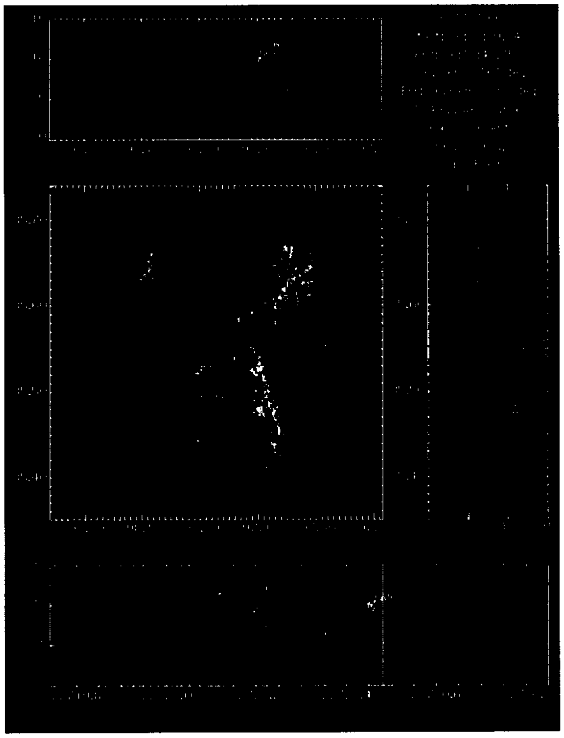

Fig 7 : An intracloud flash seen by both the NMT LDAR and LIS sensors. Counterclockwise from the top, the plots contain (longitude, height), (longitude, latitude), (time, height) and (height,latitude). LIS optical pulses are denoted by the large square "pixels".

validation study, such long time separations would have classified the flash as "missed" by OTD; hence, the high end of OTD DE results (those with loose time criteria) will be more representative of the actual CG detection efficiency. These high end results should thus be seen as *minimum* bounds on the actual OTD total lightning detection efficiency.

Future analysis of the KSC LDAR overpass datasets will improve the statistics found here, and include important electrical information from the KSC field mill network. This additional data will allow us to assess the energetic importance of flashes seen or missed by the LIS, a key component in our ultimate goal of relating total lightning energetics as inferred from optical measurements to storm kinematics and microphysics.

4.3 FIELD CAMPAIGNS

A number of field campaigns have either been conducted or are planned to extend LIS validation activities. These include TEFLUN (Texas-Florida Underflight experiment, May-Jun 1998), CAMEX-II (Atlantic hurricane overflights, Aug-Sep 1998), the TRMM-LBA "Land" campaign in Rôndonia, Brazil (Jan-Feb 1999), and the TRMM "Ocean" campaign near Kwajelein (late 1999). Validation instruments in these campaigns include aircraft data from the ER-2 LIP (Lightning Instrument Package), and in some cases deployment of local ALDF (Advanced Lightning Direction Finder) networks. Additional ground instruments may be deployed in the Huntsville, AL region during the TRMM mission.

5 EARLY SCIENCE RESULTS

5.1 CONTEXT

A central (although not exclusive) component of the MSFC space-based lightning observation program is the premise that global lightning observations will not only provide important new understanding of the Earth's electrical environment, but will also provide unique new knowledge of its meteorological environment. As a process variable closely coupled to thunderstorm dynamics and microphysics, the lightning rate is potentially a key tool to probe the kinematic properties of evolving storms, including total ice content, updraft strength, vertical mass flux and anvil detrainment rates. Many of these properties are difficult to directly measure using conventional (microwave or IR) remote sensing devices. They are, however, directly involved in the basic process physics which drive thunderstorm electrification. The conceptual map shown in Fig. 8 illustrates these basic process physics, and the physical understanding or data needed to fully comprehend – and exploit – the thunderstorm electrification physics operationally and quantitatively. The understanding of particle-scale charge separation (in the middle of this conceptual chain) has historically posed a serious obstacle to closing the link between electrification and meteorology, and many operational applications hence fall back on purely empirical relationships between observed lightning and secondary storm characteristics, such as surface severe weather or rainfall. The MSFC strategy focuses instead on the core components of the physical chain, and seeks to "whittle away" at the missing links from either end. As both adequate physical understanding *and* empirical data become available, the questionable empirical connections (the

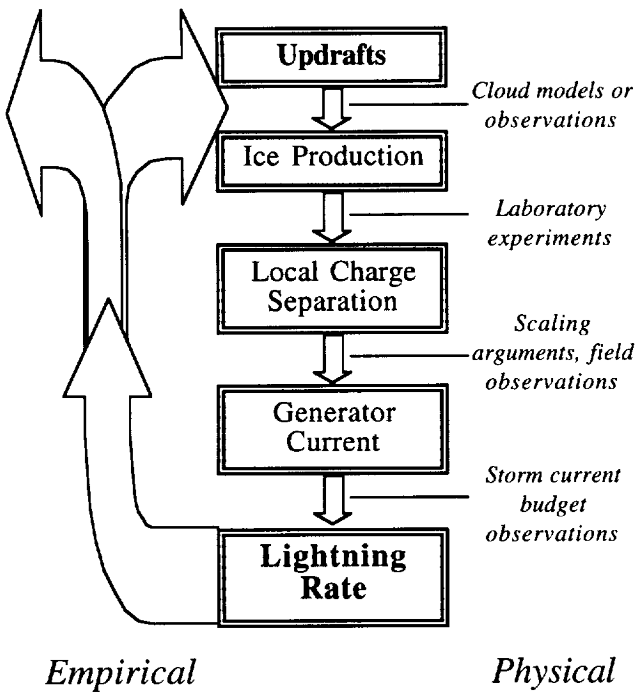

Fig 8 : Conceptual map illustrating the key process physics in thunderstorm electrification, the physical knowledge needed to understand each process, and the empirical "short circuit" sometimes used in the inference of storm properties from lightning data.

"short circuit" arrows in the diagram) may be joined further into the chain, and will become increasingly *physically based*, a key ingredient in making them more robust, less arbitrary, and on sounder scientific footing. The OTD and LIS datasets – especially in conjunction with the other TRMM sensors and with ground validation data – provide the empirical data needed to begin this process.

5.2 CLIMATOLOGY

The global and tropical lightning climatologies collected by OTD and LIS provide a clear illustration of the relevance and significance of the storm properties described in Section 5.1. Fig 9 and 10 show OTD global and LIS tropical lightning composites for 1 year and 3 months of data collection, respectively. As had been known from previous global surveys (such as the DMSP/OLS midnight lightning study of Orville and Henderson, 1986), the global lightning distribution exhibits a very strong continental bias. Indeed, the global lightning distribution is dramatically different from global maps of, e.g., outgoing longwave radiation (OLR) or surface rainfall. This immediately tells us that the storm properties most directly inferable from lightning measurements are not cloud top height or rainfall – a fact already suggested by arbitrary "regime" corrections imposed in previous lightning-cloud height (Price and Rind, 1992) or lightning-rainfall (Petersen and Rutledge, 1996) studies. While these investigations are worthwhile pursuits, it is likely that a deeper understanding of such "regime" corrections is only obtainable by understanding physically what lightning *does* tell us about the kinematics or microphysics of thunderstorms.

The global lightning climatology derived from OTD data has also raised questions about previous "conventional wisdom" about global lightning activity. Using a very conservative estimate of OTD flash detection efficiency (50%), the MSFC lightning team has derived a global flash rate of 37 flashes/sec, considerably lower than most historical estimates such as the commonly cited 100 flashes/second. The actual flash rate is likely even lower than this, given our new understanding of the OTD's detection efficiency. It is interesting to note that these low flash rates are consistent with recent results by Heckman et al (1998),

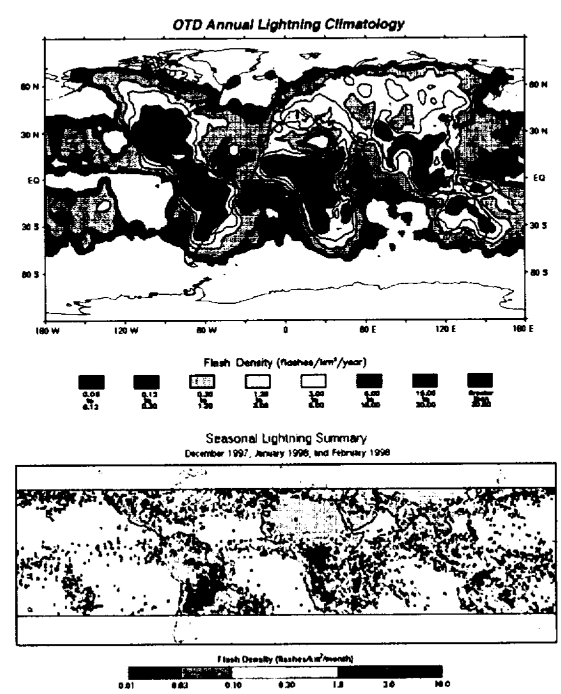

Fig 9,10 : Annual OTD and seasonal (DJF) LIS lightning composites.

who found that 100 flash/sec global rate estimates dramatically *overpredict* the amount of ELF energy actually in the earth-ionosphere cavity, as measured by calibrated ELF sensors.

5.3 LAND / OCEAN DIFFERENCES

The most striking feature of both the LIS and OTD global lightning maps is the vast difference between land and ocean flash rates. This difference is found not only in the amount of continental and oceanic lightning, but in its diurnal modulation as well. Fig. 11 shows the relative diurnal cycles of land and ocean flash rates as observed by the OTD. Nearly a sevenfold increase is seen over land in the late afternoon hours. The oceanic cycle appears to contain a semidiurnal component, although the amplitude is small. It is not yet known if this signal is a result of modulation of convection in the tropics by the atmospheric tides, modulation by radiative heating and cooling, or by other mechanisms not yet hypothesized.

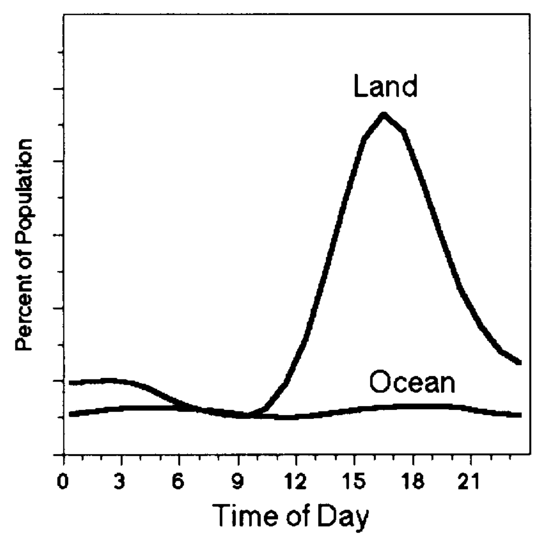

Fig 11 : Diurnal cycle of the lightning flash rate over land and ocean regions, as observed by the OTD.

Flash rates are not the only lightning property which varies between land and ocean. Fig. 12 and 13 show the populations of flash optical footprint (area) and optical radiance as seen by the LIS. At present, it is unknown whether the differences in the land and ocean population are due to differences in the energetics of the flashes themselves, or differences in the optical depth of the storms (resulting in greater optical attenuation at cloud top). Either result would have important diagnostic implications for the properties of the parent storms.

Zipser (1994) has suggested that differences in the characteristic updraft velocities of land and ocean storms may account for the observed variability of lightning. The weaker and flatter oceanic lightning diurnal cycle is certainly consistent with this theory (weaker updrafts yielding a lower average generator current and hence flash rate; little solar modulation of the enthalphy of source oceanic boundary layer air yielding little modulation in diurnal updraft strength). Either explanation for the observed optical differences in land and ocean lightning is also consistent with this theory (flashes in weaker updraft / lower flash rate storms transferring greater charge; weaker updrafts yielding less ice content aloft and hence less optical attenuation). The combined lightning and microphysical sensors aboard the TRMM mission will continue to provide a rich dataset to use in attempting to test this theory.

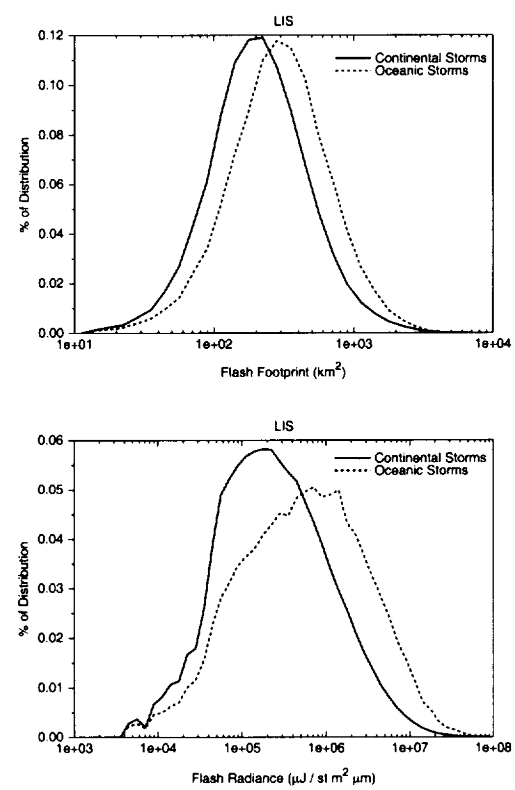

Fig 12,13 : Distributions of flash footprint (area) and total radiance in land and ocean storms, as observed by the LIS.

5.4 MICROWAVE BRIGHTNESS

In the conceptual map of Section 5.1, we generally expect the process physics (connecting arrows) to yield monotonic relationships between each step in the chain (stronger updrafts yield more ice; more ice yields greater local charge transfer; greater charge transfer yields a higher generator current; a higher current yields higher flash rates). As such, we should expect to find a monotonic (although not necessarily linear) relationship between observed lightning rates and any storm property which exists "earlier" in the chain. With the TRMM data, we can explore this hypothesis, and indeed find striking results. Preliminary work done by Dr. Kevin Driscoll of the GHCC has identified a nearly linear relationship (Fig 14) between lightning optical pulse density and TMI-observed microwave brightness temperature (a measure of the amount of large precipitation ice in the cloud). The relationship is even more striking given its preliminary nature: the brightness temperatures are uncorrected and only partially adjusted for bin-splitting and projection effects. The data in this plot was derived from four LIS storm scenes in several different regions, including the Southeastern U.S. and Atlantic ocean. Some reduction in the scatter of this plot is expected when the data is analyzed more rigorously.

The lightning-brightness temperature relationship is operationally useful in its own right, with significant implications for model assimilation and forecasting applications. In addition, it provides strong evidence

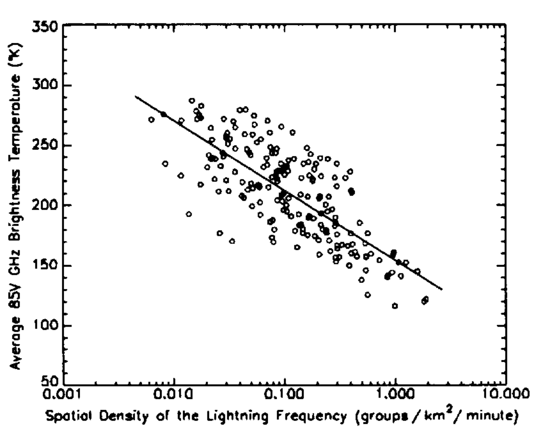

Fig. 14 : Relationship between TMI 85 GHz brightness temperatures (a measure of total ice content in storms) and the density of LIS-observed "groups" (optical pulses)

that the complicated – and still largely unconfirmed – process physics details (such as local charge separation) do not severely mask or distort the basic energetic physics which couple storm dynamics and lightning rates (this is an insight which Bernard Vonnegut, in his scaling law arguments for storm energetics, perceived several decades ago). The rigorous and quantitative determination of what the space-based optical sensors see, how they see it, how the observed data relates to storm electrical energetics, and how the storm electrical energetics relate (either empirically or physically) to storm dynamics and microphysics structures the MSFC lightning science research effort in the near future. Application of the knowledge and/or algorithms derived from this research in future missions (such as possible geostationary lightning mappers) will form the bridge between basic science gained from the OTD and LIS data and operational applications which benefit broader communities.

6 COMPLEMENTARITY

It should be noted that the space-based optical lightning measurements provide much, but not all, of the lightning "big picture". The satellite sensors should be viewed as complementary to existing ground-based installations, such as the NLDN and LDAR systems. The NLDN, in particular, provides critical information on ground strikes, and will be a necessary tool in determining IC:CG ratios, a quantity believed critical in fully understanding storm electrification and evolution. The NLDN and related systems remain best suited to identify actual ground lightning hazards. Flash energetics (beyond optical emissions) can only be diagnosed from ground or airborne field or RF sensors.

7 CONCLUSION

7.1 OTD/LIS DATA AVAILABILITY

The OTD and LIS data described in this document is described and documented on the WWW at http://thunder.msfc.nasa.gov. It can be ordered at no cost from the Global Hydrology Resource Center (GHRC), accessible from the above URL. The data undergoes rigorous automatic and manual quality-control procedures before being certified for release. Daily browse products are available at the web site for both OTD and LIS sensors. Browse products for the LIS are interactive, and single orbit data can be directly downloaded by clicking on the region of interest in the plot.

7.2 OTD/LIS SOFTWARE

The OTD and LIS science data sets are stored in Hierarchical Data Format (HDF). All information required to analyze these data, including sensor and satellite alert flags, viewtime information, etc. are stored within the orbit files themselves. A cross-platform software analysis suite is distributed with the data, and includes high-level programming interfaces (libraries) for use in either C or the IDL language. A menu-driven graphical analysis tool written in IDL is also included in the package. We have sought to make the data storage in HDF format as transparent as possible to end-users, realizing that they wish to spend more time analyzing the data than translating or extracting it.

7.3 FUTURE GOALS

As discussed in section 5, much of the near-term science work of the MSFC team is focused on understanding the relationship between optically-detected lightning (including flash, pulse and radiance information) and flash energetics, and the relationship of these energetics to storm dynamics and microphysics. An important component of this research will be the cross-calibration of the optical devices with other sensors, and the development of physically-based formalisms to quantify lightning measurements in ways that are meaningful to storm energetics. We invite interested collaborators to use the publicly available OTD and LIS data, and encourage users to contact the MSFC team with any questions regarding the use or application of the satellite data.

ACKNOWLEDGEMENTS

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