LITE: The First Atmospheric Lidar Measurements from Space

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ABSTRACT

The Lidar In-space Technology Experiment (LITE) is a three-wavelength backscatter lidar developed by NASA Langley Research Center to fly on the Space Shuttle. LITE flew on Discovery in September 1994 as part of the STS-64 mission. The LITE mission presented an opportunity to qualify lidar technologies for use in space and to gain operational experience which will benefit the development of future systems on free-flying satellite platforms. The performance of the LITE instrument was excellent, resulting in the collection of over 40 Gbytes of data along 1.4 million kilometers of groundtrack. These data present us with our first highly detailed global view of the vertical structure of cloud and aerosol from the Earth's surface through the middle stratosphere. These preliminary results highlight the benefits to be obtained from long duration satellite lidars.

INTRODUCTION

Studies were performed by NASA Langley Research Center in the 1970's and early 1980's showing the benefits to atmospheric studies of operational orbital lidar systems. Toward this end, the Lidar In-space Technology Experiment was initiated in 1985 to demonstrate operation of a lidar in space and the maturity of lidar technology. It was decided the most convincing demonstration was within the context of actual atmospheric investigations and a detailed scientific experiment plan was developed[1].

LITE was flown on the Space Shuttle Discovery as part of the STS-64 mission between September 9 and September 20, 1994. LITE was used to observe clouds, aerosols in the stratosphere and troposphere, and atmospheric temperature and density in the stratosphere between 25 km and 40 km altitude. Additionally, limited measurements of the surface return strength over both land and ocean were collected to explore retrievals of surface properties. Most surface return data were collected at near-nadir angles, but several sets of roll maneuvers were performed by Discovery to measure the angular dependence of the sea surface return.

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.

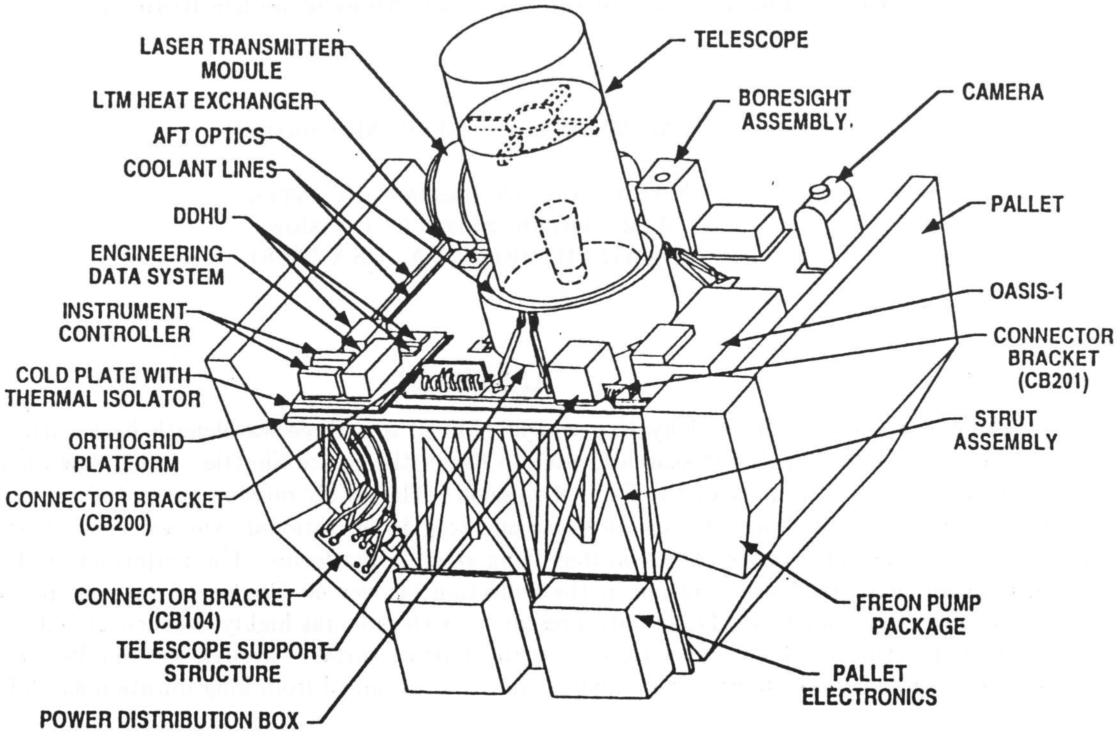

Figure 1. LITE instrument in flight configuration on the Spacelab pallet.

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. 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 which communicates with several distributed processors. A camera equipped with 35-mm film was placed on the orthogrid to allow documentation of atmospheric conditions. The camera is mounted inside a pressurized canister and is automatically sequenced to provide 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. The LITE instrument is described in more detail in Couch et al.[2] and Winker et al.[3].

MISSION OPERATIONS

LITE was launched into a circular orbit with an initial altitude of 260 km. The altitude was decreased to 240 km for the last few days of the mission to optimize landing opportunities. A 57°

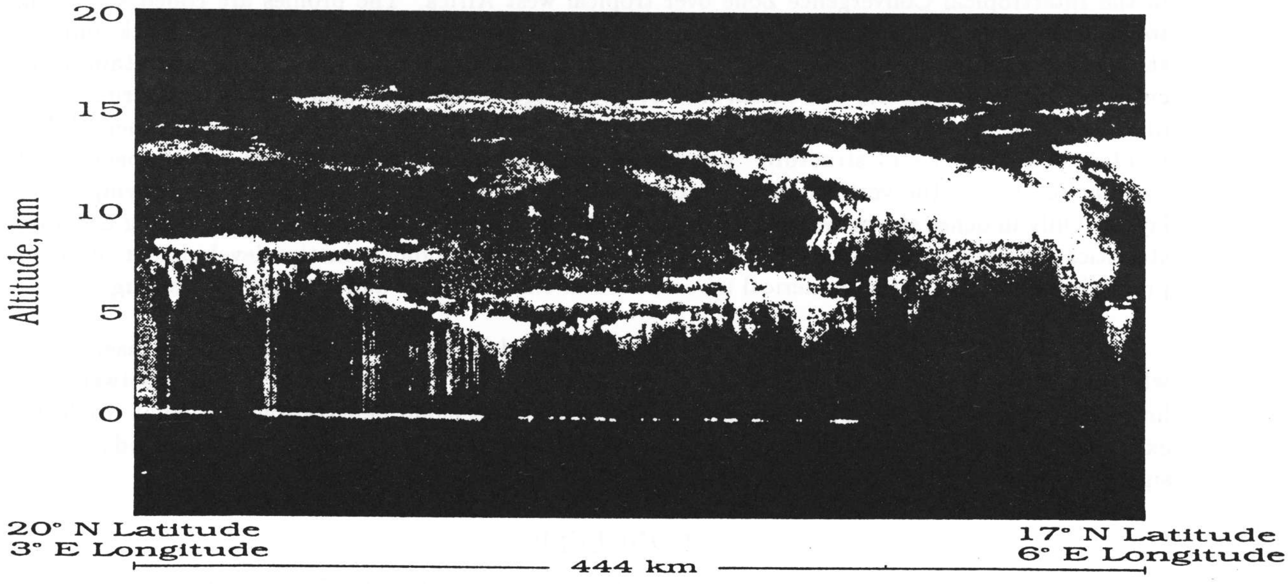

Figure 2. LITE return signal at 532 nm over West Africa showing multilayered cloud structure associated with a tropical storm system.

inclination was chosen to maximize global coverage. A late afternoon launch placed the terminator crossings near the northern and southern turning points, maximizing the latitudinal coverage in darkness. The instrument was operated about 5° off-nadir to avoid the possibility of occasional large return signals due to specular reflections from the surface.

During the mission, the LITE instrument was controlled by commands uplinked from Mission Control in Houston. The instrument will accept commands to be executed when received, or the commands can be time-tagged to execute at some future time. The instrument has the capability to autonomously reconfigure itself between day and night configurations as the terminator is crossed. The full data stream from the instrument was recorded on the High Data Rate Recorder (HDRR) located on the Shuttle aft flight deck. It was also downlinked over the Shuttle Ku-band telemetry system. The data stream was relayed to Mission Control in Houston and the lidar profiles were displayed on the ground in real time. The data stream was also archived on the ground for later playback and analysis. As a backup, the Shuttle S-band telemetry system was used to downlink the ISDB and averaged versions of the 355 nm and 532 nm lidar profiles. The S-band system was also used to uplink commands to the instrument.

The LITE instrument performed extremely well during the mission. The instrument was powered continuously for over 220 hours, with 53 hours of lasing. The instrument throughput and noise performance were very close to what had been predicted from pre-launch characterizations. The only significant anomaly experienced by the LITE hardware during the mission was a faster than expected degradation in LTM output energy. Although the laser output energy did not decrease enough to seriously impact the quality of the science data, the observed behavior was a cause of concern. Indications are that the observed loss in output was primarily due to contamination of the optical surfaces within the laser, even though great care was taken in regard to contamination during fabrication. This experience points to the critical importance of materials selection and contamination control in the design and fabrication of lasers for space applications.

RESULTS

Figure 2 is a gray-scale image of LITE raw data from the 532 nm channel showing cloud formations in the Intertropical Convergence Zone over tropical west Africa. The profiles are coded according to digitizer count and plotted vs. distance and altitude. The weakest signals are in black and the strongest, including signals which saturate the digitizer, are in white. Many of the uncertainties in current climate models are due to our lack of knowledge of the horizontal and vertical structure of multilevel cloud systems such as this. Current passive satellite instruments are limited in their ability to observe vertical cloud structure. Figure 6 shows that multiple cloud layers can be penetrated by lidar to observe the vertical structure of the clouds and detect the presence of underlying cloud layers. Only in dense storm systems is the signal attenuated within the cloud. By providing accurate statistics on cloud height and structure, LITE can provide guidance in the development of cloud prediction schemes for the numerical models used in climate study and weather forecasting.

Penetration of cirrus clouds by space lidar is enhanced by multiple scattering of the laser pulse, which for cirrus clouds is primarily small angle forward scatter[4], due to the large range between the lidar and the atmosphere. This multiple scattering enhances cloud penetration over what would be expected for a typical ground-based system. Multiple scattering in boundary layer clouds is also significant, and can result in significant stretching of the return pulse[5].

CONCLUSION

The LITE data are being processed and archived at NASA Langley Research Center, with the goal of producing data products which can be made available to the general atmospheric science research community. Concurrent meteorological data such as geosynchronous satellite imagery and global gridded analysis products are also being collected to facilitate scientific investigations using LITE data.

The success of the LITE mission demonstrates the potential for long-term orbital lidars on free-flying platforms. Recent development of high power diode-pumped lasers greatly reduces laser power requirements, permitting lidars on small spacecraft. Studies are now underway to design compact, lightweight space lidars utilizing advanced technologies which can be used as part of operational weather observation systems.

REFERENCES

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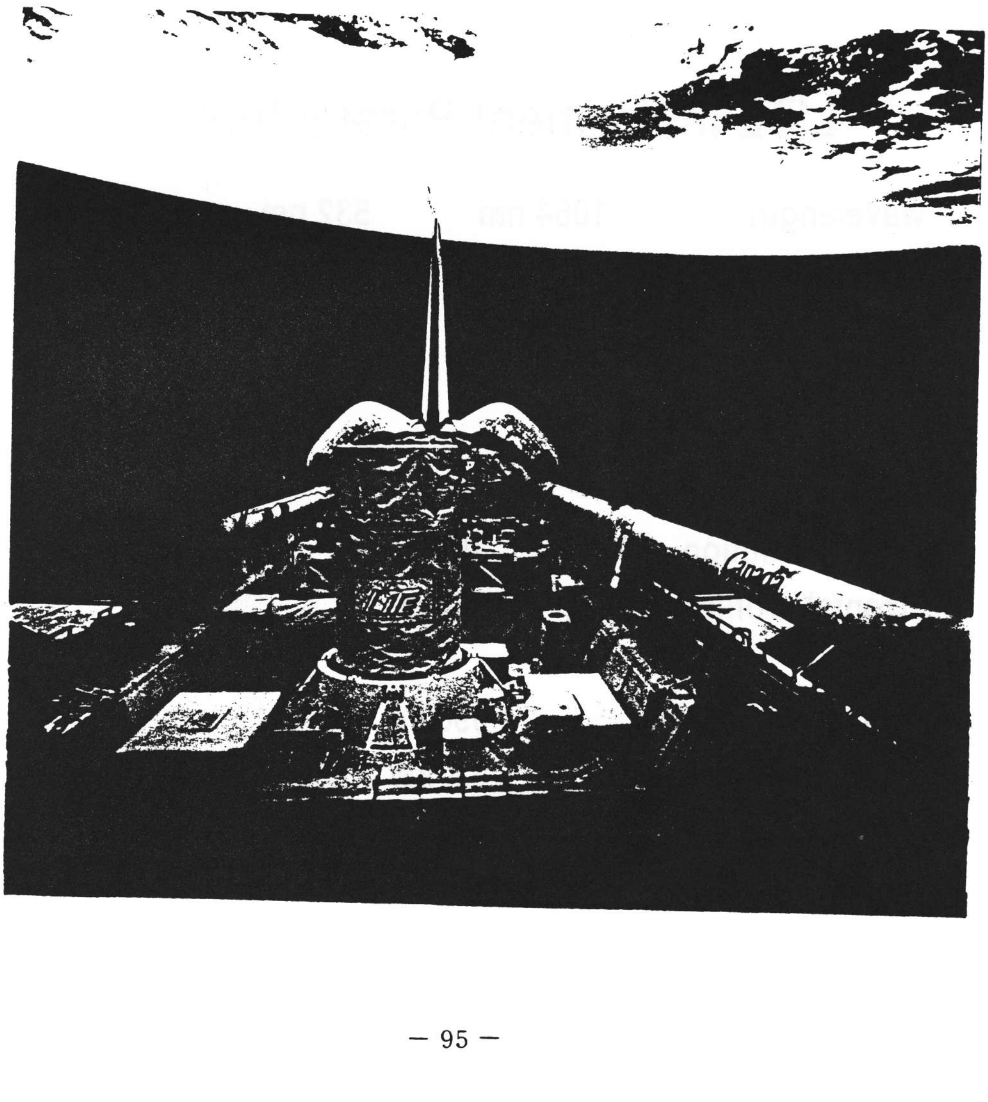
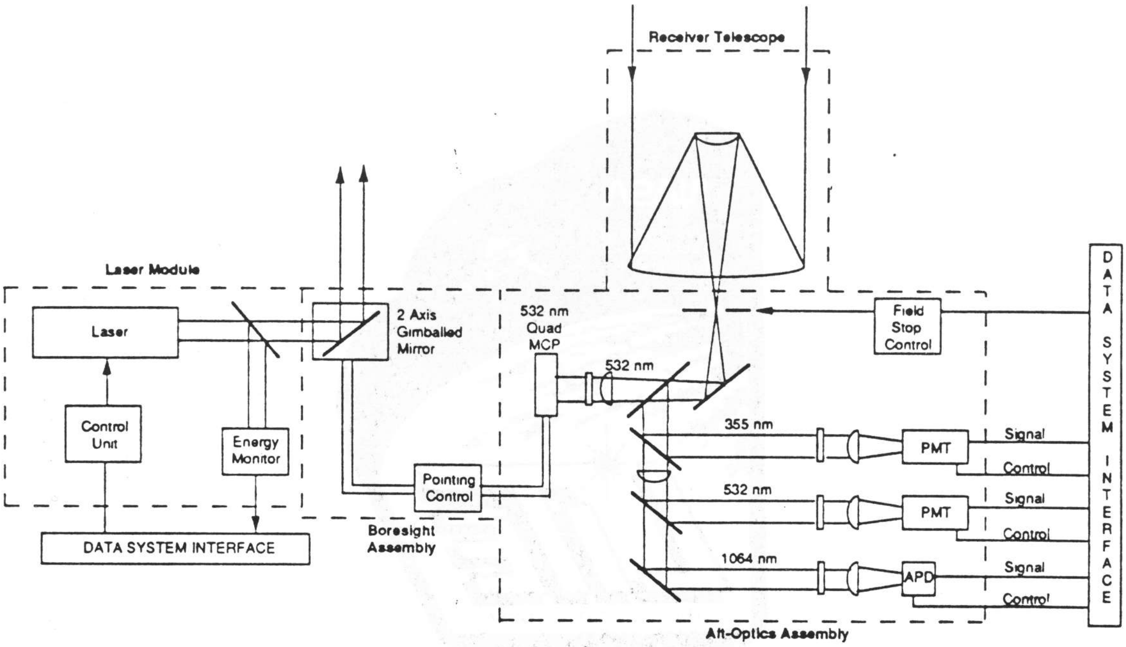
5. Winker, D. M., and L. R. Poole, 1995: "Monte Carlo calculations of cloud returns for ground-based and space-based lidars," *Appl. Phys. B* **60**, 341-344.


NASA
Lidar In Space
Technology
Experiment
LITE
LaRC - OAST - OSSA





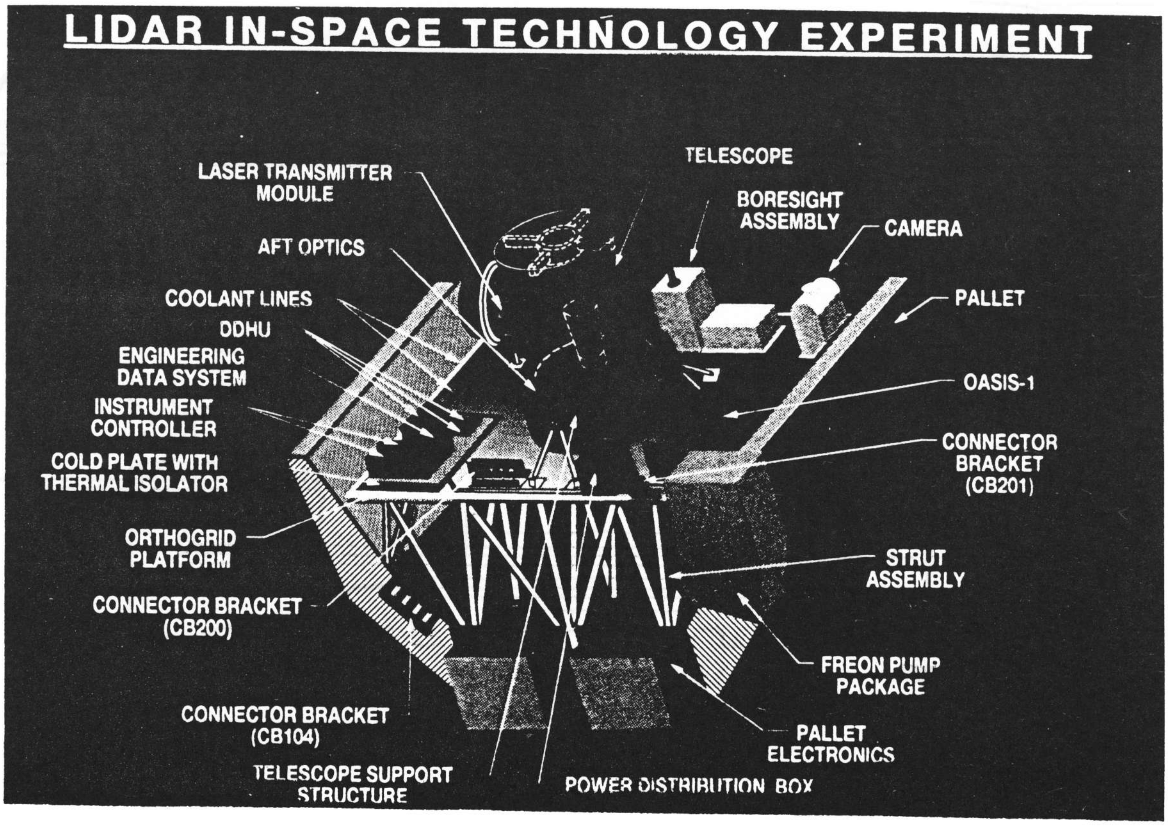
LITE System Functional Diagram

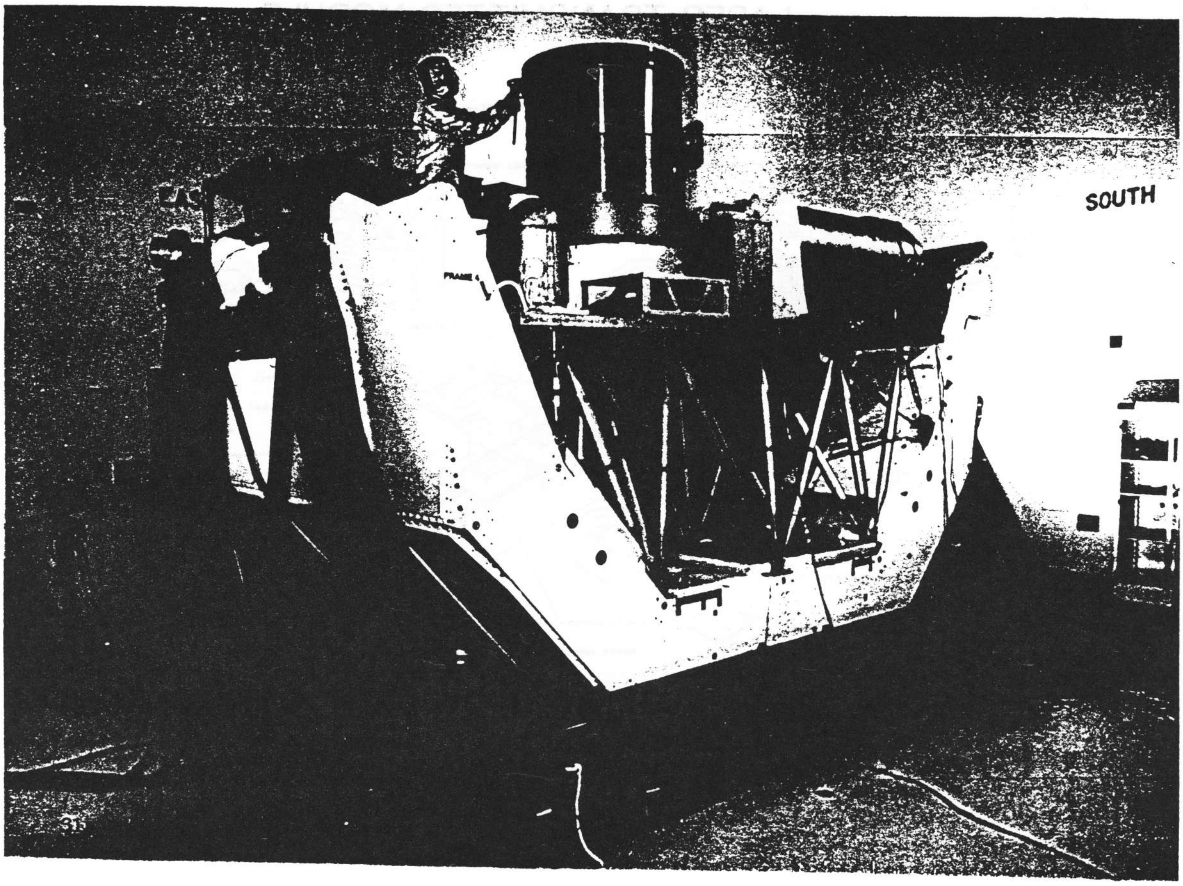
LITE Instrument Parameters

wavelength	1064 nm	532 nm	355 nm
pulse energy	440 mJ	560 mJ	160 mJ
laser footprint	365 m	245 m	190 m
pulse rate	10 Hz		

telescope diameter	98 cm
vertical resolution	35 m
horizontal profile spacing	750 m

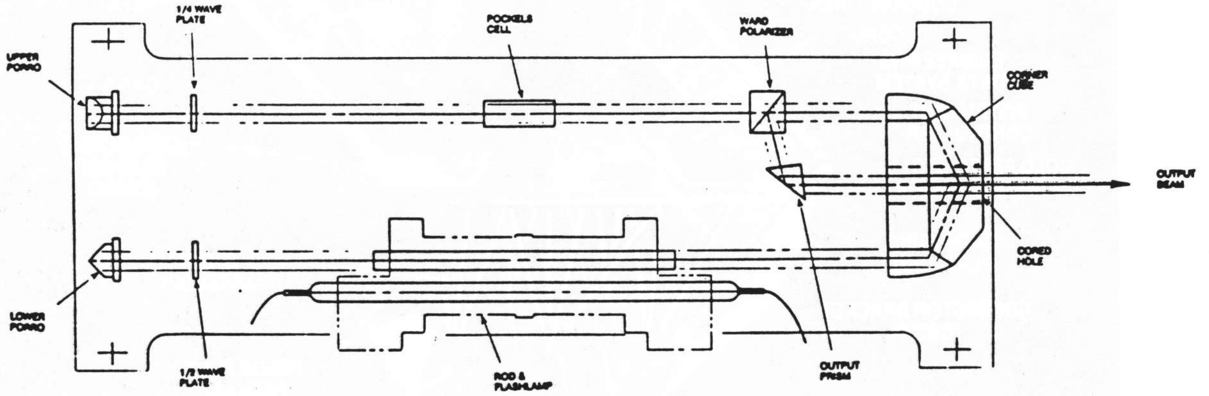
instrument mass	990 kg
instrument power	2.5 kW + 500 W


LIDAR IN-SPACE TECHNOLOGY EXPERIMENT
LASER TRANSMITTER MODULE
TELESCOPE
BORESIGHT ASSEMBLY
CAMERA
AFT OPTICS
COOLANT LINES
PALLET
DDHU
ENGINEERING DATA SYSTEM
OASIS-1
INSTRUMENT CONTROLLER
CONNECTOR BRACKET (CB201)
COLD PLATE WITH THERMAL ISOLATOR
ORTHOGRID PLATFORM
STRUT ASSEMBLY
CONNECTOR BRACKET (CB200)
FREON PUMP PACKAGE
CONNECTOR BRACKET (CB104)
PALLET ELECTRONICS
TELESCOPE SUPPORT STRUCTURE
POWER DISTRIBUTION BOX


SOUTH

OSCILLATOR

SPECTRON
A TITAN Company



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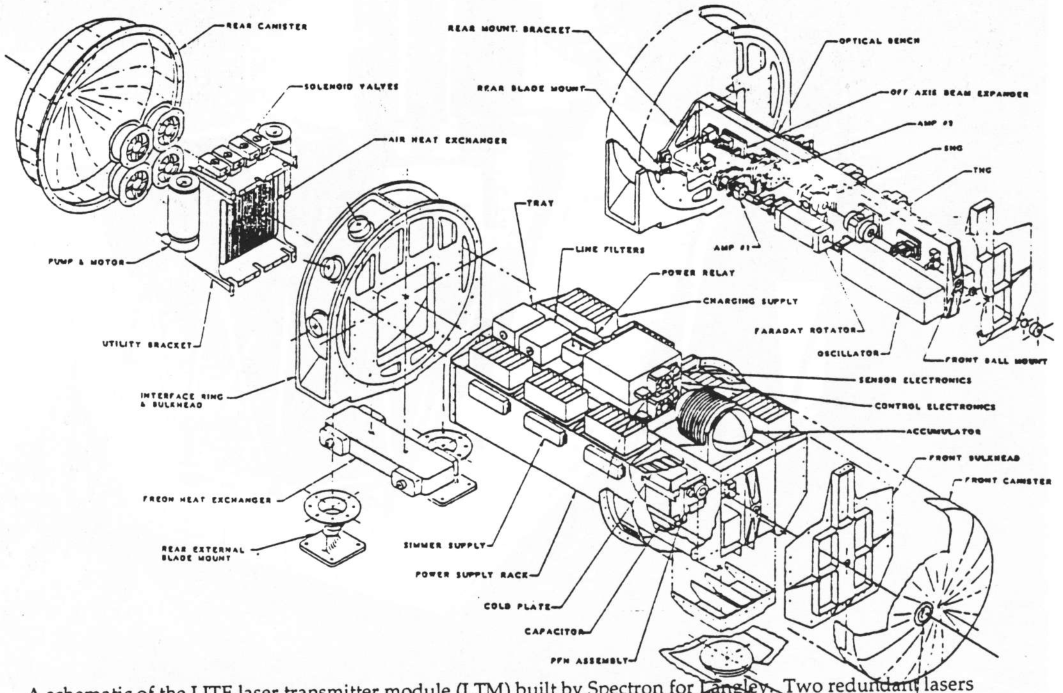
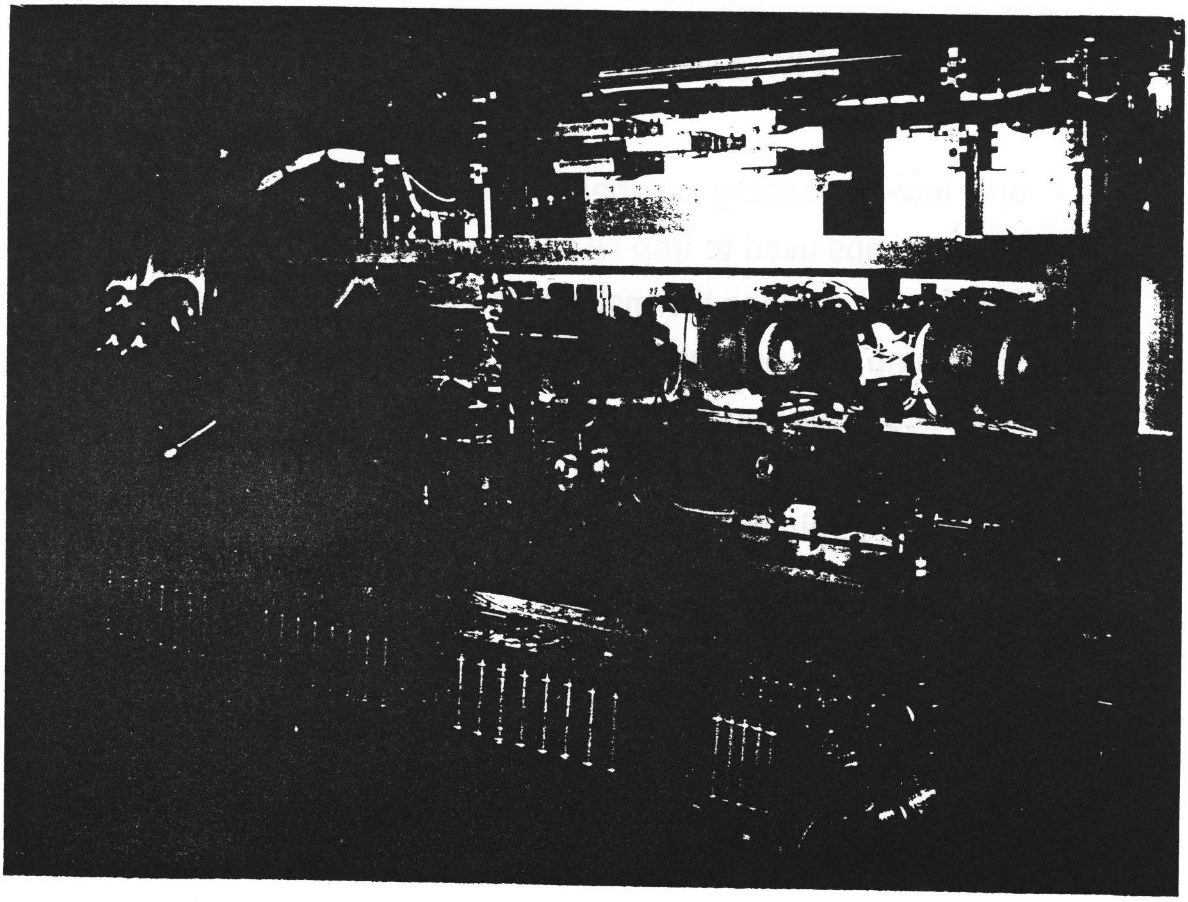
LASER TRANSMITTER MODULE



14. A schematic of the LITE laser transmitter module (LTM) built by Spectron for Langley. Two redundant lasers (optics, and some electro-optics) are mounted on the sides of a vertically-mounted optical bench. The lasers incorporate an oscillator, two amplifier stages, and second and third harmonic generators. Electronics, heat exchangers, stirring fans, and the cover are shown. The system connects to the Shuttle freon cooling system and is contained in a positive pressure nitrogen atmosphere within the canister.



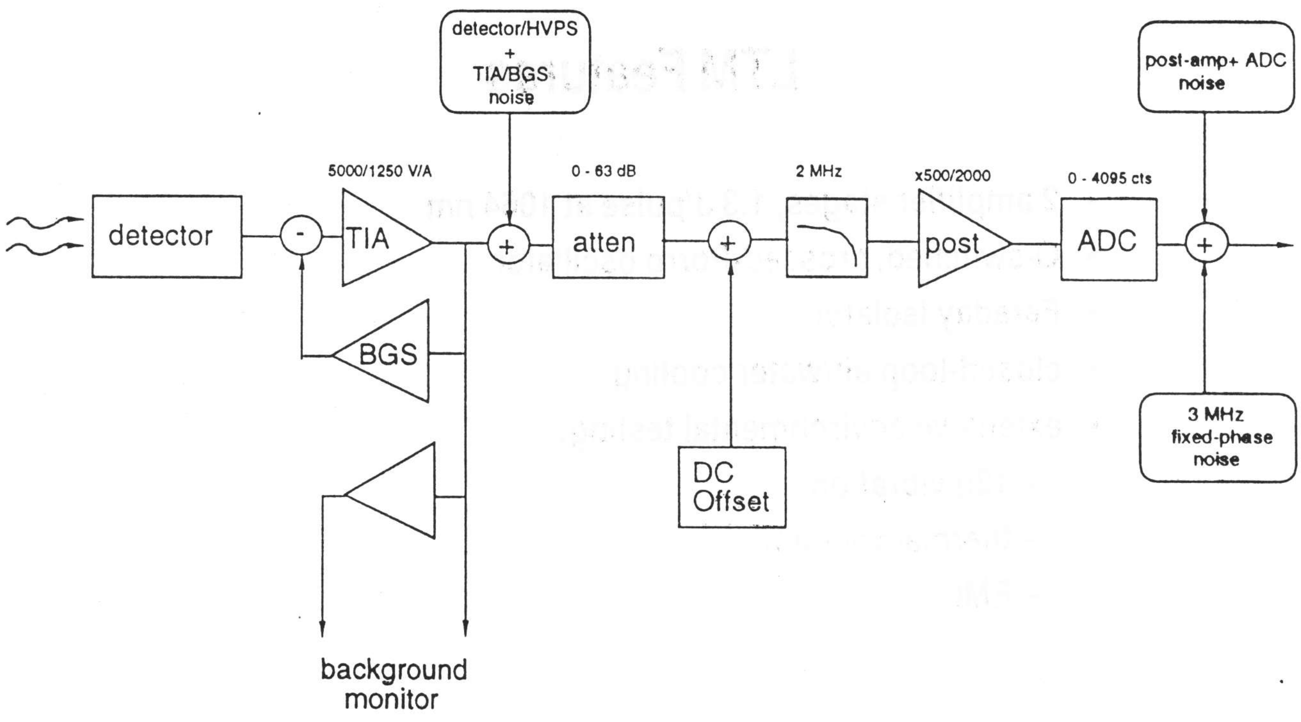
LTM Features

- 2 amplifier stages, 1.3 J/pulse at 1064 nm
- Q-switched, crossed-Porro oscillator
- Faraday isolator
- closed-loop air/water cooling
- extensive environmental testing:
  - 12g vibration
  - thermal/vacuum
  - EMI

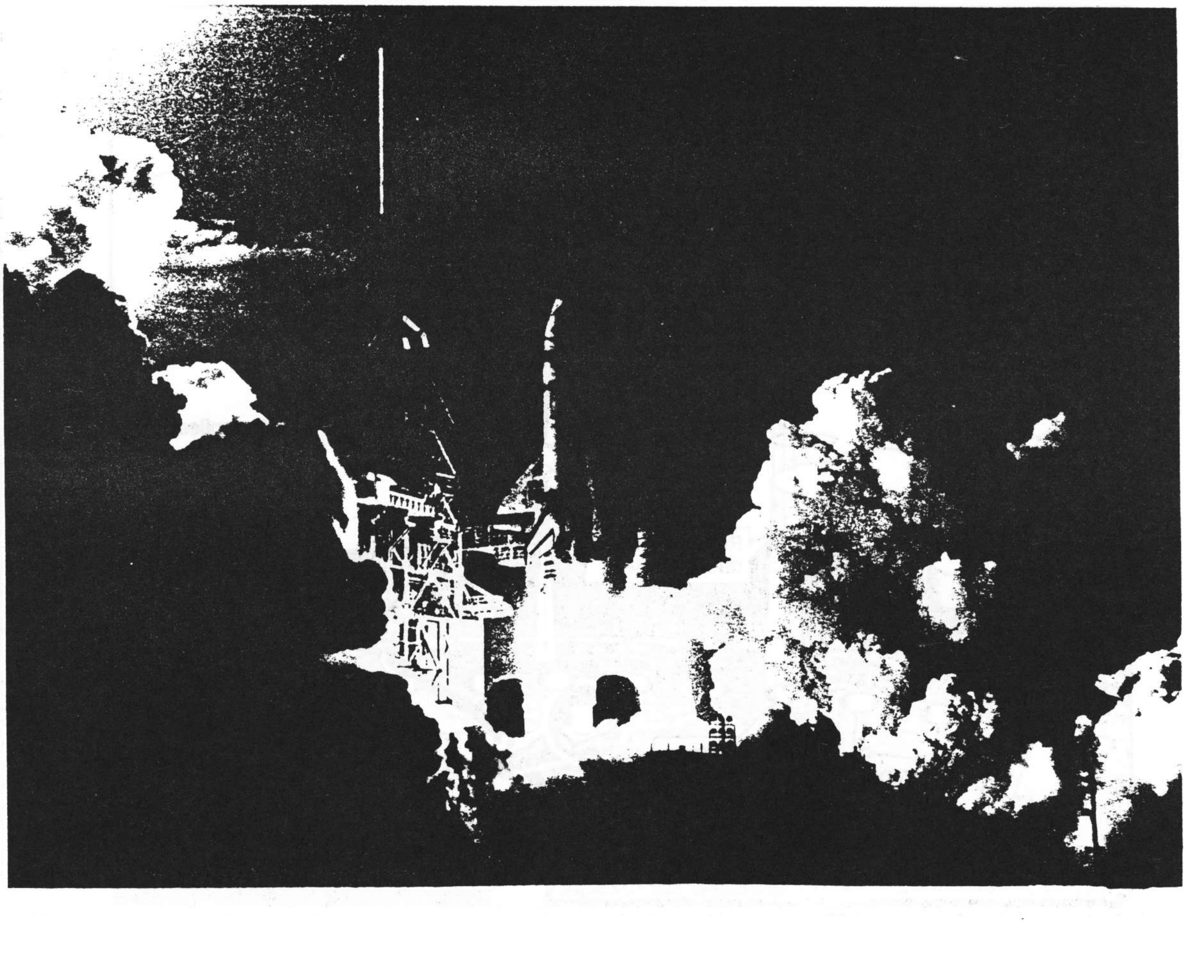
LTM Space-hardening

- only low-outgassing materials used
- beam dumps used to trap all back-reflections
- flashlamp housings thermally isolated from optical bench
- slow ramp turn-on feature to avoid optical transients
- all optics glued and clamped
- optical mounts are custom w/ extra locking and clamping
- all fasteners pinned and epoxied

Model of LITE Signal Processing Electronics

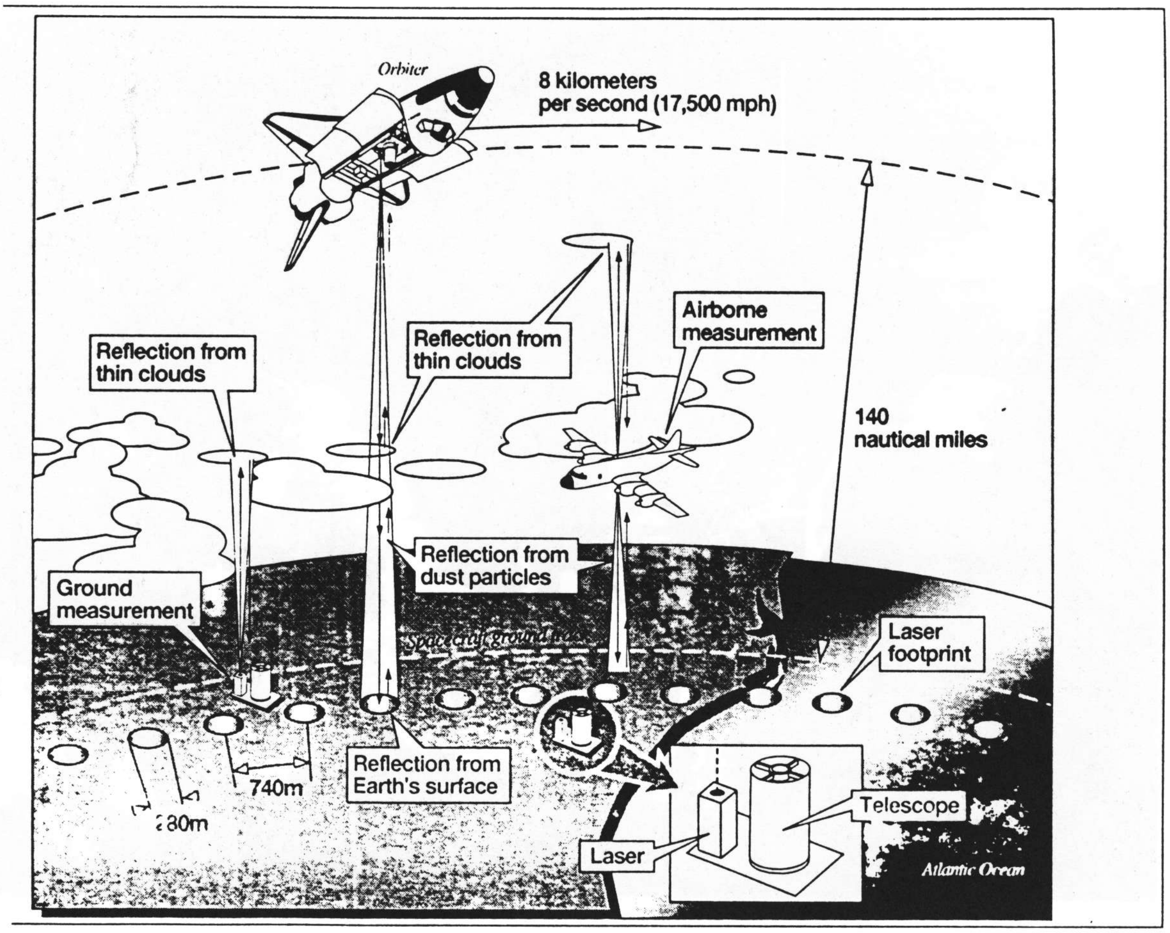



LITE
LANGLEY RESEARCH CENTER

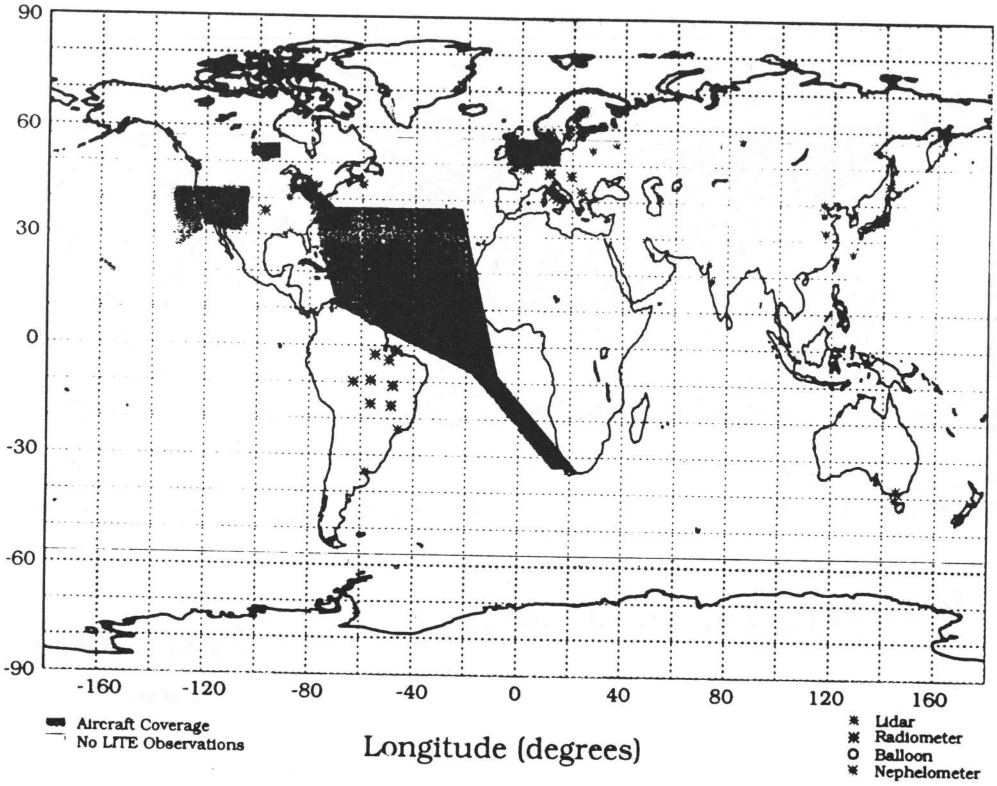


LITE Mission Parameters

Dates	9 - 20 September, 1994
mission	STS-64, Discovery
launch	22:22 GMT (6:22 PM, EDT)
inclination	57°
altitude	260 km (140 n. miles)
attitude	5° off-nadir
lasing	53 hours
groundtrack observed	1.4 million km

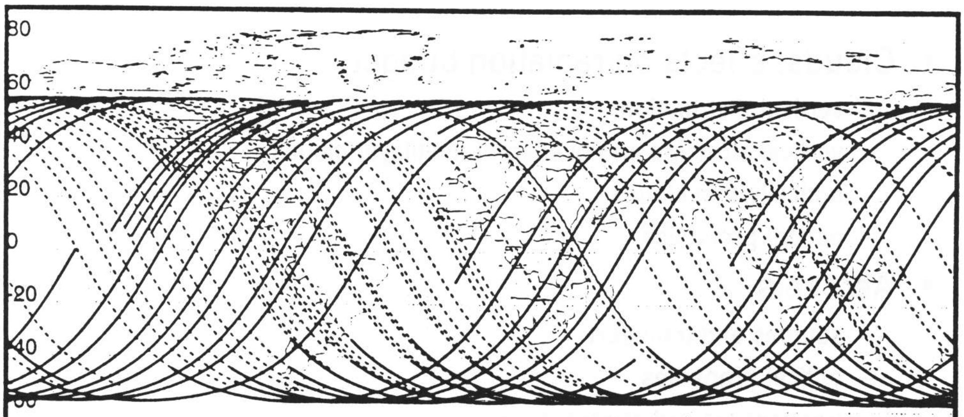


LITE Correlative Measurements Sites



NASA — LiTE

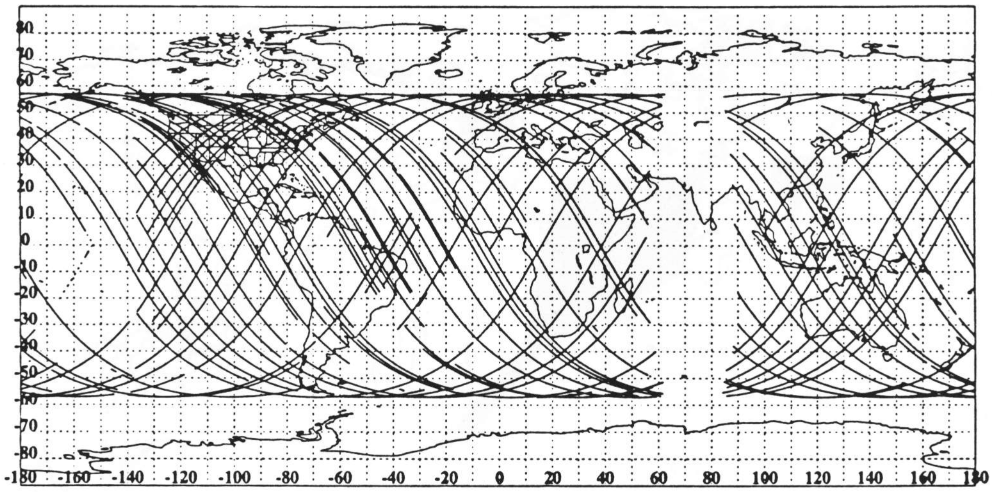
Combined Data Takes and Snapshots



STS–64 Launch: 9 September 1994 22:22:54.95 GMT

LaRC

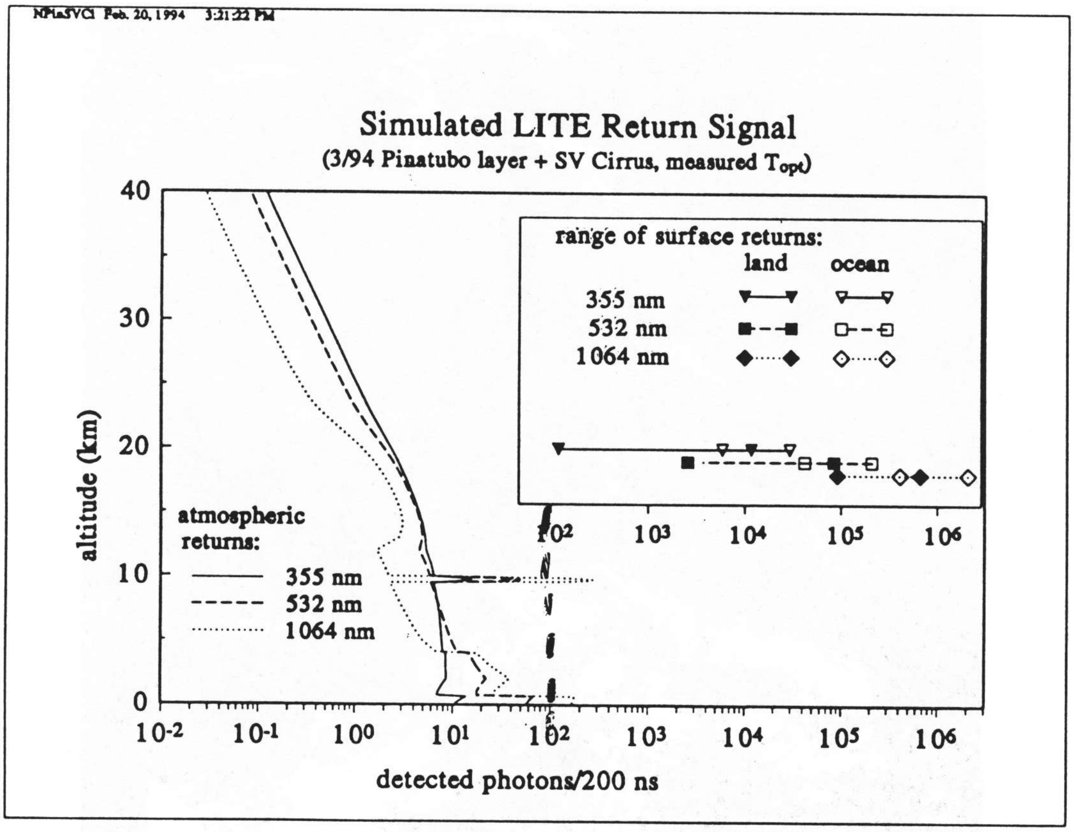
LITE Ku AOS coverage



Winker, Couch & McCormick – Proc. IEEE,

Primary Science Objectives

- Clouds: effects on radiation budget
  - vertical distribution
  - vertical structure and overlap of multilayer clouds
  - optically thin clouds
  - optical properties
- Aerosols
  - sources and transport
  - optical properties
  - troposphere and stratosphere
- Planetary Boundary Layer: height and structure
  - study the role of PBL in the transfer of heat, moisture, and momentum between ocean and atmosphere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Simulated LITE Return Signal
(3/94 Pinatubo layer + SV Cirrus, measured T_{opt})
range of surface returns:
land
ocean
355 nm
532 nm
1064 nm
atmospheric returns:
355 nm
532 nm
1064 nm
altitude (km)
detected photons/200 ns
0
10
20
30
40
10^{-2}
10^{-1}
10^{0}
10^{1}
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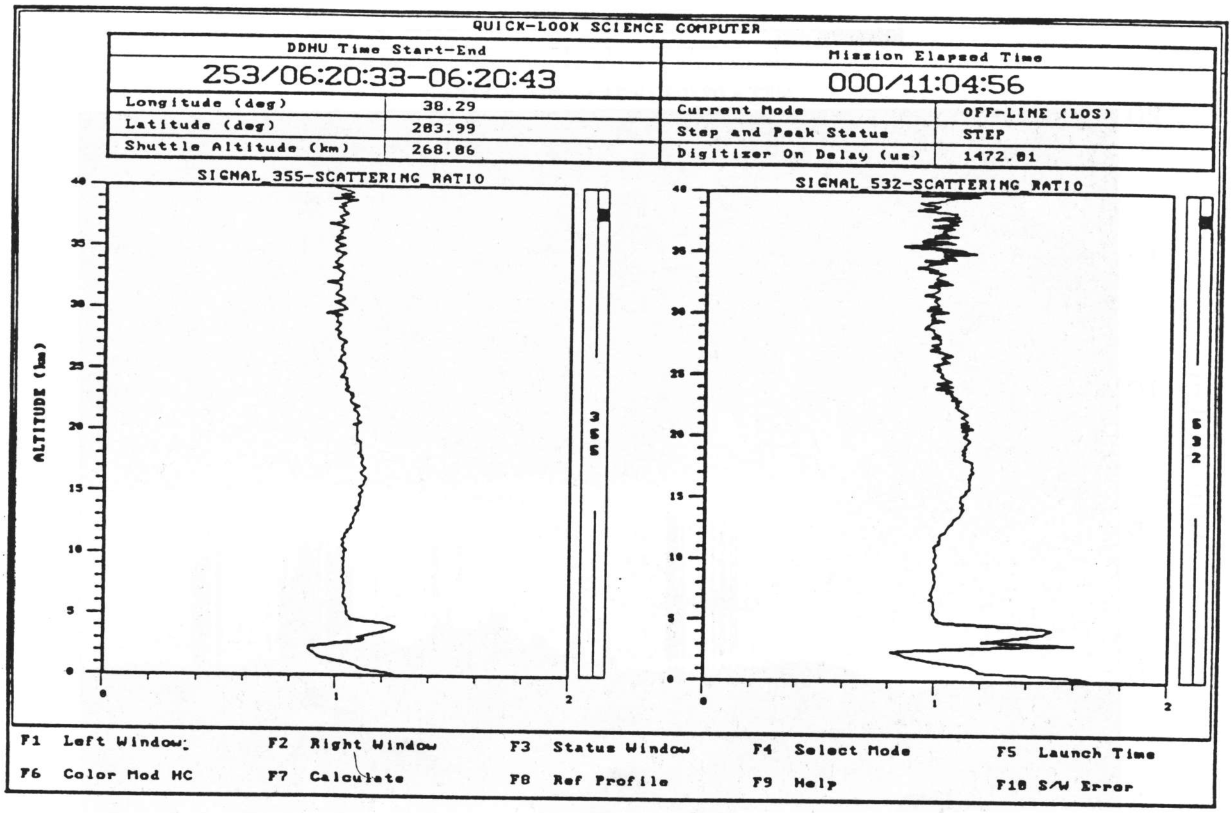
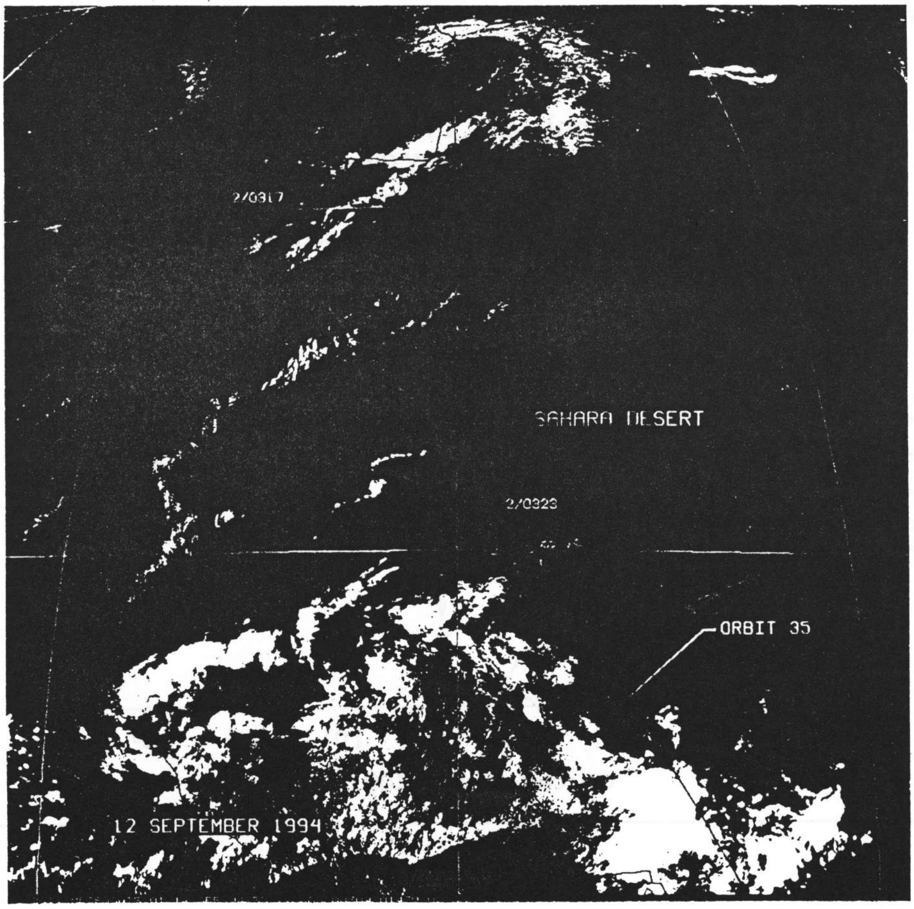
10^{5}
10^{6}


QUICK-LOOK SCIENCE COMPUTER
DDHU Time Start-End
253/06:20:33-06:20:43
Mission Elapsed Time
000/11:04:56
Longitude (deg)
38.29
Latitude (deg)
283.99
Shuttle Altitude (km)
268.86
Current Mode
OFF-LINE (LOS)
Step and Peak Status
STEP
Digitizer On Delay (us)
1472.81
SIGNAL_355-SCATTERING_RATIO
SIGNAL_532-SCATTERING_RATIO
ALTITUDE (km)
355
532
F1 Left Window
F2 Right Window
F3 Status Window
F4 Select Mode
F5 Launch Time
F6 Color Mod HC
F7 Calculate
F8 Ref Profile
F9 Help
F10 S/W Error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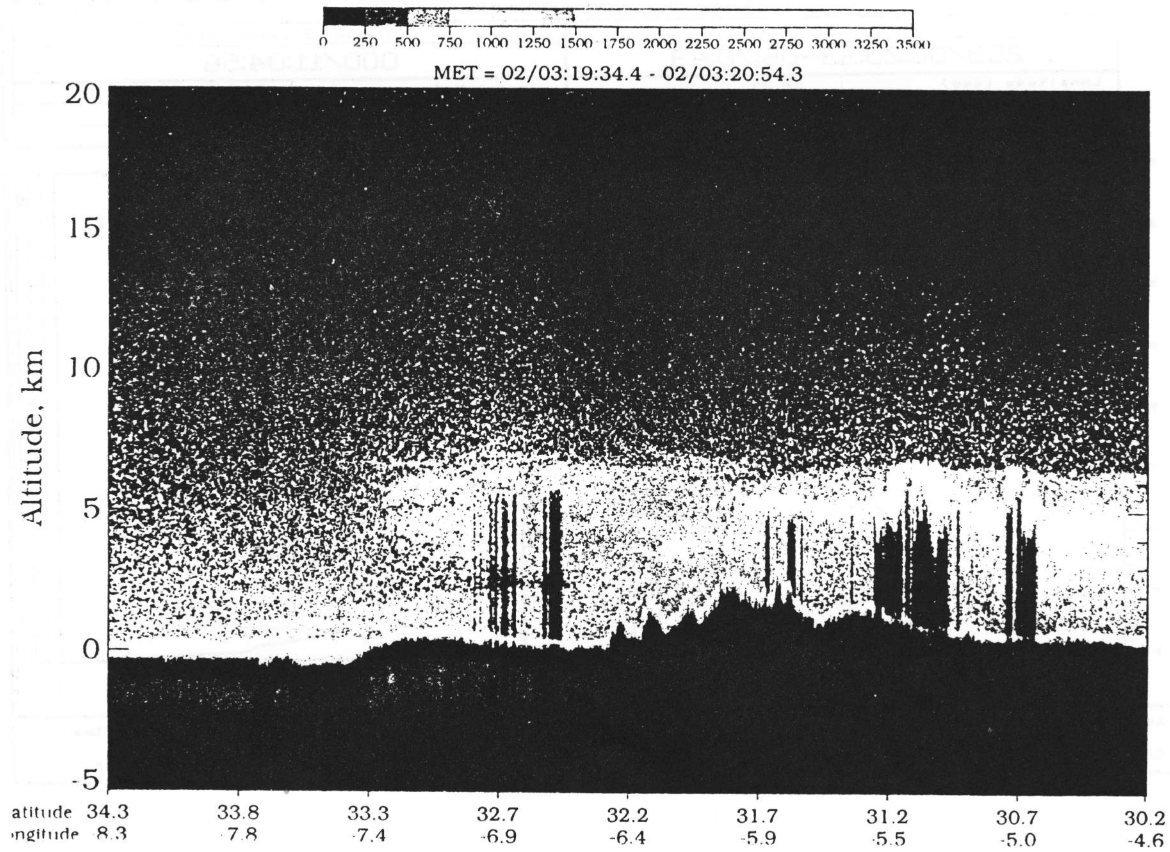
SAHARA DESERT
2/0323
ORBIT 35
12 SEPTEMBER 1994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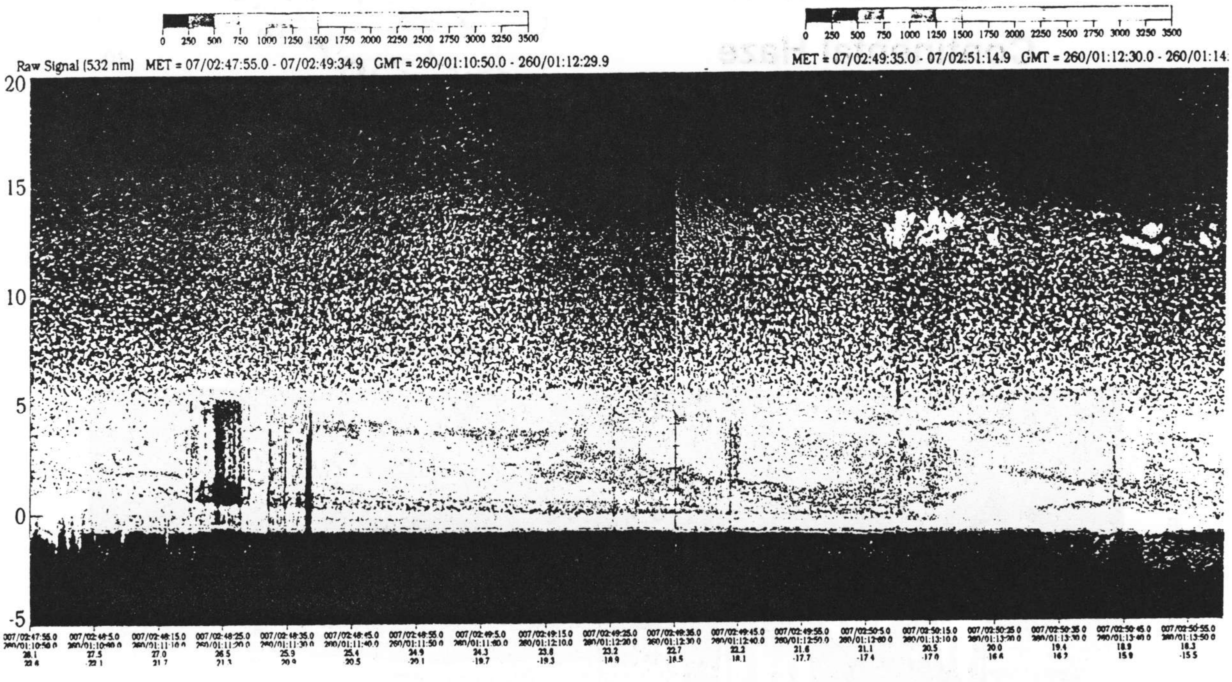
MET = 02/03:19:34.4 - 02/03:20:54.3
Altitude, km
20
15
10
5
0
-5
atitude 34.3 33.8 33.3 32.7 32.2 31.7 31.2 30.7 30.2
ongitude 8.3 -7.8 -7.4 -6.9 -6.4 -5.9 -5.5 -5.0 -4.6

Orbit 115 22°N, 18°W



LITE Pass S71
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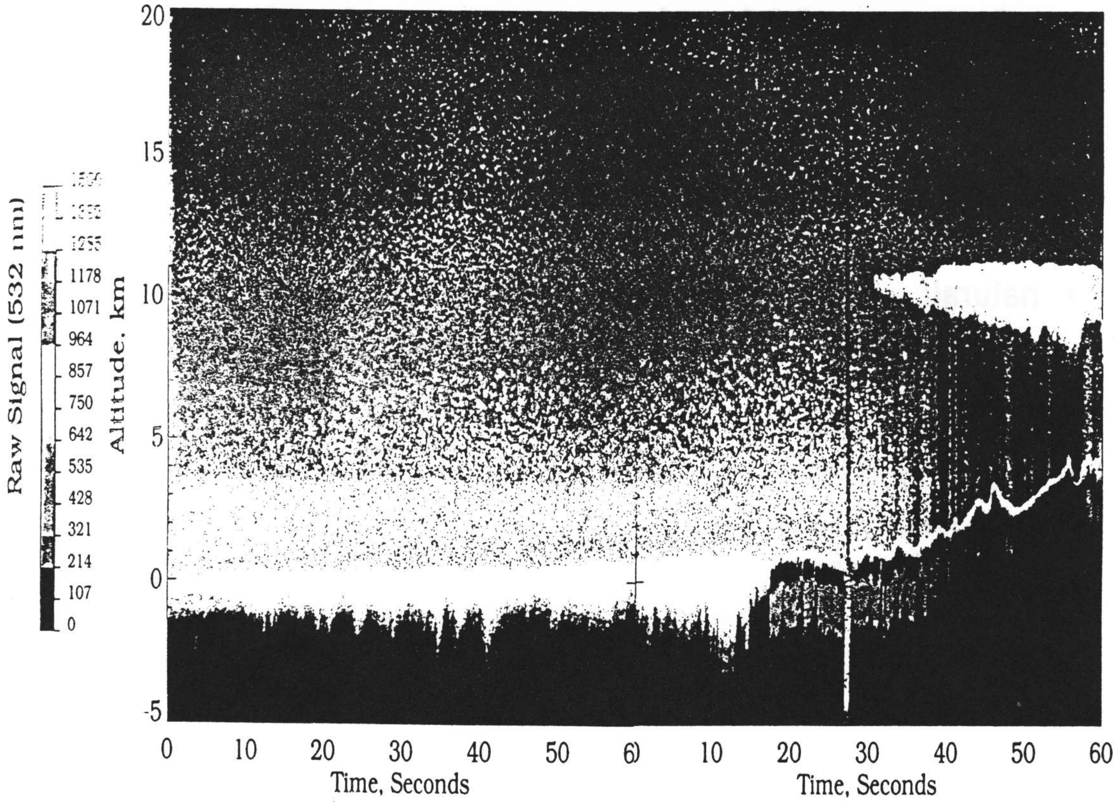
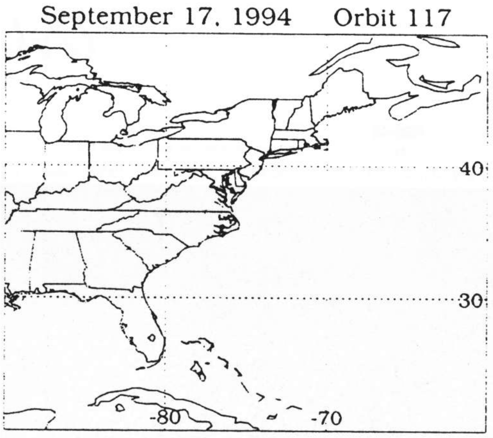
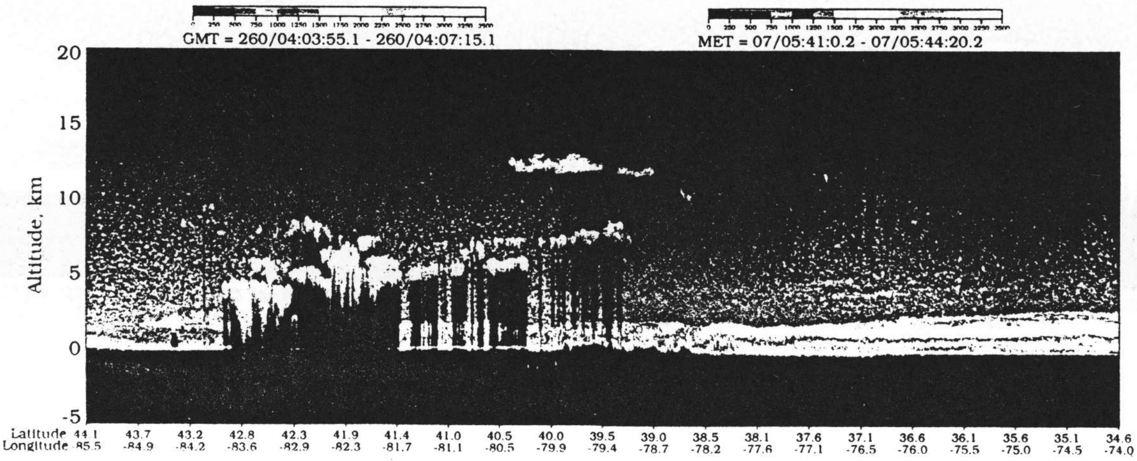
LITE Pass Over Andes Mountains
08:48:26, MET 4/09:25:31, Orbit 71, Latitude -23.5



Observations of Continental Haze by LITE



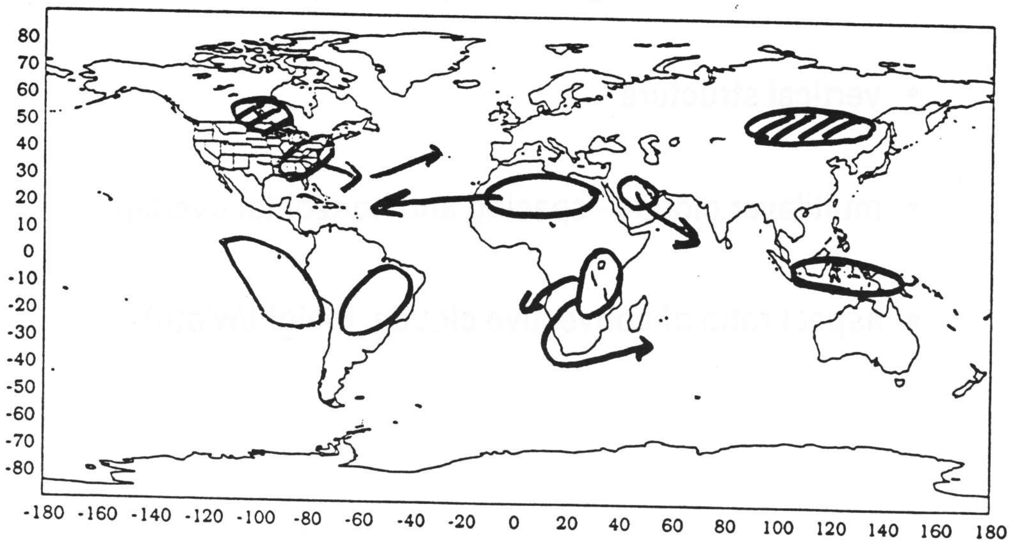


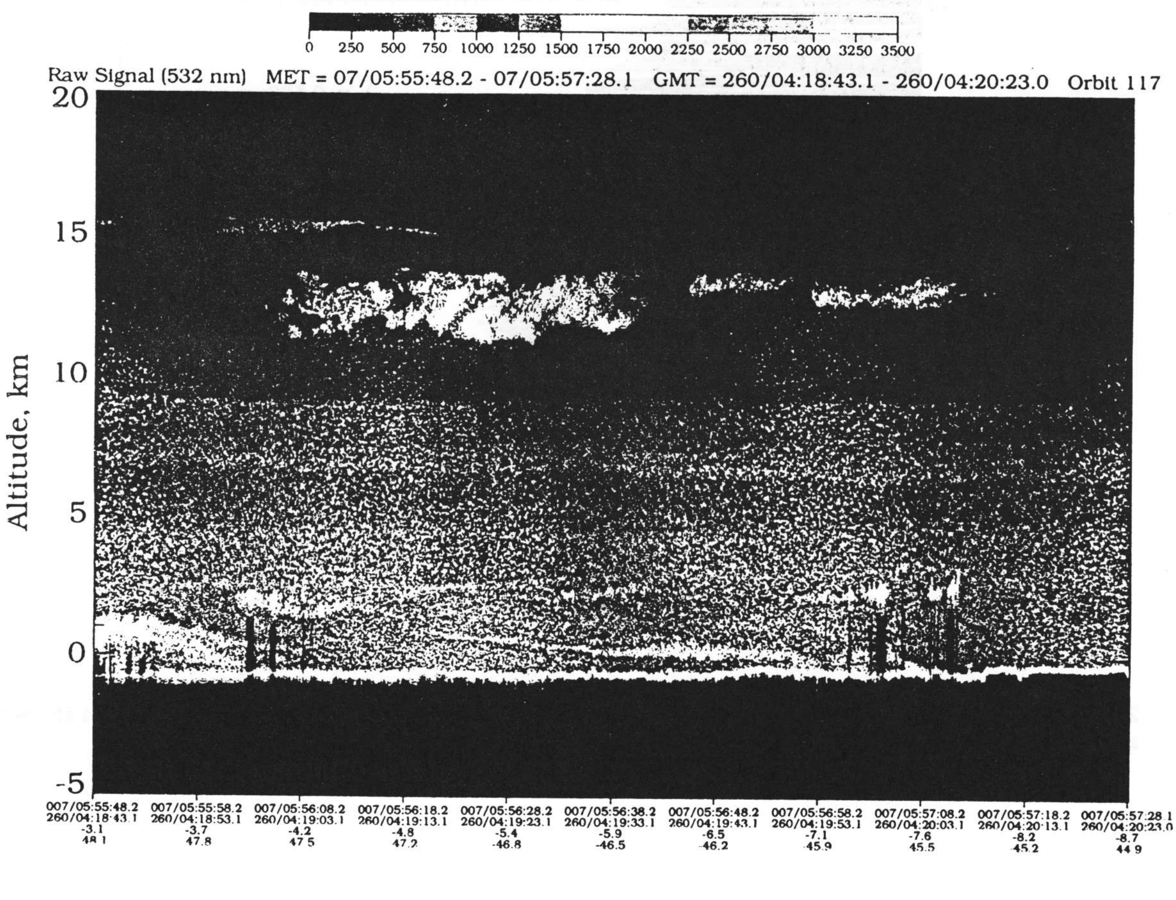
Science Objectives - tropospheric aerosols

- study source regions and transport of aerosols in the upper and lower troposphere
- natural:
  - desert dust
  - biochemical haze
  - forest and grass fires
- anthropogenic
  - industrial pollution
  - biomass burning

- impacts on radiation budget, tropospheric chemistry

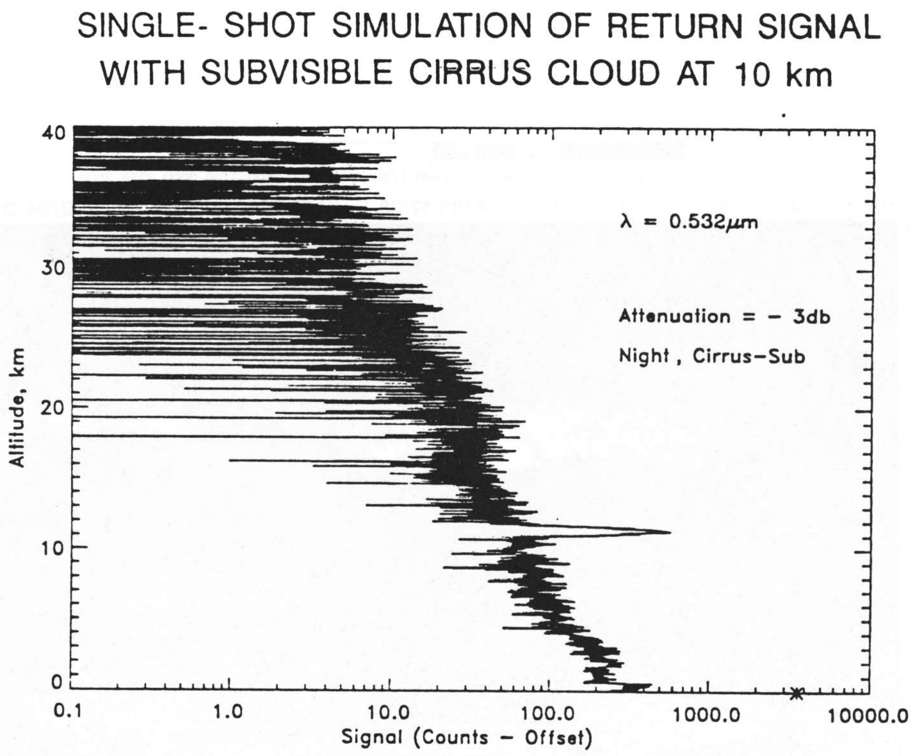
Tropospheric aerosol sources and transport





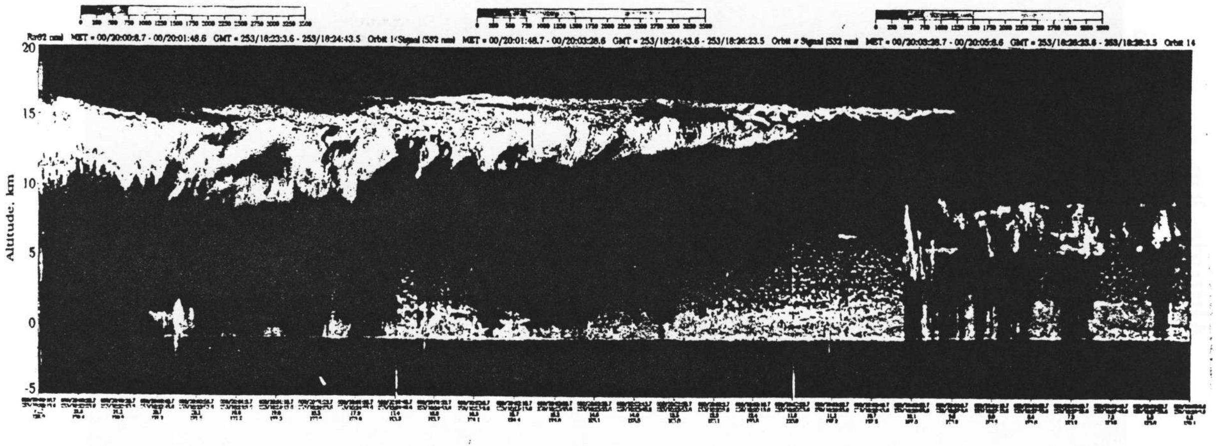
Radiatively Significant Cloud Properties

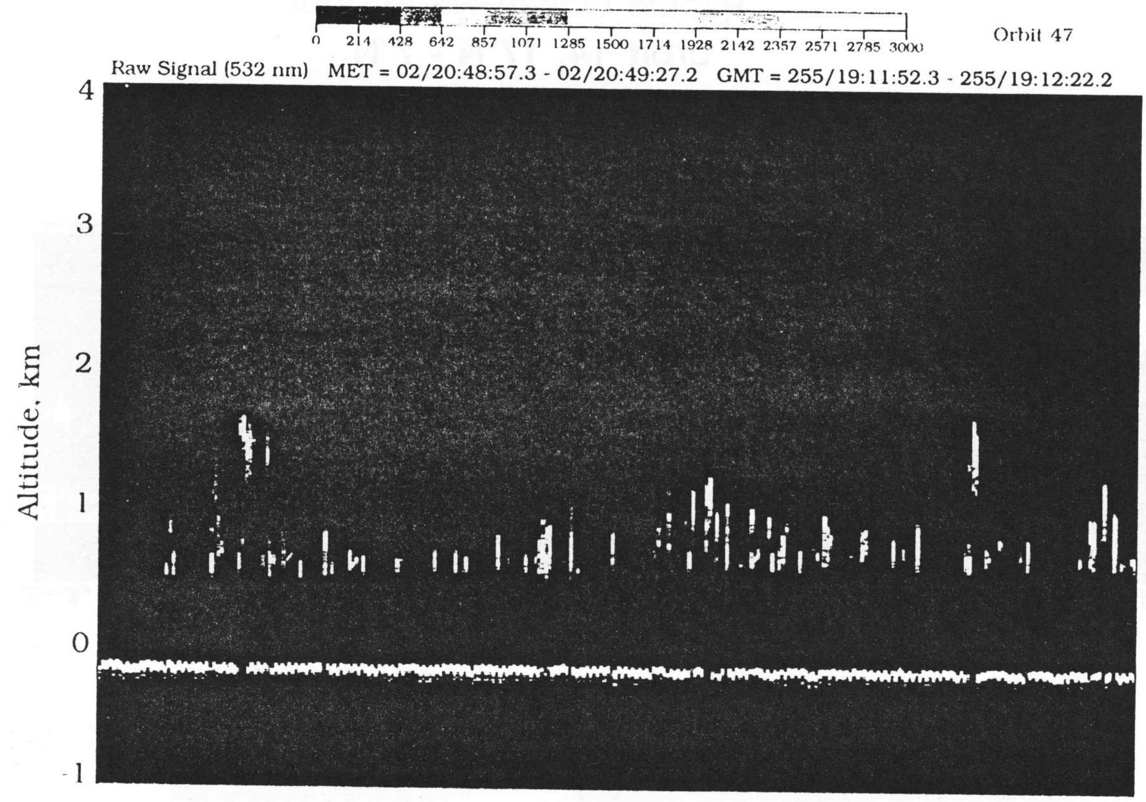
- cloud amount, height, and optical depth/albedo
- vertical structure
- multilayer clouds - spacing and horizontal overlap
- aspect ratio of convective clouds (height/width)



23. A simulation of a single return profile at 532 nm using the LITE parameters of vu graph 22. A 1994 atmosphere and a subvisible cirrus cloud at 10 km was assumed.

Pacific Ocean warm pool
orbit 14, 17°N - 7°N

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3
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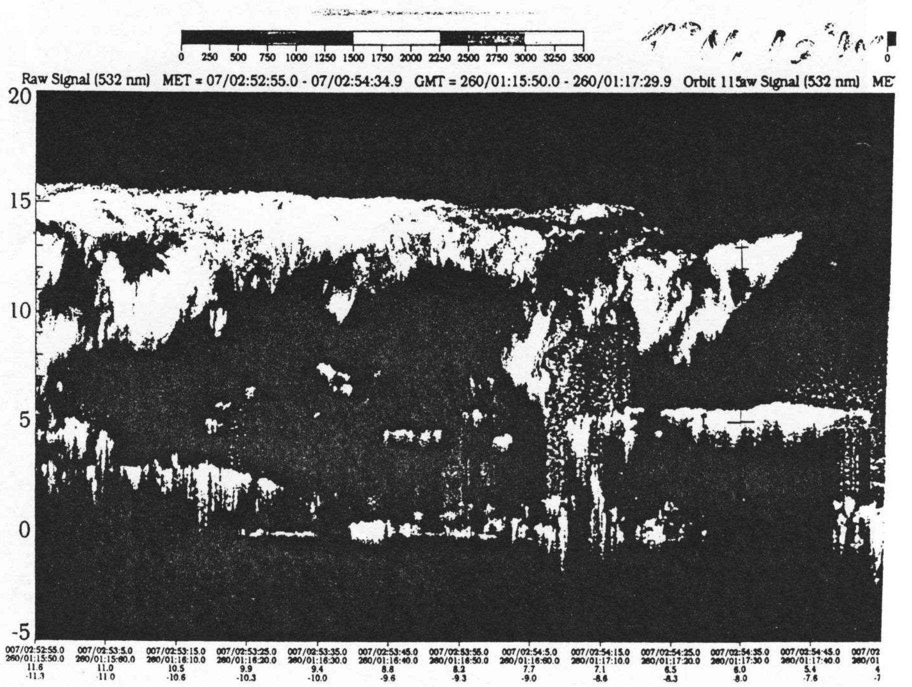
1
0
-1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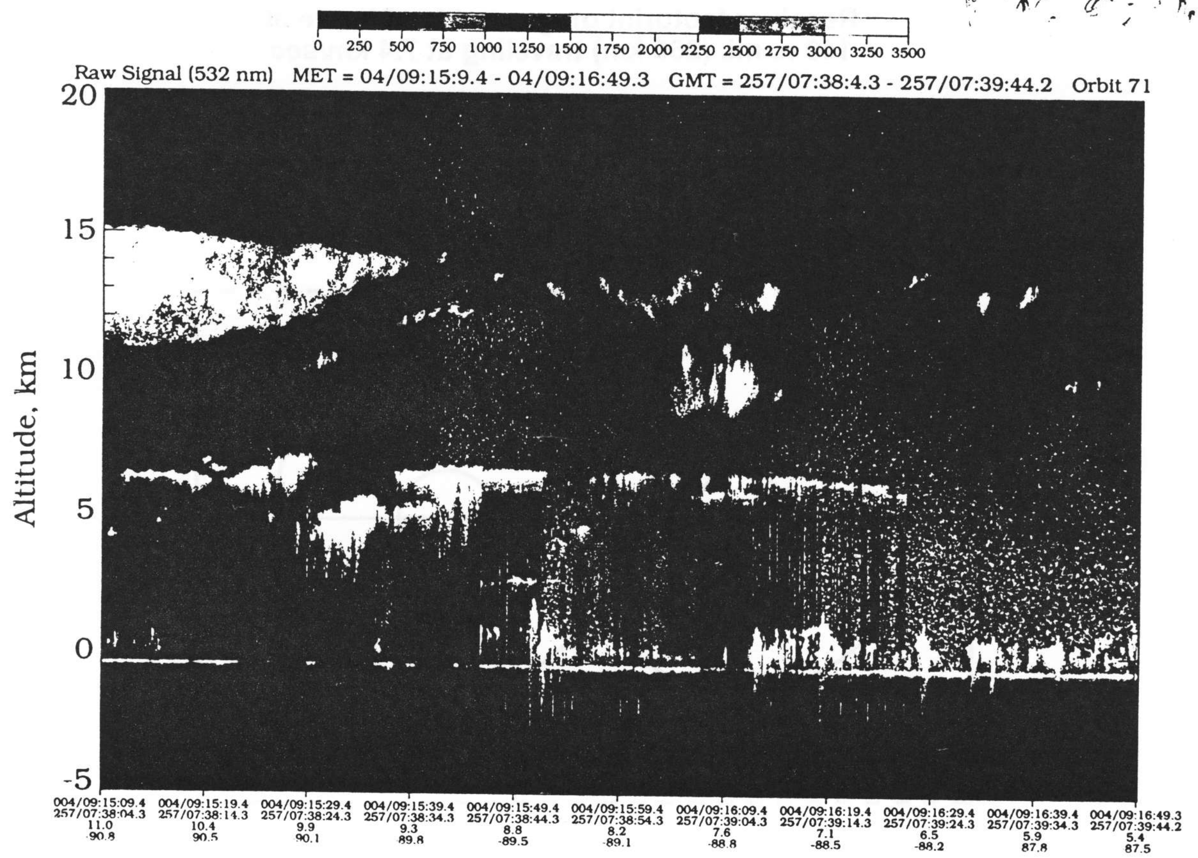
15
10
5
0
-5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Raw Signal (532 nm) MET = 04/09:15:9.4 - 04/09:16:49.3 GMT = 257/07:38:4.3 - 257/07:39:44.2 Orbit 71
Altitude, km
20
15
10
5
0
-5
004/09:15:09.4 257/07:38:04.3 11.0 -90.8
004/09:15:19.4 257/07:38:14.3 10.4 90.5
004/09:15:29.4 257/07:38:24.3 9.9 90.1
004/09:15:39.4 257/07:38:34.3 9.3 89.8
004/09:15:49.4 257/07:38:44.3 8.8 -89.5
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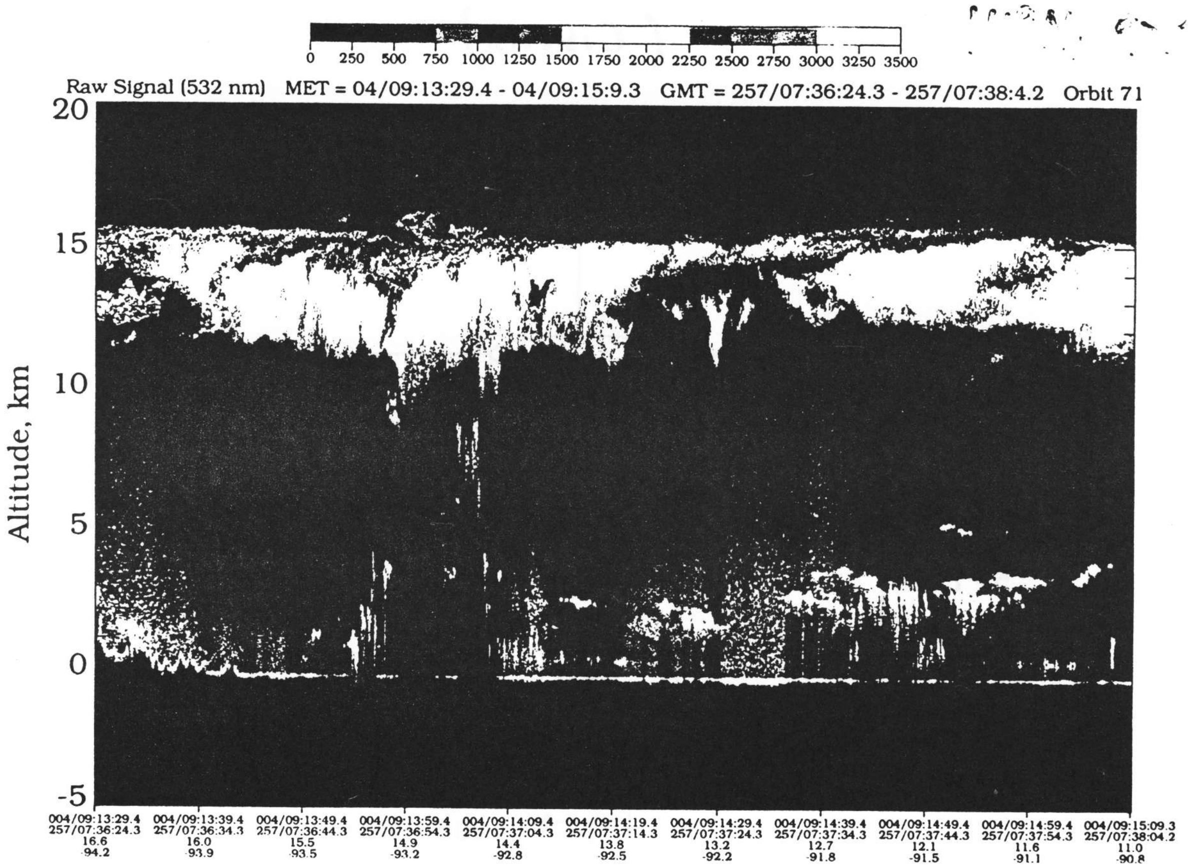
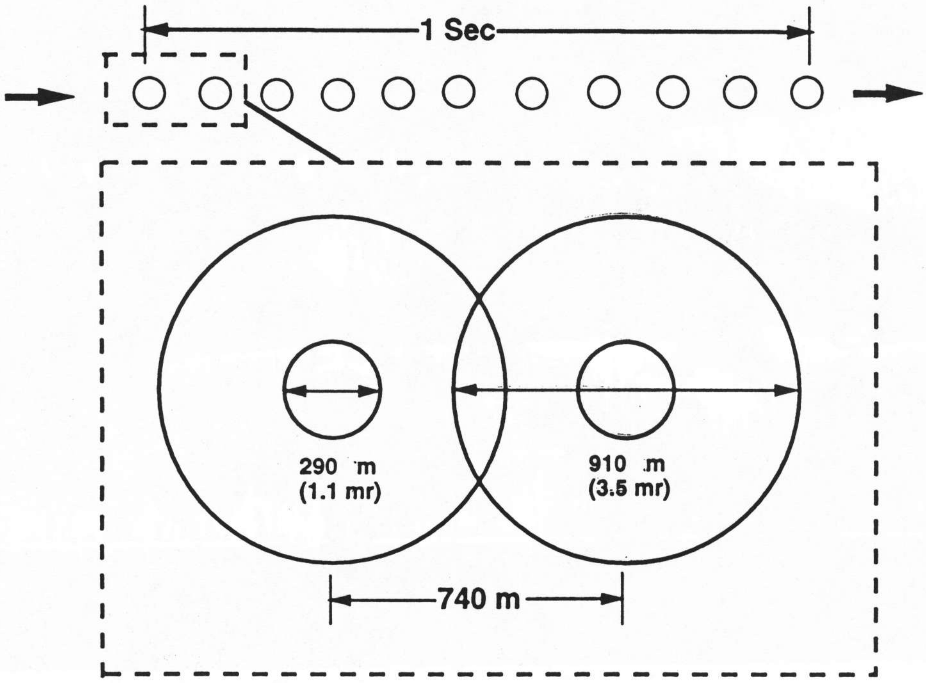
004/09:16:39.4 257/07:39:34.3 5.9 87.8
004/09:16:49.3 257/07:39:44.2 5.4 87.5

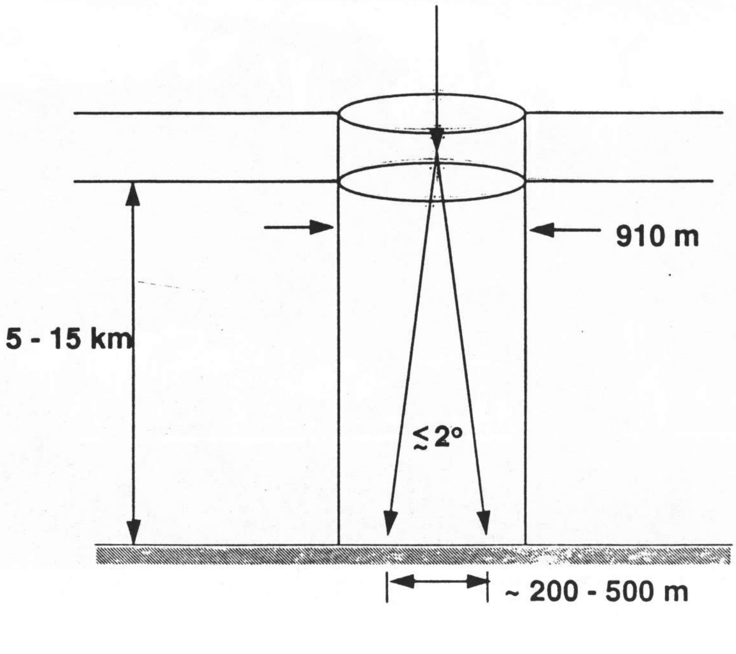

0 250 500 750 1000 1250 1500 1750 2000 2250 2500 2750 3000 3250 3500
Raw Signal (532 nm) MET = 04/09:13:29.4 - 04/09:15:9.3 GMT = 257/07:36:24.3 - 257/07:38:4.2 Orbit 71
Altitude, km
20
15
10
5
0
-5
004/09:13:29.4 257/07:36:24.3 16.6 -94.2
004/09:13:39.4 257/07:36:34.3 16.0 -93.9
004/09:13:49.4 257/07:36:44.3 15.5 -93.5
004/09:13:59.4 257/07:36:54.3 14.9 -93.2
004/09:14:09.4 257/07:37:04.3 14.4 -92.8
004/09:14:19.4 257/07:37:14.3 13.8 -92.5
004/09:14:29.4 257/07:37:24.3 13.2 -92.2
004/09:14:39.4 257/07:37:34.3 12.7 -91.8
004/09:14:49.4 257/07:37:44.3 12.1 -91.5
004/09:14:59.4 257/07:37:54.3 11.6 -91.1
004/09:15:09.3 257/07:38:04.2 11.0 -90.8

Receiver footprint on ground for Shuttle at 140 n. mi. (260 km) traveling at 7.4 km/sec

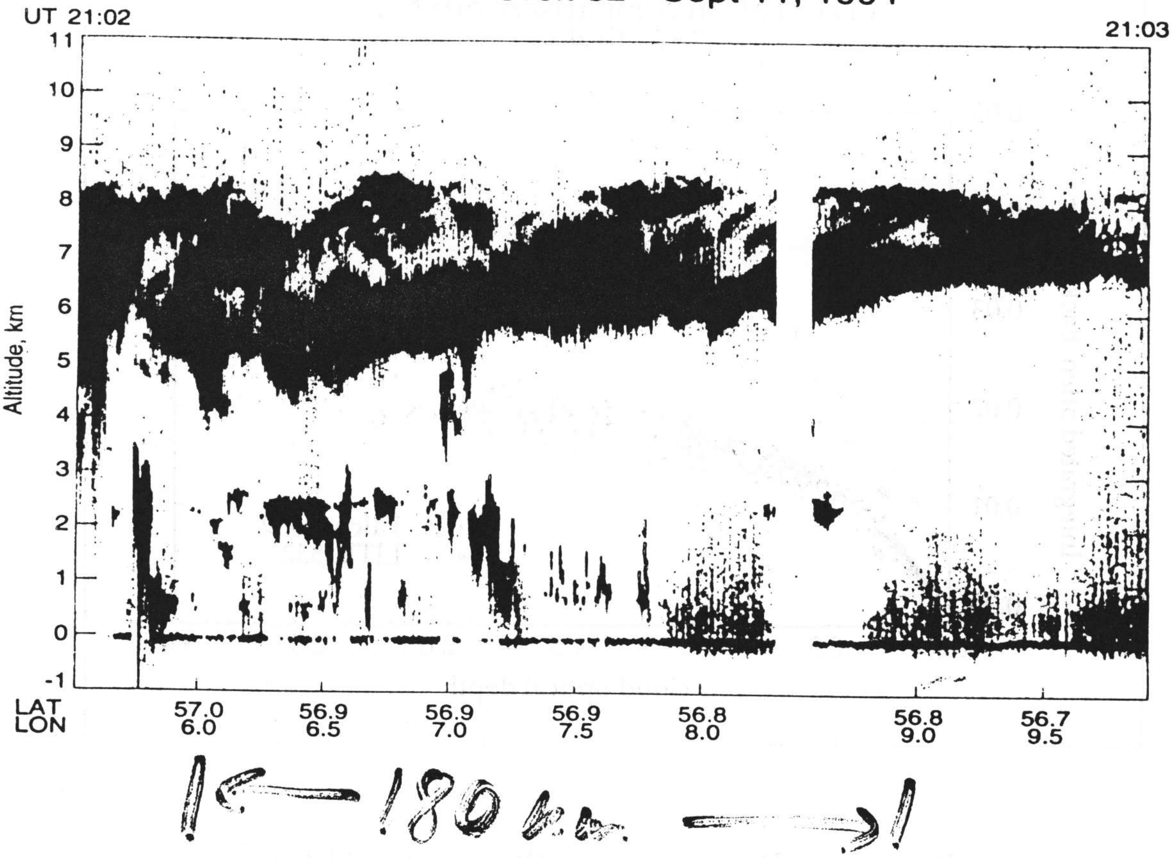


(Cirrus)

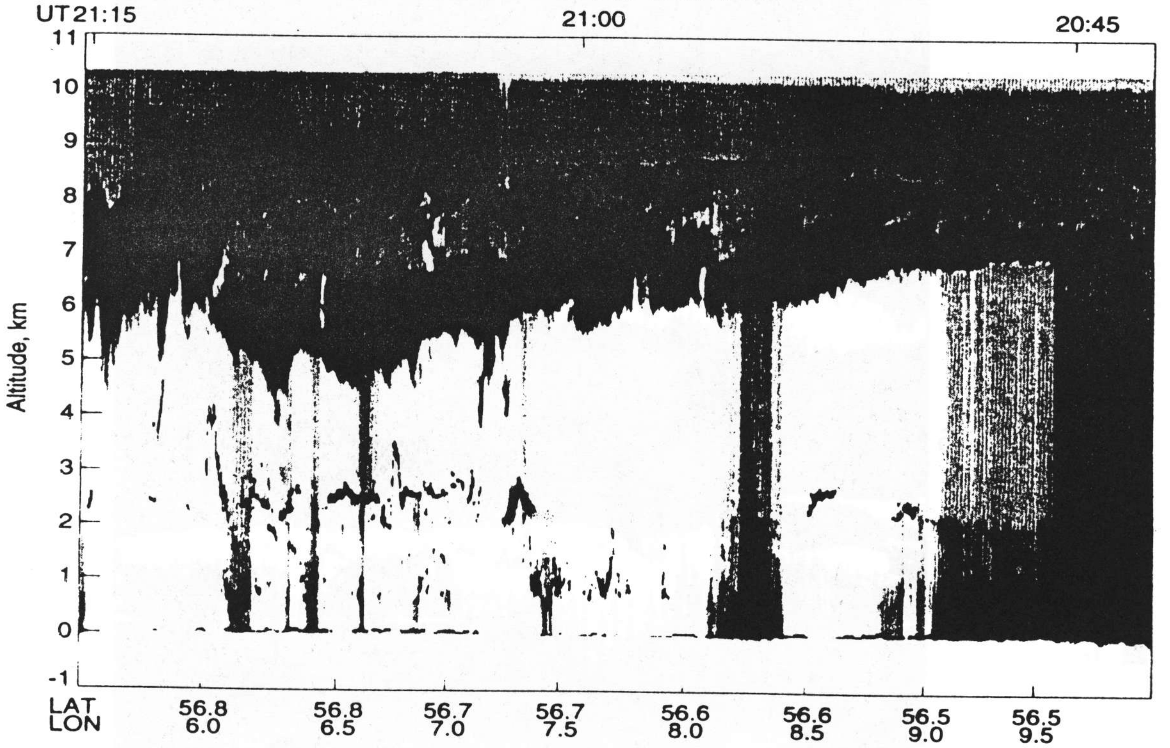
Light within forward diffraction peak remains within LITE FOV

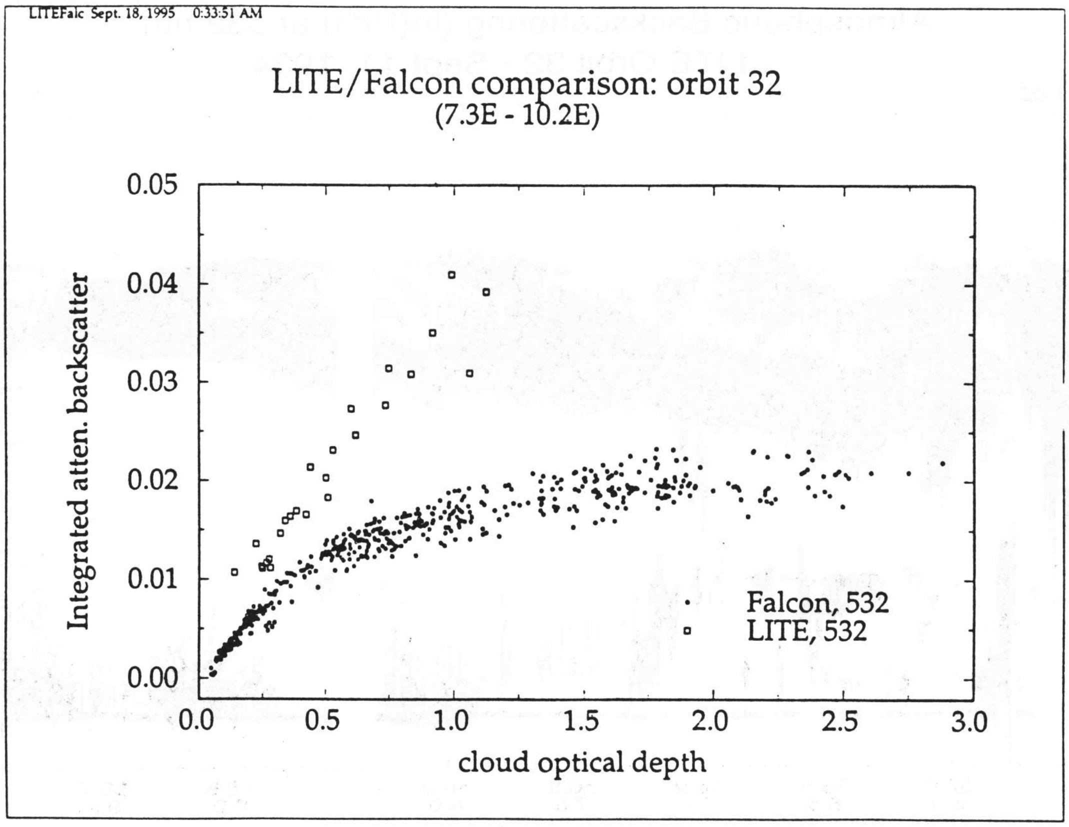


Atmospheric Backscattering (ln(Pr²)) at 532 nm
LITE Orbit 32 - Sept 11, 1994

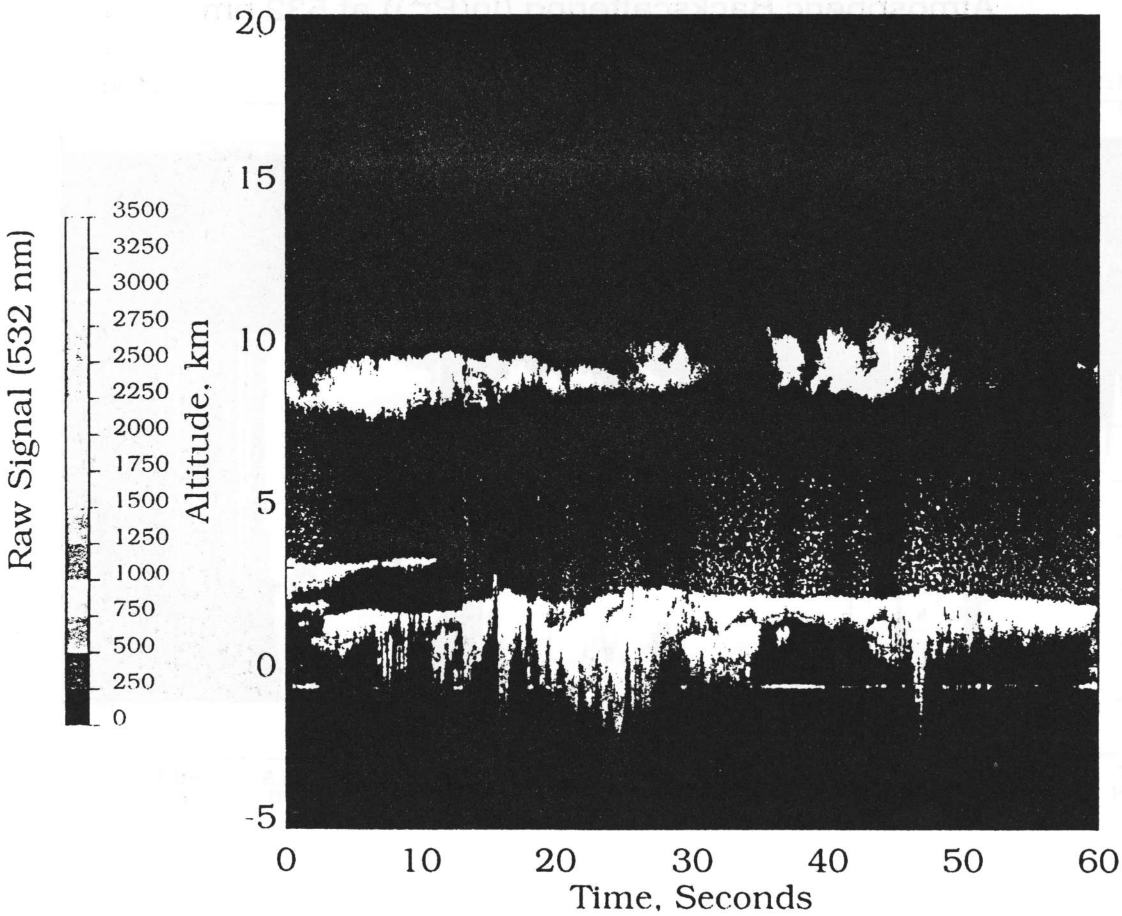


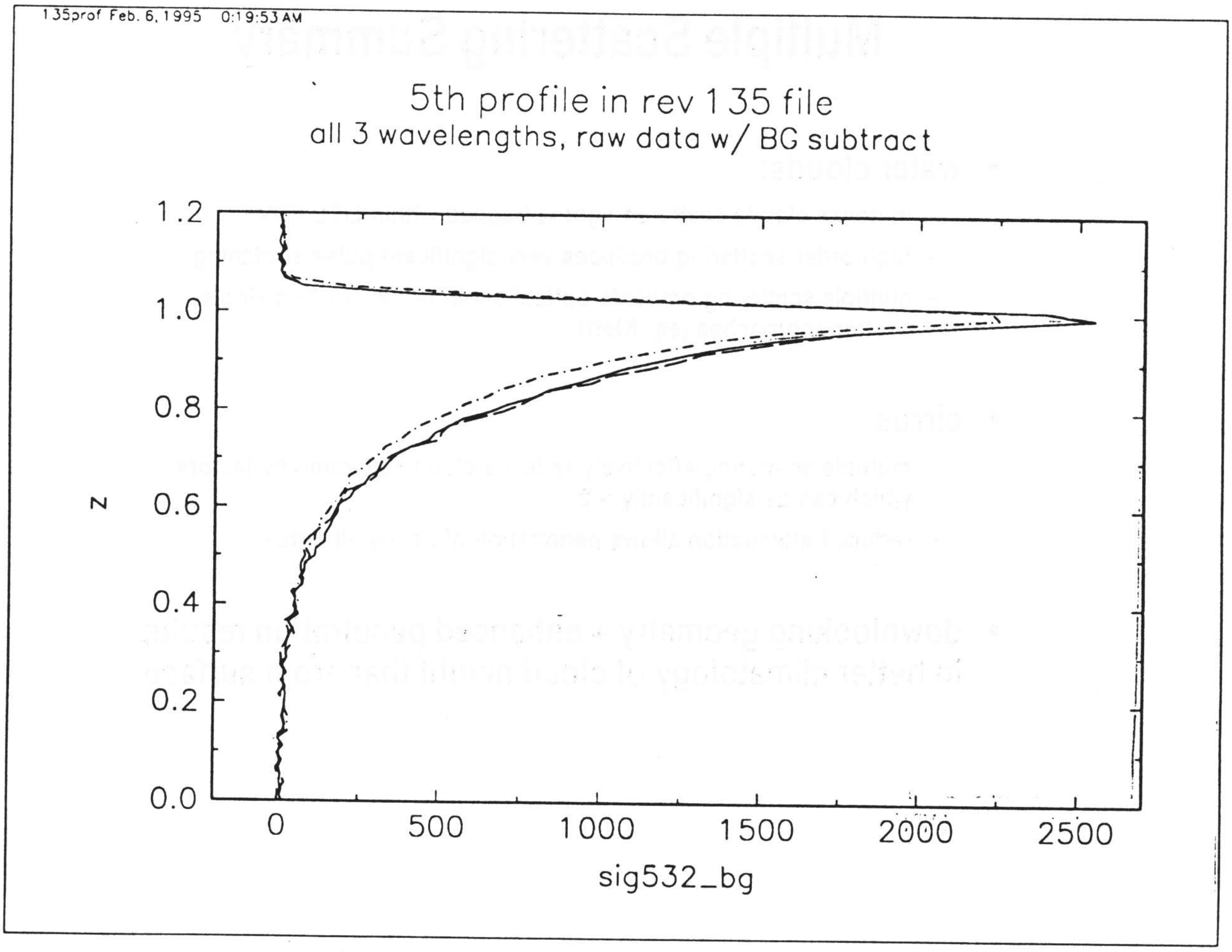
Atmospheric Backscattering (ln(Pr²)) at 532 nm
Falcon - LITE Orbit 32



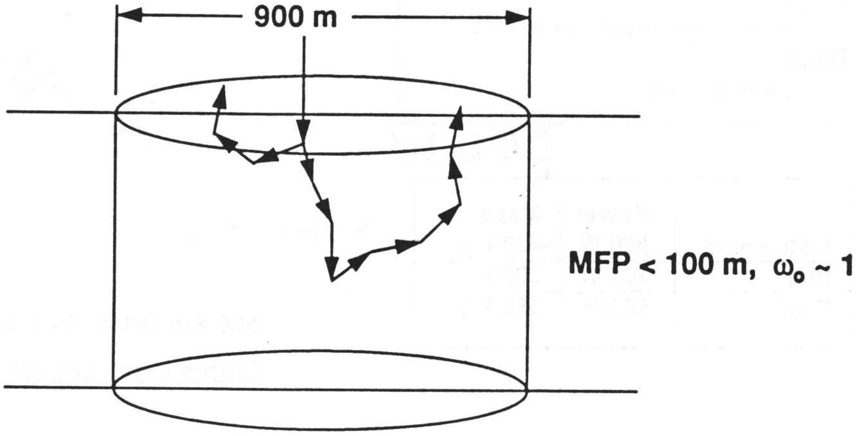


LITE Pass Over Pacific Ocean Warm Pool Orbit 14
MET = 000:20:08:52.50, Orbit = 14, Latitude = -6.31011





Multiple Scattering in Dense Clouds



Multiple Scattering Summary

- water clouds:
  - in dense clouds scattered light is trapped within LITE FOV
  - high-order scattering produces very significant pulse stretching
  - multiple scattering prevents optical depth retrieval using single-scatter approaches (eg: Klett)

- cirrus:
  - multiple scattering effectively reduces cloud extinction by factors which can be significantly > 2
  - reduced attenuation allows penetration of nearly all cirrus

- downlooking geometry + enhanced penetration results in better climatology of cloud height than from surface

Langley

SPARCLE Baseline Concept

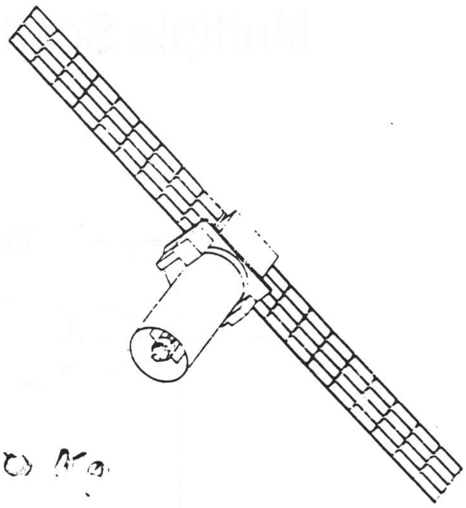
(2 year mission)

Lidar instrument mated to light-sat bus of SSTI heritage

Laser:
  Diode-pumped, doubled Nd:YAG
  300 mJ/pulse @ 532 nm (10 HZ)
Receiver:
  1 meter aperature telescope
Data:
  32 KByte/sec

200 W

	Power	Mass
Instrument	300 W	450 Kg
Bus	200 W	200 Kg
Total	500W	650 Kg



500 Km Orbit - 97.1 Degrees

Taurus Class Launch Vehicle

Summary

- LITE flight builds confidence in the lidar approach
- LITE exhibits much better cloud penetration than expected
- highlights phenomena not observed by current instruments
  - thin cirrus at tropopause, not observed by current instruments
  - vertical structure and laminar features of tropospheric aerosol
  - vertical structure in tropical cloud systems

SUMMARY

- LITE was operated for 52 hours from 9-19 September
- about 47 Gbytes of lidar data was collected
- correlative measurements were made by 91 groups, including 6 aircraft
- data to be archived and processed at Langley
  - validation conducted by LITE Science Steering Group and correlative investigators

LITE will help sell future missions

- builds confidence in maturity of lidar as a technology
- LITE demonstrates much better cloud penetration than was generally expected
- highlights phenomena not observed by current instruments
  - thin cirrus at tropopause, not observed by current instruments
  - unexpected vertical structure of tropospheric aerosol
  - vertical structure in tropical cloud systems