NASA

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

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SCIENCE DATA VALIDATION PLAN FOR THE LIGHTNING IMAGING SENSOR (LIS)

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February 29, 1996
Revised October 18, 1996

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1. INTRODUCTION

1.1 Science and Measurement Objectives

Science Objectives

The overall science objectives of this instrument are to fly a calibrated optical Lightning Imaging Sensor (LIS) in order to acquire and investigate the distribution and variability of total lightning over the Earth, and to increase understanding of underlying and interrelated processes in the Earth/atmosphere system. Lightning is one of the responses of the atmosphere to thermodynamic and dynamic forcing and, consequently, contains significant information about the atmosphere. LIS data will provide important research information for a number of diverse fields in the geophysical sciences such as hydrology, cloud physics, atmospheric chemistry, global electric circuit, and magnetospheric and ionospheric physics [1-3, 14].

The processes that lead to the production of lightning are tightly controlled by the cloud updraft and the formation of precipitation. Lightning seems to initiate soon after the onset of strong convection, after significant cloud mass and ice have formed in the upper regions of the thunderstorm. Lightning activity tends to track the updraft in both amplitude and phase with rates increasing as the updraft intensifies and decreasing rapidly with cessation of vertical growth. The charging process is dominant in the convective regions of the storm. It has been demonstrated that lightning observations from space will clearly delineate the regions of convection embedded within large stratiform cloud systems. Thus, the detection of lightning from space specifically identifies those regions that are of paramount importance in the rain formation process. This ability to uniquely identify and quantify the convective core regions of storm systems and the existence of a linear relationship between total rain volume and lightning flash rate make LIS an important addition on TRMM. The LIS will be particularly valuable in providing observations over the data sparse oceans and tropical regions of the world

Some of the unique ways that the LIS global data sets will contribute to studies of convective storms include detection and location of deep convection without land-ocean bias, estimation (and constraint) of precipitation mass in the mixed phased region of thunderclouds, and differentiation of storms with strong updrafts from those with weak vertical motions.

Mesoscale phenomena, in turn, influence and are influenced by global scale processes. Hence, the LIS will contribute to understanding of the global hydrological cycle, general circulation and sea-surface temperature variations. Since lightning activity is closely coupled to storm convection, dynamics, and microphysics, it is also related to atmospheric instability and to the release and transport of latent heat. The LIS will provide a global lightning climatology from which changes, caused perhaps by subtle temperature variations, may be detected. LIS data will be useful in investigations of the electrical coupling of thunderstorms with the ionosphere and magnetosphere, and with observations and modeling of the global electric circuit. LIS will produce the most complete and accurate data base to date to perform correlations with lightning on a global scale in the production of natural NO_X and other trace gas processes in the atmosphere will also be made possible with the LIS data.

Measurement Objective

The overall measurement objective of LIS is to detect and locate lightning during day and night with high spatial resolution and high detection efficiency. During the 1980's, extensive optical and electrical observations of lightning were made from a high altitude U-2 aircraft with the primary goal of defining a baseline design criteria for space sensors capable of meeting this measurement objective. The results of the U-2 investigations, parametric trade-off studies, and other research [4-8] have clearly established the feasibility of making this kind of lightning measurement from space using present state-of-the-art technology. The successful launch of the Optical Transient Detector (OTD) in 1995 has demonstrated that the LIS measurement objective can be met.

In terms of measurement capabilities, the Lightning Imaging Sensor (LIS) is a staring imager optimized to detect and locate the strong cloud-top lightning emissions near 777.4 nm (this is a prominent neutral atomic emission line in the lightning spectrum comprised of an oxygen triplet). The LIS will detect these events with storm scale resolution (i.e., ~ 5 km) over a large region of the Earth's surface along the imager's orbital track, mark the time of occurrence, and measure the radiant energy. The LIS instrument will detect both intracloud and cloud-to-ground discharges during the day and night with a high detection efficiency (i.e., 90 %) and a temporal resolution of 2 ms. In addition to the lightning event data the LIS will also periodically capture an image of the background.

The LIS will image a scene much like a television camera, however, daytime detection of highly transient lightning sources against a bright cloud-top background makes actual data handling and processing more involved than that required by a simple imager. Overall, LIS is composed of six major subsystems including: an imaging system, a focal plane assembly (including a CCD array, preamplifiers, and multiplexers), a real-time signal processor and background remover, an event processor and formatter, power supply, and interface electronics. The imaging system is a simple telescope consisting of a beam expander, an interference filter, and re-imaging optics [1, 9].

Consideration of the background signal strength also was an important element in determining sensor design requirements. As the background signal increases, random photon shot noise in the sensor increases and the probability of false lightning event detections (or *false alarms*) increases. During the day, diffuse cloud reflectance of solar radiation constitutes the primary background signal and it is generally steady in comparison to the transient lightning pulses discussed above. At night, electronic noise tends to dominate background sources. The maximum background expected due to diffuse cloud-top reflection of solar radiation is about 331 $Wm^{-2}\mu m^{-1}ster^{-1}$. Much larger values are obtained from specular reflection of solar radiation, e.g., reflection from quiescent water surfaces.

Background sources that change suddenly, i.e., within the 2 ms integration time of LIS, may also introduce false triggers. These sources may include surface glint (e.g., direct solar reflection from ocean or lakes), and radiation or orbit-induced changes in the background. For example, the passage of LIS over a changing cloud field tends to reduce the system signal-to-noise ratio because of the filter response lag. This can lead to higher false event rates. This type of false alarm will be simulated in the calibration laboratory by yawing the LIS sensor head as it is illuminated by an 8" integrating sphere output (see [11] for additional details).

Based on the properties of the cloud-top lightning [6, 7] and background signals, the LIS sensor design requirements and calibration facility requirements are summarized in Table 1.

	SENSOR DESIGN REQUIREMENTS	**CALIBRATION REQUIREMENTS**
Detection efficiency	> 90% of all events	fully characterize
False alarm rate	< 10% of total events	fully characterize

Background		
Radiance	331 $W/m^2/ster/\mu m$	0-331 $W/m^2/ster/\mu m$
Accuracy	10%	5%
Lightning signal		
Threshold	4.7 $\mu J/m^2/ster$	3.0 $\mu J/m^2/ster$
Dynamic range	100:1	0-300 $\mu J/m^2/ster$
Accuracy	10%	5%
Spectral		
Accuracy	0.1 nm	0.05 nm
Resolution (FWHM)	1.0 ± 0.1 nm	0.1 nm
Spatial		
Resolution	0.625° IFOV	0.001°
Angular range	80° x 80° FOV	82° x 82°
Temporal		
Resolution	2.0 ms	2.0 ms
Accuracy	2.0 ms	2.0 ms

Table 1. Sensor and calibration requirements.

1.2 Missions

The LIS is a scientific payload on the Tropical Rainfall Measuring Mission (TRMM) satellite. The engineering prototype of LIS, called the Optical Transient Detector (OTD), was launched in April 1995 aboard a Pegasus rocket on the MicroLab-1 satellite. OTD has proved the LIS design concept. OTD is serving as a test bed for the science data validation plans outlined in this document.

1.3 Science Data Products

The basic science data product of LIS is lightning [9, 10]. This product is comprised of several components, including: raw data (level 1-A), background image (level 1-B), events (level 1-B), groups (level 2), flashes (level 2), areas (level 2), vector data (level 2), browse data (level 3), orbit statistics (level 3), flash density maps (level 4), and metadata. A detailed description of these components and the LIS HDF data structure can be found in [10].

1.4 Applicable Documents

1. Lightning Imaging Sensor (LIS) for the Earth Observing System, NASA TM 4350, February, 1992.
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10. Algorithm Theoretical Basis Document for the Lightning Imaging Sensor, NDN, February 10, 1995. http://spso.gsfc.nasa.gov/atbd/pg1.html
11. LIS Calibration Procedures Document, NDN, March 30, 1995, *final version to be submitted*.
12. NASA-MSFC LIS/TRMM Master Schedule, NDN, rebaseline date September 13, 1995, rundate January 11, 1996.
13. NASA TOGA COARE Science Data Workshop-II, NASA TOGA COARE Project Office, M.S. 483, NASA Langley Research Center, Hampton, VA 26381, July 1994.
14. Lightning Imaging Sensor (LIS) Science Team Meeting, *The Earth Observer*, September/October, Vol.7, No.5, 3-6, 199 http://spso.gsfc.nasa.gov/eos_observ.html
15. Data Production Software and Data Management Working Agreement for LIS, GSFC 424-27-92-01, November, 1994.

1.5 List of Acronyms

ALDF	Advanced Lightning Direction Finder
BATSE	Burst and Transient Source Experiment
CaPE	Convection and Precipitation/Electrification Experiment
CCD	Charge Coupled Device
COARE	Coupled Ocean Atmospheric Response Experiment
COHMEX	Cooperative Huntsville Meteorological Experiment
DMSP	Defense Meteorological Satellite Platform
ECS	EOSDIS Core System
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
ESIP	Earth Science Information Partners
FORTE	Fast On-board Recording of Transient Events
FOV	Field-Of-View
GAI	Global Atmospherics, Inc.
GHCC	Global Hydrology and Climate Center
GRO	Gamma Ray Observatory
GSFC	Goddard Space Flight Center
GTAS	Ground Truth Analysis Software
HDF	Hierarchical Data Format
IMS	Information Management System (for EOSDIS)
KSC	Kennedy Space Center
LDAR	Lightning Detection and Ranging
LIS	Lightning Imaging Sensor
LPATS	Lightning Position and Tracking System
LSIM	Lightning Simulator
MCTEX	Maritime Continent Thunderstorm Experiment
MSFC	Marshall Space Flight Center
MSX	Mid-course Space Experiment
NBS	National Bureau of Standards
NDN	No Document Number
NIDS	Nexrad Information Dissemination Services
NLDN	National Lightning Detection Network
NSIDC	National Snow and Ice Data Center
NSSFC	National Severe Storms Forecast Center
OLS	Optical Line Scan
OPS	Optical Pulse Sensor
OSC	Orbital Sciences Corporation
OTD	Optical Transient Detector
RTEP	Real-Time Event Processor
SCF	Science Computing Facility
SSM/I	Special Sensor Microwave/Imager

1.5 List of Acronyms (continue)

TOA	Time Of Arrival
TOGA	Tropical Ocean Global Atmosphere

TRMM	Tropical Rainfall Measuring Mission
WSI	Weather Services, Inc.

2. VALIDATION CRITERION

2.1 Overall Approach

In providing guidance on the content and format of the EOS instrument team validation plans, the EOS Panel on Data Quality has stated:

> Validation is the responsibility of the *algorithm providers* (i.e., the LIS Science Team). It involves specifications of the transformations required to extract estimates of high-level geophysical quantities from calibrated basic instrument measurables and specification of the uncertainties in the high-level geophysical quantities. Validation requires detailed knowledge of the relationship between measurables and geophysical quantities of interest over the full range of possible conditions. Pre-launch activities include determination of algorithms and characterization of uncertainties resulting from parameterizations and their algorithmic implementation. Post-launch activities include refinement of algorithms and uncertainty estimates based on near-direct comparisons with correlative data and selected, controlled analyses.

The LIS Science Team is pursuing a validation plan consistent with this approach. *Validation*, in this document, is defined as the process of verifying and/or tuning the performance of the sensor performance parameters, data processing algorithms, and sensor hardware. *Calibration*, in this document, shall generally refer to any activity whereby a known sensor stimuli is used to determine the geophysical value of, judge or improve the sensor output.

The LIS validation will address *Sensor Performance*, *Data Processing Algorithms,* and *Scientific Retrieval Algorithms*. Observations of lightning from a broad range of lightning detector technologies shall be used to judge the correctness or quality of the LIS data, and the overall sensor and algorithm performance. The independent lightning observations (referred to as *ground-truth* data in this document) will be used to characterize existing random and/or systematic sensor errors that might exist. With knowledge of such errors, it will be possible to improve the LIS data product by removing a portion (perhaps most) of the possible error.

Sensor Performance

The overall on-orbit performance parameters of LIS to be evaluated during validation includes the following parameters: detection efficiency, false alarm rate, geolocation accuracy, signal amplitude (background and event intensity) accuracy, and timing accuracy. The quality and variability of these parameters over time shall also be monitored. In addition the validation process will include remotely adjusting the LIS threshold settings to maximize detection and minimize false alarm rate.

The detection efficiency is defined as the percentage of lightning flashes occurring in the FOV of the instrument that are detected by the sensor. False alarm rate is defined as the percentage of total detections that are not attributable to lightning. These performance parameters may display significant dependence on the conditions under which the observations are obtained. These conditions include LIS threshold setting, background intensity, observation time (e.g., time of day, time of year), storm characteristics (e.g., continental vs. maritime, large vs. small, developing vs. decaying, high flash rate vs. low flash rate), geographical location, and the version of the data processing software employed. The effects of these conditions may be very interdependent and the responses nonlinear.

Data Processing Algorithms

In the TRMM pre-mission period, we plan to take advantage of the space lightning observations provided by the April 1995 launch of the Optical Transient Detector (OTD). The LIS data processing algorithm described in detail in the ATBD [10] will be initially validated by using it to process data from the OTD instrument. The OTD, being a prototype of the LIS instrument, will detect lightning in a similar way and produce a similar data stream as the LIS. We will verify the LIS data processing algorithm using data from the OTD, various ground-based lightning detecting systems and other ground truth observations (ground-, airborne-, and satellite-based).

After launch, the LIS data processing algorithm will be validated using data from LIS and coincident ground truth lightning observations. The post-launch validation process will determine how well the data algorithm processes the LIS data stream and how accurately the defined data structures correspond with the observed lightning. The LIS data processing algorithm will be adjusted or tuned to provide the best correspondence with the observations. The capability for easily adjusting the higher order data structures has been designed into the code. Any changes that are made in the LIS data processing algorithm will be reflected in updates to the ATBD.

Scientific Retrieval Algorithms

The LIS Science Team will participate in the development, testing, and validation of scientific retrieval algorithms that incorporate LIS data. The process will be similar to that described for validation of the data processing algorithms but will undoubtedly include modeling studies in addition to field observations.

2.2 Sampling Requirements and Trade-Offs

A broad range of ground-truth observations will be utilized to validate the LIS data. These include a variety of lightning measurement systems and networks as well as ancillary observations (e.g., radar data and products, satellite data and products). The specific temporal, spatial, radiometric sampling requirements depend upon the particular LIS data process being validated. In some cases, the ground-truth lightning measurements provide only cloud-to-ground detections (e.g., National Lightning Detection Network (NLDN)) or have uncertain detection efficiencies (e.g., NLDN, long range sferics networks). In these cases, a *cross-calibration* approach will be taken. Every effort will be made to sample different portions of the globe (during different seasons and time of day) with equivalent and/or similar ground truth observations in order to fully validate the performance of LIS. Broadly sampled data over extended time periods and wide geographical regions are particularly important for accurately characterizing the LIS detection efficiency. The validation of the accuracy of LIS timing, geolocation, and signal intensity, while fundamental to the scientific applications of LIS data, probably do not require as broad of a sampling requirement as that associated with detection efficiency validation.

2.3 Measures of Success

Validation shall be considered successful when it can be shown that correlative ground-truth data sets scientifically establish or prove the accuracy of the LIS data product. Following the launch of LIS, each facet of the LIS sensor performance and data processing algorithms shall be analyzed. These analyses shall be submitted for publication in scientific journals (such as the Journal of Geophysical Research). If these analyses, being independently reviewed by the standard peer-review process for scientific publication, are accepted for scientific publication in credible journals, the validation process shall be deemed successful.

3. PRE-LAUNCH ACTIVITIES

3.1 Laboratory Radiometric Tests

Laboratory calibration will determine the radiometric response of LIS on a pixel by pixel basis. The pre-launch calibration activities and procedures are described in detail in [11]. These activities include a D.C. uniformity and linearity test, field-of-view (FOV) test, A.C. response test, and a spectral test. This pre-launch activity was completed for LIS in December 1996 prior to delivery of the instrument to GSFC for integration on the TRMM satellite [12].

D.C. Uniformity and Linearity Test

The D.C. uniformity and linearity test involves exposing the entire LIS FOV to a steady, isotropic optical source and varying the source amplitude level. The D.C. response for each pixel is fully characterized in this test. The response of a pixel to various D.C. stimulus levels defines the pixel linearity. The variability in D.C. response from pixel to pixel is a measure of pixel uniformity.

Field-of-View (FOV) Test

In the FOV test set-up, the LIS is illuminated with a highly collimated light source whose azimuth and elevation incidence angles are precisely known relative to the LIS boresight. An Euler angle analysis of LIS output data from this test provides a precise mapping between illuminated pixel and associated light source incidence angles. This test also determines the extremities of the LIS FOV.

A.C. Response Test

In the A.C. response test, a pixel is illuminated with a steady background signal while stimulated with a transient optical pulse. The test provides a very precise radiometric calibration of several pixels throughout the FOV and the transient piece-wise linear response of the Real-Time-Event-Processor (RTEP) of LIS is quantified.

Spectral Test

The narrow pass-band filter of LIS is scanned using a monochromator as part of the spectral test set-up. Center wavelength and full-width at half power are characterized in the LIS spectral test.

Calibration Instrumentation and Facilities

Calibration of test instrumentation and traceability of test equipment back to secondary or primary standards will be maintained at all times. The calibrations will be expressed in terms of physical standards and the optical sources employed will be traceable back to National Bureau of Standards (NBS) maintained services or materials (e.g., NBS calibrated silicon photodetector in our spectroradiometer system).

The LIS laboratory calibration facility is in the Space Sciences Laboratory, NASA-Marshall Space Flight Center. This laboratory is a class 10,000 clean to insure the integrity of the cleanliness of the optical system.

Standard radiometric response curve data derived from laboratory calibration of LIS is forwarded to the LIS Science Computing Facility (SCF) software development team for incorporation into the LIS Data Processing Algorithm.

3.2 Laboratory Performance Tests

In this document, *performance test* refers to those tests that include, but are not limited to, determining the LIS lightning detection efficiency and false alarm rate. The lightning detection efficiency is defined as that fraction of flashes in the LIS FOV that are actually detected by LIS. The false alarm rate is defined as the number of false event detections by LIS per second.

The A.C. response test described above provides an initial estimate of the LIS detection efficiency. The results of this test are then correlated with lightning optical energy distribution statistics derived from U2 aircraft thunderstorm overflights. With this data and knowledge of the lower limits of detectability from the A. C. test, an initial estimate of LIS detection efficiency on-orbit can be obtained.

The calibration facility shall also conduct an end-to-end test of the optics, focal plane array, and the real time event processor of the LIS instrument using a Lightning SIMulator (LSIM) optical test set-up. The LSIM hardware is described in [11]. The simulator employs an acousto-optic modulator and a mirror scanner to externally modulate a laser light signal to generate simulated lightning transients. LSIM also employs a halogen lamp illuminated slide (of a satellite cloud field) to simulate a realistic background. In the LSIM test, LIS is illuminated by several thousand simulated lightning transient waveforms on top of various background brightness levels. The fraction of these events that are detected is logged, as well as the number of false event detections. The lightning simulator signal quality and stability is not as accurate as in the radiometric calibration tests.

3.3 Field Experiments and Studies

The launch of OTD in April 1995 has provided the LIS Science Team with the unique opportunity to develop, test, and refine the procedures, analysis tools and investigations needed for LIS validation. An important pre-launch field campaign, the Maritime Continent Thunderstorm Experiment (MCTEX), was conducted at the TRMM ground-truth site in Darwin Australia in late 1995. During MCTEX the LIS Science Team deployed a four station Advanced Lightning Direction Finder (ALDF) network to detect ground discharges. This network will remain operational through the TRMM program. Total lightning (both intracloud and cloud-to-ground discharges) was also acquired during MCTEX. Analysis of the MCTEX data in support of OTD validation is now underway. Data from a lightning mapping interferometer (SAFIR) deployed by Japanese scientist near Darwin during MCTEX (and at other sites preceding and continuing through the TRMM mission) will be provided to the LIS Science Team. Identical systems are also deployed in Europe.

We are also presently using regional lightning networks (e.g., NLDN, KSC LDAR) as well as numerous ancillary data sets to validate OTD. The same procedures and studies that are now being performed and perfected with OTD spacecraft will be applied to LIS after it is launched in 1997. Archived data bases from previous large field campaigns (e.g., CaPE, 1991 and TOGA COARE, 1993) are being applied to the investigation/development of scientific retrieval algorithms

3.4 Operational Surface Networks

There are a large number of surface lightning networks that will prove useful for LIS science data validation. These include regional lightning networks (e.g., NLDN), local lightning networks (e.g., Darwin ALDF, KSC LDAR, KSC Field Mill Network, LPATS, SAFIR), and long range TOA systems. Important ancillary data sets include composite radar data and associated products (e.g., radar derived precipitation estimates) We have initiated the process of locating and/or archiving the data sets needed to support the LIS validation.

3.5 Existing Satellite Data

We plan to take advantage of the space-based lightning observations that are being provided by the OTD. The LIS data processing algorithm described in the ATBD [10] is being tested/tuned by using it to process data from the OTD instrument. Since OTD detects lightning in the same way and produces a similar data stream as LIS we can verify the LIS data processing algorithm using data from the OTD. In turn, the OTD is undergoing post-launch calibration using ground truth data similar to that discussed earlier and in Section 4 below. The ground truth data and LIS data shall be collectively analyzed using version 4.0 (and subsequent upgraded versions) of the Ground Truth Analysis Software (GTAS) defined in Section 3.6.

We also plan intercomparisons of LIS with a wide range of satellite detection systems such as: FORTE, DMSP OLS, GRO/BATSE, ALEXIS/Blackbeard, and MSX (see acronym list in Section 1.5).

Just as in the case of the operational surface networks, satellite platforms extensive use will be made of ancillary data sets for LIS validation, calibration, and science investigations. This will include visible and infrared imagery and associated products (e.g., precipitation estimates, brightness temperatures, etc.) from geostationary (e.g., GOES, GMS) and low Earth orbit (e.g., DMSP SSM/I) satellites.

3.6 Ground-Truth Analysis Software

In order to study and compare LIS data with data taken from field experiments, operational surface networks, and OTD, a variety of display and analysis software is being developed. Any software used to explicitly compare independent lightning data with LIS data is collectively referred to as Ground Truth Analysis Software (GTAS). These data may or may not be correlated in time. Some GTAS includes statistical analyses that quantify the accuracy of LIS event location, event amplitude, background amplitude, event time-tag, detection efficiency, and false alarm rate. The development of this software began soon after the launch of OTD, and, because a large variety of ground-truth data are available, is being continuously upgraded.

4. GENERAL POST-LAUNCH ACTIVITIES

4.1 Planned Field Activities and Studies

The same approach with regards to field activities and studies describe in Section 3.3 for post-launch OTD validation will be adopted for LIS validation as well. Intensive ground truth field experiments and continuously collected ground-truth data sets (e.g., NLDN, KSC LDAR) shall be used to evaluate and optimize the LIS performance parameters. From these sources we shall produce data bases consisting of coincident observations from the LIS with detailed ground-based lightning observations at the TRMM ground truth sites in Florida and elsewhere, and augmented with radar/rain gauge networks, geostationary satellites, and other ground-based lightning detection systems. In addition, coincident ground truth measurements will be made using the high altitude ER-2 aircraft. During the ER-2 flights simultaneous lightning, infrared, passive microwave, radar observation will be obtained.

The ground truth lightning data that will be collected and analyzed includes, but is not limited to, long range sferics networks, lightning location networks (e.g., NLDN, LPATS systems, local ALDF networks), interferometers (e.g., SAFIR), radio frequency time-of-arrival systems (e.g., KSC LDAR), Schumann resonance detectors, electric field mill networks, optical and electric field sensors and satellite observations (e.g., OTD).

4.2 New EOS-Targeted Coordinated Field Campaigns

Plans for specific field experiments following the launch of TRMM (1998, 1999 time frame) have not yet been defined in detail but may include campaigns in the United States, Brazil, Australia, and Kwajalein in conjunction with TRMM validation activities. The LIS Science Team will participate in all EOS-targeted coordinated field campaigns.

4.3 Needs for Other Satellite Data

The utilization of other satellite data shall generally be consistent with the pre-launch plans discussed in section 3.5. In addition, from our experiences with OTD over the South Atlantic Southern Anomaly, we shall continue to collect any satellite or remote sensing data that characterizes the intensity of energetic particles (protons, electrons) at the LIS altitude of 350 kilometers. These high energy particles cause excessive false alarms for imaging sensor technologies and require post processing filters for removal.

4.4 In Situ Measurement Needs at Calibration/Validation Sites

Sections 3.3, 3.4, and 4.1 describe the in-situ measurement needs at the calibration/validation sites (note: site may include an aircraft platform such as the ER-2). The LIS in situ needs include instrumentation for detailed lightning characterizations to provide field calibration/validation of the LIS performance parameters and data processing algorithms. In situ instrumentation for meteorological or other (e.g., NO_X) characterizations will be needed for the science retrieval algorithm validations.

4.5 Needs for Instrument Development

After launch, it is anticipated that calibration/validation underflights of the TRMM satellite will be conducted with the NASA high altitude ER-2 aircraft with a sensor payload similar to that used during TOGA COARE [13]. The ER-2 payload will include the Lightning Instrument Package (LIP). The existing ER-2 LIP will be augmented to include optical pulse sensors, electric field change sensor, and a high speed spectrometer to provide detailed optical and electrical transient waveforms of lightning. The optical measurements will provide calibrated radiometric measurements of the radiant intensity for direct comparison with LIS (and with OTD if still operational). This new LIP instrumentation is presently being developed/assembled. Some LIP instrumentation was integrated and tested on the high altitude WB-57 (operated by NCAR) during the summer of 1996.

4.6 Geometric Registration Site

The TRMM ground truth site at KSC Florida is uniquely instrumented to provide excellent validation of LIS geolocation and timing accuracy. The LIS Science Team will utilize the satellite navigation derived from the other sensors flown on board TRMM. In addition the LIS instrument produces periodic background images that can supplement LIS navigation requirements. Clearly, intercomparisons with a number of ground-based and satellite observing systems (e.g., see Sections 3.4, 3.5, 4.7) will be used in validation of the LIS geometric registration.

4.7 Multi-Instrument Intercomparisons

A variety of instrumentation shall be used in the field to obtain useful ground-truth data for intercomparisons with LIS data. After launch several LIS performance parameters, the data processing algorithms, and scientific retrieval algorithms will be validated (see Section 2.1). Below we list specific validation/calibration activities and provide examples of instrument intercomparisons that will be conducted in support of these activities. Of course, all performance parameters of OTD and LIS will be compared provided the mission lifetimes intersect.

Detection Efficiency and False Alarm Rate

It is important that the LIS data is compared to all TOA (including LDAR) ground truth data to assess the true fraction of events detected (i.e., detection efficiency) and the number of false alarms encountered. With this knowledge, the 6-bit threshold levels can be properly set so as to maximize detectability while minimizing false alarms. A priority task following launch of LIS shall be to optimize the transient channel trigger threshold settings (one setting for each of the sixteen background levels).

Geolocation Accuracy

LIS geolocation of lightning events and background images involves many facets of the LIS program testing process. The orientation of the CCD with respect to the LIS alignment cube is determined from an Euler angle analyses of precise yaw and pitch maneuvers of the LIS sensor head assembly during radiometric calibration of LIS by ES-Lab. As part of this analysis, alignment cube theodolite measurements are necessary. The orientation of the cube to a spacecraft-based attitude reference frame is then determined. Only when these essential features are completed, along with real-time updates of spacecraft ephemeris and attitude data, can LIS geolocation accuracy be characterized.

One form of intercomparison involves using the LIS background image and basic knowledge of geography. Because the radiant properties from land and water differ, LIS pointing can be verified by coastline discrimination of background images. In addition, we will match LIS background cloud-field images to appropriate visible and near-infrared satellite images.

After launch, data from the NASA KSC LDAR system shall be a primary means for assessing event location errors. The 7-antenna LDAR time-of-arrival system maps lightning with high spatial resolution for sources within 100 km of the antenna network. This location accuracy is sufficient when compared to the storm-scale spatial resolution of LIS. Data from the National Lightning Detection Network (NLDN), long range sferics systems, time-of-arrival (TOA) systems, and other lightning detection systems (e.g., interferometers) and networks (e.g., local networks operated at TRMM ground truth sites) will also be used to verify LIS pointing accuracy.

Event Amplitude Accuracy

We shall compare LIS-derived event amplitudes with the existing lightning optical energy statistics derived from various NASA U2 aircraft flights above thunderstorms in the 1980's. This will help determine if values are within reasonable bounds. Time-synchronized overpasses between LIS and ER-2 aircraft equipped with calibrated optical pulse sensors shall also be used to explicitly validate the transient amplitude calibration of LIS.

Finally, general source amplitude characteristics shall also be validated using a wide range of satellite detection systems such as OTD, FORTE, and DMSP OLS.

Background Amplitude Accuracy

Quantitative measurements from a general class of near-infrared radiometers and spectrometers (aircraft and space-based sensors) shall be used to analyze calibrated 12-bit background images.

Timing Accuracy

Time correlation of lightning events with a number of independent ground-truth lightning measurement systems will be will be used to validate the LIS (2 ms resolution) absolute time-stamp of events (see Sections 3.3-3.5, 4.1). Since many of the ground-truth measurement systems detect only cloud-to-ground lightning or detect total lightning with uncertain and/or range dependent detection efficiency, statistical procedures will be employed to validate LIS timing. These procedures are being developed and tested with the OTD.

LIS Data Processing Algorithms

The validation of the LIS data processing algorithms is discussed here pursuant to the LIS ATBD [10, Section 3.3.5.1]. After launch, the processing algorithm shall be validated using data from LIS and coincident ground truth lightning observations of all types mentioned above. The post-launch validation process will determine how well the data algorithm processes the LIS data stream and how accurately the defined data structures correspond with the observed lightning. The processing algorithm will be adjusted or tuned to provide the best correspondence with verified ground observations. The capability for easily adjusting the higher order data structures has been designed into the code. If these adjustments still do not produce acceptable or improved results, the calibration parameters supplied to this algorithm shall be scrutinized.

Scientific Retrieval Algorithms

As specific scientific retrieval algorithms are developed and implemented procedures for validation will be initiated. As noted in the Introduction, LIS data will provide important research information for diverse fields in the geophysical sciences [1-3, 14]. There is already much research and collaboration underway to quantify relationships and test hypotheses that employ LIS data [14].

5. IMPLEMENTATION OF VALIDATION RESULTS IN DATA PRODUCTION

5.1 APPROACH

The validation data sets will be used as confirmation of the on-orbit performance of LIS and the algorithms. A large data base of coincident measurements with OTD overpasses can determine the detection probabilities (efficiency), geolocation accuracy, false alarm rate and flash/area determination (see Section 2.1 for additional details). Corrections and refinements to the algorithms will be tracked with reprocessing planned at six months intervals commensurate with TRMM plans.

5.2 ROLE OF EOSDIS

The role of EOSDIS is to ingest, process, archive and distribute the massive amounts of Earth science data that will be collected throughout the next decade. EOSDIS anticipates that over 300 terabytes of data will be archived during these years.

The initial paradigm was that data would be collected and archived at Distributed Active Archive Centers (DAACs). However, experience with the EOSDIS program has led to the proposal of a new direction for information management of the EOS data in the form of a more distributed federation of information service providers and their users.

As one of the first members of the EOSDIS Federation, the LIS SCF is a precursor to the Earth Science Information Partners (ESIP) concept, which calls for a strong working partnership between a data center and a science team in order to provide support to the research community for a specific set of products. With a goal of focusing data management around primary science research areas, the LIS Science Computing Facility (SCF) will augment its original roles of science research and algorithm production with the additional roles of such data center functions as producing, archiving and distributing data. This effort provides continued critical science data support within the Global Hydrology and Climate Center (GHCC) for lightning and ancillary data. This "enhanced" LIS SCF represents a new direction for EOSDIS, namely, with science data management and operations under the control of the instrument Principal Investigator.

An important aspect of data distribution is providing user accessibility to the data through electronic means. At this writing, EOSDIS data catalogs are all accessible through a common user interface called the EOSDIS Information Management System (IMS) Version 0 (V0). Additional versions of the IMS will be provided by the EOSDIS Core System (ECS). In addition, NASA has proposed implementation of "federations" of data providers who will work together to provide data and information services to their users.

The LIS SCF will provide users on-line data access through locally developed World Wide Web (WWW) data search and order applications and dataset-specific "home pages". It will build on Marshall Space Flight Center's (MSFC) EOSDIS Version 0 heritage by providing on-line access to its data through EOSDIS search and order systems as well. Data catalog interoperability with the ECS is also planned, although the LIS SCF will not have the full complement of ECS Version 1 hardware and software. The LIS SCF will have to address many on-line data access issues including bandwidth limitations, multimedia displays, definition and generation of both test data and other sample data, and interoperability with other systems. The experience gained as a partner in the EOS Baseline Federation will provide lessons learned for other SCFs and science data producers as the EOSDIS Federation grows.

5.3 Plans for Archival of Validation Data

The LIS SCF will archive data retrieved from the Lightning Imaging Sensor, various lightning on-orbit calibration and validation data sets, and ancillary data. Table 2 lists the planned calibration and validation data set holdings of the LIS SCF. This list should not be considered exhaustive, and is likely to be expanded. The most current information about these data sets can be accessed via the home page: http://wwwdaac.msfc.nasa.gov . Additional data sets may be obtained on an as needed basis through collaboration with other scientists.

Product	Source	Period of Record	Annual Vol
Lightning Data			
OTD Raw Data	LIS Science Team	4/95 - present	63.0 GB
OTD Lightning Products	LIS Science Team	4/95 - present	42.0 GB
OLS Analog Derived Lightning	NGDC / LIS Science Team	6/73 - 12/91 (intermittent)	0.01 GB
OLS Digital Derived Lightning	NGDC / LIS Science Team	1993, '94, '96	
Lightning Ground Strike data *(restricted)*	GAI NLDN	1/94 - present	14.6 GB
US Composite Lightning Products from NLDN *(rstr)*	LIS Science Team	1/94 - present	15.0 GB
West Atlantic Lightning *(restricted)*	GAI	8/96 - present	15.0 GB
LIS Ground Truth	LIS Science Team	11/95 - present	0.4 GB
LDAR	KSC / Lincoln Labs	Intermittent	0.4 GB
Field Mill	KSC	Intermittent	25.0 GB
Radar Data			
US Composite Rainfall Products from NWS Radars	WSI / LIS Science Team	1/94 - present	14.6 GB
Melbourne US Nexrad site	NWS / Lincoln Labs	4/95 - present	13.0 GB
Ancillary Satellite Data			
Global IR composite	NSSFC	7/95 - present	52.5 GB
GOES Visible/IR	NSSFC	Intermittent	1.0 GB
SSM/I Brightness Temperature Products	MSFC	10/95 - present	58.4 GB

Table 2. LIS SCF Calibration and Validation Data Holdings

6. SUMMARY

All laboratory calibration activities are detailed in [11, 12]. Key ES-lab milestones/tasks from this schedule (rundate March 24, 1995) include: (1) pre-environmental calibration effort: 3/9/96 - 3/15/96, (2) thermal/vacuum test calibration support: 3/30/96 - 4/15/96, and (3) post environmental calibration effort: 4/23/96 - 5/4/96.

It is expected that, by the time LIS is in orbit, most critical GTAS shall be operational as shown in the summary schedule in Table 3 below. Planned implementation of long term calibration/validation, i.e., from the time of launch until the end of the functional lifetime of LIS, will primarily involve application of the GTAS.

As the GTAS becomes mature, the GTAS summary products shall be upgraded at quarterly intervals. In addition, any useful GTAS summary data obtained shall be archived during the lifetime of LIS. When the specific and most optimum nature of the GTAS is determined during GTAS development more specific long range plans shall be formulated.

	1995				1996				1997 and beyond			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4 and beyond
OTD and LIS milestones		OTD launch			GTAS study of OTD data	GTAS study of OTD data	GTAS study of OTD data		GTAS study of OTD data		GTAS study of OTD data	LIS launch
GTAS develop-ment		v0.0 begin dev.			v0.0 done -TOA	v1.0 done -TOA -MDF	v2.0 done -TOA -MDF -charge		v3.0 done -TOA -MDF -charge -OPS		v4.0 done -TOA -MDF -charge -OPS -other	finalize GTAS

Table 3. Schedule of GTAS pre-launch activities.