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Aerosol and cloud sensing with the Lidar In-space Technology Experiment (LITE)

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ABSTRACT

The Lidar In-space Technology Experiment (LITE) is a multi-wavelength backscatter lidar developed by NASA Langley Research Center to fly on the Space Shuttle. The LITE instrument is built around a three-wavelength Nd:YAG laser and a 1-meter diameter telescope. The laser operates at 10 Hz and produces about 500 mJ per pulse at 1064 nm and 532 nm, and 150 mJ per pulse at 355 nm. The objective of the LITE program is to develop the engineering processes required for space lidar and to demonstrate applications of space-based lidar to remote sensing of the atmosphere.

The LITE instrument was designed to study a wide range of cloud and aerosol phenomena. To this end, a comprehensive program of scientific investigations has been planned for the upcoming mission. Simulations of on-orbit performance show the instrument has sufficient sensitivity to detect even thin cirrus on a single-shot basis. Signal averaging provides the capability of measuring the height and structure of the planetary boundary layer, aerosols in the free troposphere, the stratospheric aerosol layer, and density profiles to an altitude of 40 km. The instrument has successfully completed a ground-test phase and is scheduled to fly on the Space Shuttle Discovery for a 9-day mission in September 1994.

1. THE LITE INSTRUMENT

The LITE instrument is shown in its flight configuration in Figure 1. The instrument consists of seven major components: the laser transmitter module, telescope/receiver assembly, a boresight assembly containing a gimballed prism for aligning the laser beam to the receiver telescope, control and data handling electronics, a film camera, the OASIS-1 data acquisition system for characterization of the launch and landing loads experienced by the instrument, and an orthogrid structure. The orthogrid is a stable platform attached to a standard 3-meter Spacelab pallet with a system of tuned struts. The pallet provides avionics, cooling, and electrical power necessary to operate the instrument. The instrument is operated while in the cargo bay of the Space Shuttle with the Shuttle oriented with the cargo bay pointing to nadir.

The laser transmitter module contains two identical Nd:YAG lasers mounted on opposite sides of a vertical optical bench inside a pressurized canister. The canister maintains the lasers at standard atmospheric pressure and uses an active cooling system to remove the waste heat and maintain a uniform thermal environment. Two lasers are provided for redundancy; only one laser is operated at a time. The output of the lasers is doubled and tripled to provide roughly 500 mJ at 1064 nm and at 532 nm and about 150 mJ at 355 nm. Figure 2 shows a functional diagram of the instrument. The instrument employs a Cassegrain telescope with a 1-meter clear aperture, using a beryllium primary for light weight. Dichroic filters are used to separate the three wavelengths. Ruggedized photomultiplier tubes (PMT's) are used for 355 nm and 532 nm detection, and a silicon avalanche photodiode is used at 1064 nm. The signals are digitized with 10 MHz, 12-bit analog-to-digital converters. During daytime, the signal processing chain performs an automatic subtraction of the mean background illumination signal on each channel. A small amount of the backscattered 532 nm optical signal is focused onto an intensified quadrant detector as an alignment aid. The quadrant detector generates error signals which can be used by the gimballed prism assembly to align the laser to the receiver telescope. The prism assembly can steer the beam over a range of $\pm 1°$ in each axis. Instrument operations are controlled by a central processor, called the instrument controller, which communicates with several distributed processors. Finally, a camera loaded with a 400-foot roll of 35-mm film has been placed on the orthogrid to allow documentation of atmospheric conditions. The camera is mounted inside a pressurized canister and is automatically

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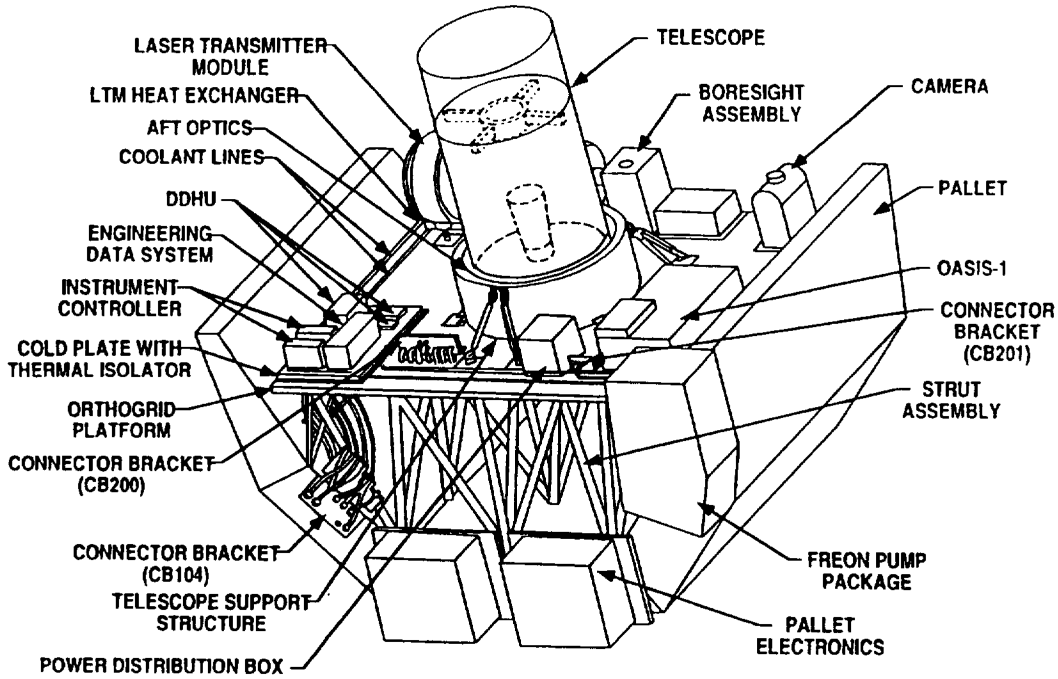

Figure 1. LITE instrument in flight configuration, mounted on the 3-meter Spacelab pallet.

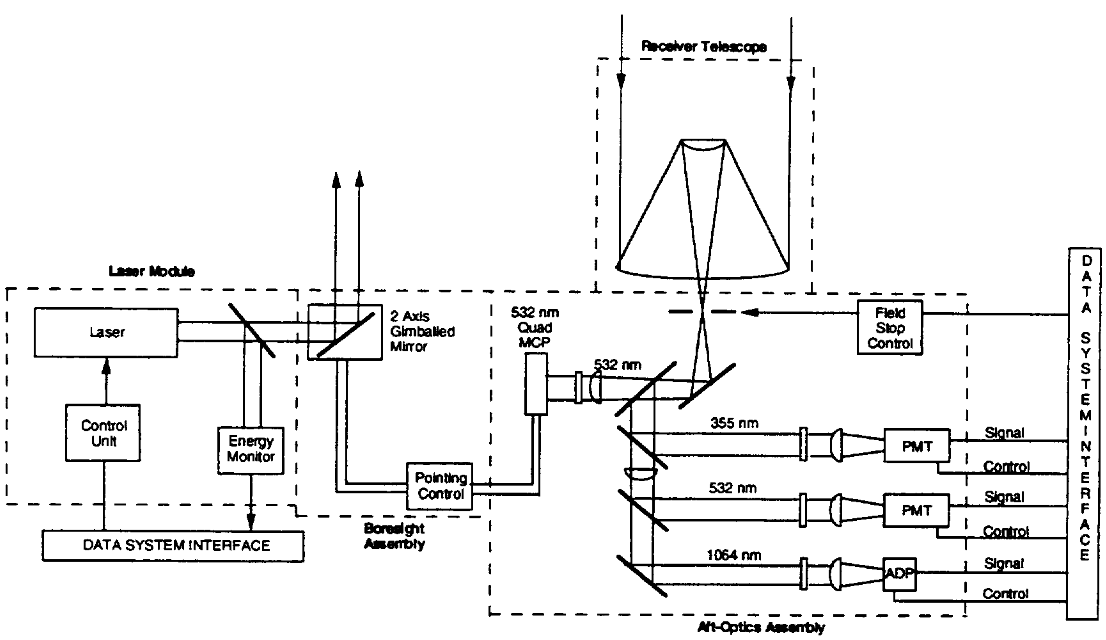

Figure 2. LITE system functional diagram.

sequenced to take a picture once every 21 seconds, providing continuous coverage of the orbiter ground track during daylight portions of the orbit.

The components and subassemblies used in the instrument were put through extensive characterization and space qualification testing. The completed instrument was put through a comprehensive series of ground-based outdoor tests over a period of 9 months, operating in a zenith-pointing mode. Comparison with other lidars operated during the tests for validation purposes showed excellent performance. The LITE instrument is described in more detail in Couch et al.[1].

2. EXPERIMENT OBJECTIVES

The impact of clouds and aerosols on global climate is now a very active area of research. LITE will be the first lidar designed for atmospheric studies to fly in Earth orbit and will give the first highly detailed global view of the two-dimensional vertical structure of clouds and aerosols. LITE will be used to study the atmosphere from the Earth's surface to the middle stratosphere. Additionally, a limited data set will be collected on the magnitude of the return from land and ocean surfaces. The primary geophysical parameters to be measured by LITE are listed in Table 1. The 9-day LITE mission offers the chance to explore the applications of space lidar and to gain operational experience which will benefit the development of future systems on free-flying orbital platforms.

Troposphere	**Clouds**
aerosol scattering ratio	vertical distribution
and wavelength dependence	fractional cloud cover
PBL height and structure	albedo
PBL optical depth	optical depth
Stratosphere	**Surface**
aerosol scattering ratio	surface albedo
and wavelength dependence	multi-angle backscatter
density and temperature to 40 km	(±30° from nadir)

Table 1. Primary parameters to be measured by LITE.

Simulation studies have been conducted to estimate the magnitude of the signal return and the signal-to-noise ratio for the purpose of planning the experiment. A representative simulation of mean signal from a cloud-free atmosphere is shown in Figure 3. The atmospheric model used here includes a stratospheric aerosol layer centered at about 20 km, a Saharan dust layer at the top of the mixed layer at about 4 km, and a marine boundary layer which is 600 m deep. The inset shows the range of returns which can be expected from various land and ocean surfaces. From an altitude of 40 km to the surface return pulse, the signal covers a dynamic range of 5 to 6 orders of magnitude. Peak signal returns from clouds will vary by more than 2 orders of magnitude. The instantaneous linear dynamic range of the system is much less than this. The system was designed to cover a dynamic range of 6 orders of magnitude by varying the PMT gain and by adding attenuation between the PMT anode and the analog-to-digital converter input. Observing time during the mission has been split between aerosols, clouds, and surface, which will generally require separate gain and attenuation settings. The instrument has the flexibility to configure the three channels independently. For example, the instrument could be set up so that stratus cloud returns could be measured at 532 nm, while the 355 nm channel is used for stratospheric aerosol studies.

A science steering group (Table 2) was formed in 1989 to utilize the scientific data provided by the instrument. The team has also participated in formulating the mission objectives and experiment plan for the instrument. The group has identified three major goals for the experiment:

1) overflight of correlative measurement sites to validate the instrument

2) global surveys of stratospheric aerosol, clouds, and the planetary boundary layer height and structure

3) regional studies of clouds and aerosols in areas of particular interest

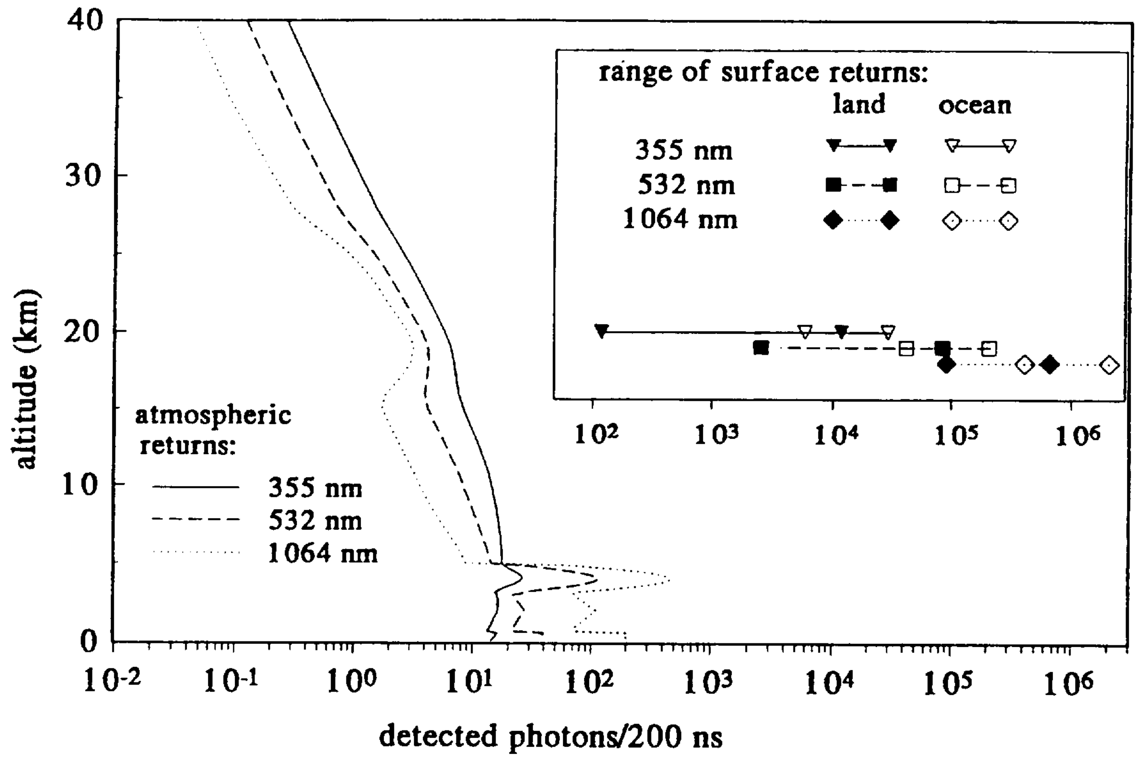

Figure 3. Simulation showing the magnitude of the LITE atmospheric return signal, and the range of returns expected from land and ocean surfaces in terms of the number of photons detected per system time constant. The atmospheric model used includes a Saharan dust layer centered at 4 km altitude, and a stratospheric aerosol layer reflecting the current aerosol loading resulting from the Mt. Pinatubo eruption in June 1991.

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Dr. Martin Platt	CSIRO (Australia)
Dr. Dave Randall	Colorado State Univ.
Dr. John Reagan	Univ. of Arizona

Table 2. LITE Science Steering Group Membership.

Clouds have been extensively studied using passive satellite instruments[2,3], but current instruments are limited in their ability to sense tenuous clouds and multi-layer cloud systems[4,5]. LITE will unambiguously sense even subvisible cirrus and will provide a global look at the prevalence and heights of very thin cloud. Cirrus clouds can generally be penetrated by lidar so that the vertical structure of the cloud can be observed. Additionally, the tops of possible underlying dense water clouds can be measured. By providing accurate statistics on cloud heights, LITE can provide guidance in the development of realistic retrieval models on which to base the analysis of routine satellite observations.

Phenomena of particular interest include the organization of cloud in the western Pacific warm pool, frontal clouds, and marine stratus decks off the coasts of California and Peru.

The impact of tropospheric aerosols on the global radiative budget is not well understood due to our lack of knowledge on the global distribution and characteristics of natural and anthropogenic aerosols[6]. The sources and sinks of tropospheric aerosols and the long-range transport of aerosols in the free troposphere are also poorly understood. Existing satellite technology lacks the vertical resolution necessary to properly study these issues. Phenomena of particular interest for the LITE mission are the transport of desert dust from the Sahara, the generation and transport aerosols of anthropogenic origin such as from biomass burning in South America and Africa, and urban pollution from the industrialized regions of the northern hemisphere.

The planetary boundary layer (PBL) contains most of the aerosol and water vapor in the atmosphere and thus has a major influence on radiative fluxes. The PBL also acts as the interface where the coupling between the atmosphere and the Earth's surface occurs and controls the transfer of moisture and momentum between them. Studies of climate sensitivity, therefore, require careful consideration of the role of the PBL. By measuring the aerosol gradient typically found at the top of the PBL, LITE will provide the first global measurements of PBL height. This will aid in developing GCM parameterizations of the PBL and improve our abilities to model the coupling between the atmosphere and the Earth's surface.

The dispersion of volcanic aerosols in the stratosphere and their effects on the global radiation budget have been studied using both solar occultation[7] and nadir-viewing[8] satellite instruments, and also by airborne lidars[9]. Spaceborne lidar can provide better spatial sampling than occultation instruments, better vertical resolution and better sensitivity than a nadir-viewing instrument, and can provide global coverage which is not possible from an aircraft platform. LITE should provide a more detailed look at dynamic mixing and transport processes than is currently possible, and give a better indication of the degree of spatial homogeneity of the aerosol.

More details on the investigations planned are given in McCormick et al.[10].

3. MISSION OPERATIONS

LITE will fly on the Space Shuttle Discovery on the STS-64 mission, currently scheduled for launch on 9 September 1994. The planned orbit is circular with a 57° inclination and an initial orbital altitude of 260 km. The altitude will be decreased to 240 km for the last few days of the mission to optimize landing opportunities. The mission will last 9 days with LITE operating a total of 45 hours during that time. Figure 4 shows the mission timeline for STS-64. The instrument is activated soon after the payload bay doors are opened, about 2 hours after the insertion into orbit is complete. After a warmup period of several hours, the instrument is operated on the night portion of two orbits to check the instrument performance. Routine operations commence toward the end of the first flight day. LITE operations are concentrated in 10 "datatakes" of 4.5 to 5 hours (shown as wide areas with fine hatching), and several "snapshots" lasting 15 to 30 minutes (narrow bars with fine hatching). Activities of some of the other payloads are denoted by coarse hatching. An additional LITE datatake will be performed on orbits 123-125 if excess power is available near the end of the mission. This set of datatakes and snapshots corresponds to the groundtracks shown in Figure 5. Each datatake covers roughly three orbits and was located in the timeline to accomodate a mix of correlative measurement activities and studies of regional phenomena.

Two surface sites in the southwest US, at Edwards Air Force Base (EAFB), California, and White Sands, New Mexico (WSNM), have been characterized and will be used to explore atmospheric retrieval algorithms utilizing surface returns from a surface of known albedo[11]. A certain amount of additional surface data will be taken during the mission to allow quantitative measurements of the strength and variation of the surface return signal over land and ocean. Surface return data will be taken over the ocean and over a variety of land surface types. Over certain ocean sites the Shuttle will be rolled ±30° about nadir, using the Shuttle "landmark track" (LMT) mode, to study the variation in surface backscatter with angle of incidence. This will help provide basic design inputs for future spaceborne lidars, such as wind sensors, which will be operated in an off-nadir orientation. It will also allow investigation of the possibility of using multi-angle sea surface returns from space lidars to monitor sea surface wind speeds[12].

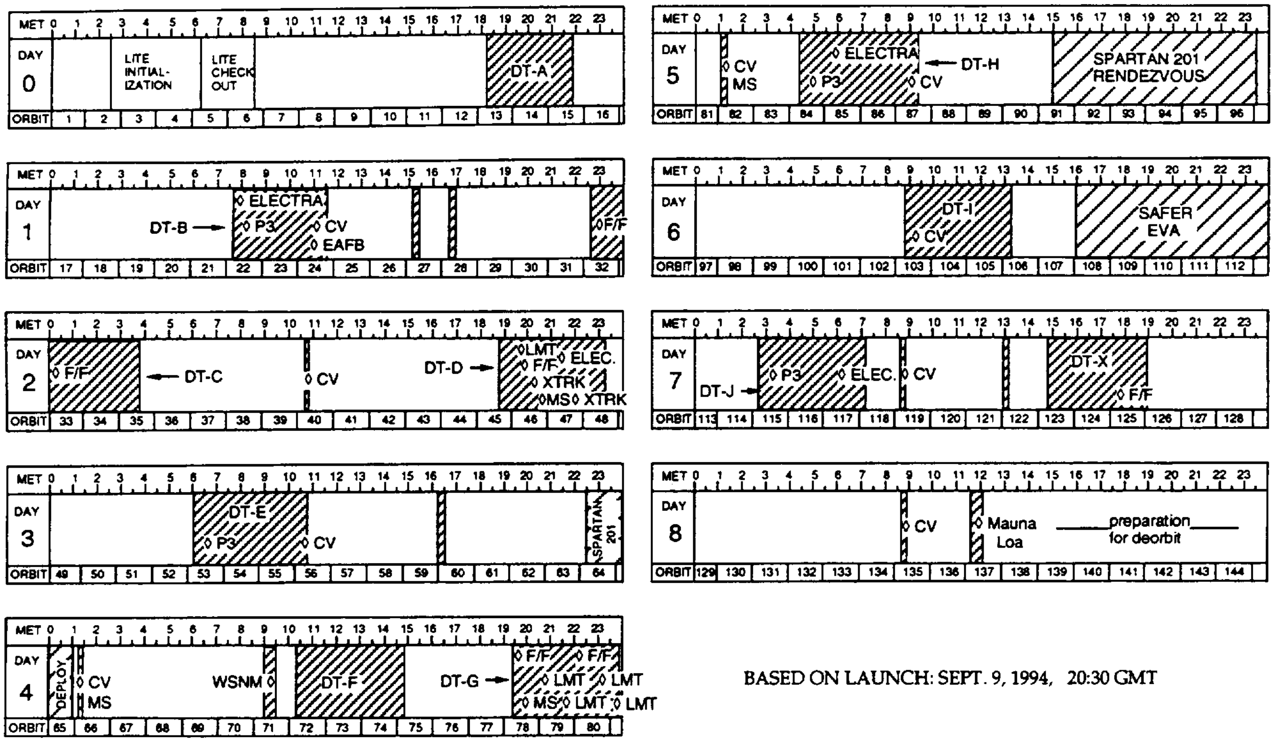

Figure 4. STS-64 mission timeline.

During the mission, the LITE instrument controller is controlled by commands uplinked from Mission Control in Houston. Over 200 commands are available to configure, control, and monitor the status of the instrument. The instrument will accept commands to be executed when received, or the commands can be time-tagged to execute at some future time. In the case of the loss of the telemetry command link, the crew of the Shuttle has a limited capability to command the instrument from the Shuttle. A variable aperture stop and movable interference filters are used to optimize the signal-to-noise ratio during day and night portions of the orbits. PMT voltages, amplifier gains, and DC offsets may also be varied to optimize acquisition of the lidar return signals. The instrument has a limited capability to autonomously reconfigure itself from night to day or day to night configurations, as required, as the terminator is crossed.

Figure 6 illustrates the routing of LITE data. The full data stream from the instrument is recorded on the High Data Rate Recorder (HDRR) located on the Shuttle aft flight deck. It is also downlinked over the Shuttle Ku-band telemetry system at a rate of about 2 Mbits/sec. This high-rate data stream includes the digitized lidar profiles at their original resolution. It also includes an averaged version of the 355 nm and 532 nm lidar returns obtained by truncating the lowest three bits of each 12-bit sample and summing 100 successive pulses. This operation is handled by special digital hardware. Finally, the Ku-band telemetry stream contains the Instrument Status Data Block (ISDB) which contains nearly 1000 engineering parameters concerning the configuration, health, and thermal/mechanical environment of the instrument. The ISDB also includes ephemeris and timing information and background illumination values. This data stream is relayed to Mission Control in Houston and the high-rate lidar profiles are displayed on the ground in real time. The data stream is also archived on the ground for later playback and analysis.

As a backup, the Shuttle S-band telemetry system is used to downlink just the ISDB and averaged versions of the 355 nm and 532 nm lidar profiles. These data are displayed in real time to the LITE engineering team to monitor the instrument health and status. The S-band system is also used to uplink commands to the instrument.

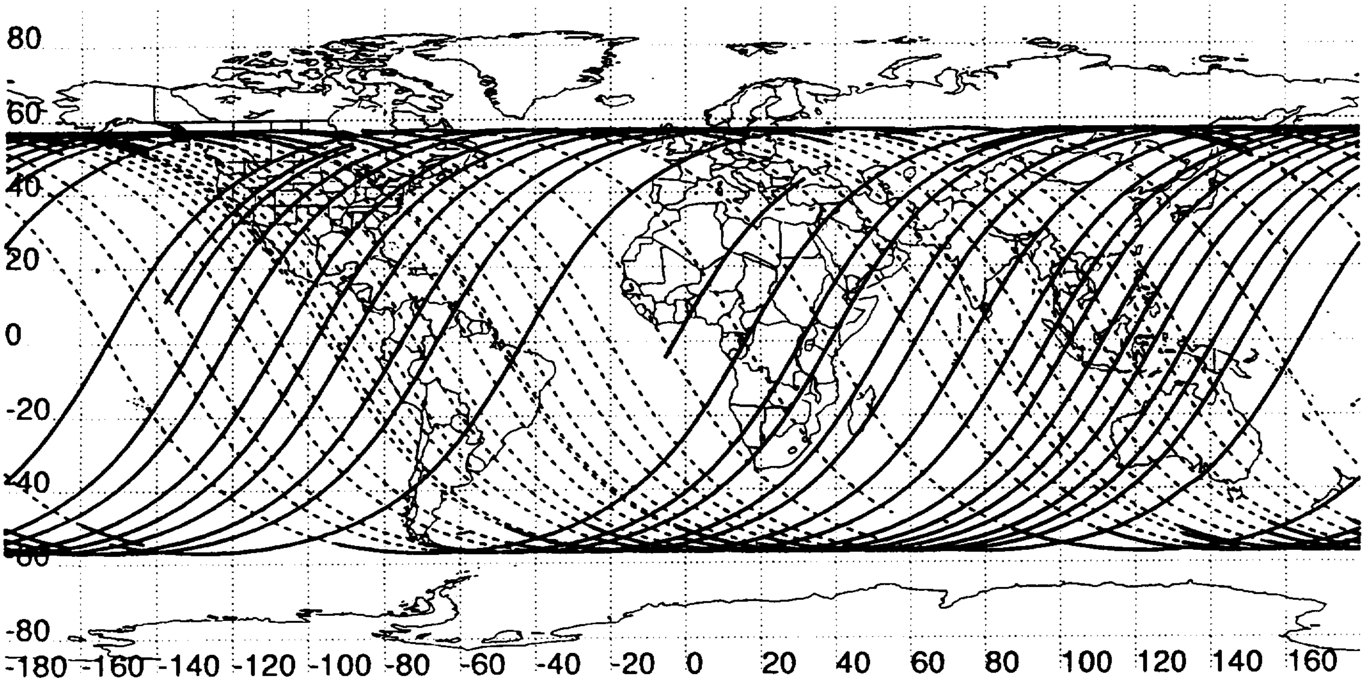

Figure 5. Shuttle ground tracks during LITE datatakes. Solid lines indicate orbit segments in daylight; dashed lines, nighttime. Lighting based on September 9, 2030 GMT launch. Location of terminator refers to Shuttle lighting.

The data recorded on the HDRR tapes represent the primary LITE dataset. After the mission, the HDRR tapes will be removed from the Shuttle, copied to optical disks, and archived at Langley Research Center. Initial data analysis and validation will be conducted by members of the LITE Science Steering Group.

4. CORRELATIVE MEASUREMENTS PROGRAM

It is necessary to verify the accuracy of the measurements made by LITE and to make quantitative performance assessments. The Science Steering Group has designed and is leading a comprehensive, worldwide correlative measurements program to assist in measurement validation. This effort employs airborne and space-based sensors, and an extensive world-wide network of ground-based lidars and other instruments. Airborne instruments are especially important in this effort due to their ability to fly directly under the Shuttle and to make observations in remote areas. The timeline in Figure 4 shows underflights (indicated by diamonds) by NASA P3 and Electra aircraft, and a Convair 580 (CV) aircraft operated by the Canadian Atmospheric Environment Service. These aircraft carry upward- and downward-looking lidars, visible and infrared radiometers, and in situ sensors which will be used to validate LITE measurements of clouds and aerosols. The P3 and Electra each carry lidars capable of both tropospheric and stratospheric aerosol measurements. The two NASA aircraft will underfly LITE orbits over the Atlantic and eastern Carribean, extending as far south as Cape Town, South Africa. The Convair 580 will be based in southern California. The Convair will focus on marine stratus and the marine boundary layer off the coast, and on the various urban and natural aerosols originating in the Los Angeles basin and nearby desert regions. Recently, additional aircraft and instruments operated by DLR and CNRS have become involved in the correlative effort. Operational areas will be northern Europe, the North Sea, and the Baltic.

LITE was sponsored by NASA Headquarters through the Offices of Advanced Concepts and Technology (Code C), Life and Microgravity Sciences and Applications (Code U), and Mission to Planet Earth (Code Y). The NASA Langley Research Center was responsible for developing the flight hardware, conducting the flight experiment, and managing and analyzing the flight data. The laser transmitter module was developed under contract by the Titan

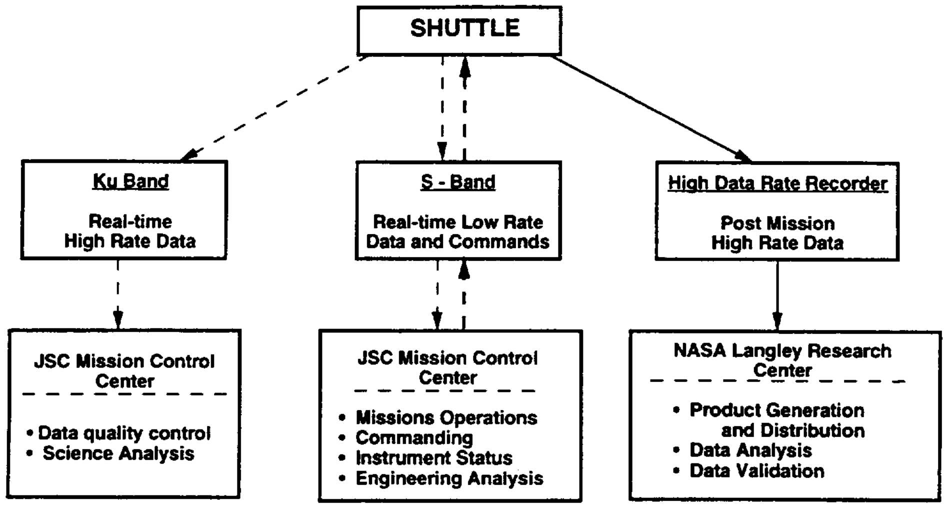

Figure 6. LITE data flow during mission.

Spectron Development Labs, Costa Mesa, California.

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