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Paper Session I-C - Lidar in Space- The First Flight

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Lidar In Space - The First Flight

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Lidar is an acronym for light detection and ranging and refers to a technique for profiling atmospheric parameters using lasers and a time-of-flight ranging technique. Lidars were first used to study the Earth's atmosphere in the early 1960's following the development of the first pulsed lasers. Since then many advances in technology and application have occurred and lidars are commonly deployed in ground-based and aircraft-based measurement programs worldwide. These efforts have focused on a variety of studies, including, range-resolved measurements of the structure and optical properties of aerosols and clouds, distributions of trace gases such as ozone and water vapor, tropospheric winds, and atmospheric density and temperature. Lidars in Earth orbit have long been considered a potentially attractive way to perform many of these measurements on a global basis and, over the past 20 years, a number of studies have been made concerning satellite and shuttle based systems (see, for instance, Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) Payload for Spacelab/Shuttle (ref. 1)). However, it was not until September of 1994 that the first lidar was operated in Earth orbit when the Lidar In-Space Technology Experiment (LITE) was flown on Space Shuttle Discovery.

Figure 1 shows the layout of the LITE instrument on the Shuttle pallet. The transmitter consisted of a 10 Hz Nd:YAG laser which was doubled and tripled to produce approximately 500 mJ per pulse at 1064 and 532 nm, and 160 mJ per pulse at 355 nm. The backscattered laser light was collected by a 1-m diameter Cassegrain telescope. The three wavelengths were spectrally separated by a series of beamsplitters and imaged onto separate detectors. The signals from the detectors were amplified and digitized at a 0.1 μs sampling rate, corresponding to a vertical resolution of 15 m; however, the 2 MHz analog bandwidth of the amplifiers limited the overall vertical resolution to approximately 35 m. The laser was aligned to the optical axis of the telescope via the boresight assembly consisting of a movable turning mirror at the laser exit and a quadrant detector in the receiver. A camera was also boresighted with the telescope to provide correlative photographs during the day portions of the orbits. The laser and electronics were cooled by the Shuttle's freon cooling system. A stand-alone engineering system, the Orbiter experiments Autonomous Supporting Instrumentation System (OASIS), was also mounted on the pallet to record accelerations, strains, and other aspects of the Shuttle environment during launch and landing. The overall instrument weighed approximately 4000 pounds and consumed over 3 kW of power. More detailed information on the instrument may be found in refs. 2 and 3.

Figure 2 depicts the near-nadir geometry of the majority of observations. At the Earth's surface, the footprint of the laser from the 265 km altitude of the Shuttle was approximately 300 m. The 7.4 km/s speed of the shuttle and the 10 Hz repetition rate of the laser provided a horizontal sampling of 740 m. Backscatter profiles were collected for each laser shot and telemetered to ground-based mission operations computers via Ku-band, and profiles averaged over 100 laser shots were telemetered via S-band. Over the course of the 10 day mission, 43 hours of single-shot data and 53 hours of 100-shot data were recorded. The orbital inclination of 57° allowed observations over most of the globe.

A detailed mission plan and supporting correlative measurement plan was painstakingly developed for the 10-day mission. Nominally, data acquisition was planned for ten 4-1/2 hour intervals and several 10-20 minute "snapshots" over specific targets. During the mission, an extension day was granted which allowed the addition of several half-orbit sequences to the data plan. Six aircraft

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carrying a number of uplooking and downlooking lidars underflew LITE performing validation measurements. In addition, ground-based lidars, radiometers and other measurements were coordinated with LITE overflights. In all, the correlative measurements program involved 60 groups in 20 countries.

The observations made from the first lidar in space were nothing less than spectacular. LITE made measurements of clouds, storm systems, tropospheric and stratospheric aerosols, smoke from biomass burning, desert dust injected into the lower troposphere by wind storms, and various surface characteristics. Figures 3, 4, and 5 show examples of 532 nm data collected with the LITE instrument. Figure 3 is a gray-scale plot of the daytime data collected as LITE flew directly over Super Typhoon Melissa. To our knowledge, this is the first lidar cross-section of the eye of a typhoon or hurricane. Figure 4 shows nighttime data collected over Northwest Africa, illustrating LITE's ability to measure clouds, desert dust, and local topography. Figure 5 shows a nighttime data sequence which provides an excellent example of the complex multilayered cloud structure in the intertropical convergence zone over West Africa.

The data collected during the 10-day LITE mission will be invaluable for a variety of studies. The extensive observations of cloud height, optical properties, and multilayer structure will provide new insights on cloud systems. Clouds have an enormous effect on the Earth's radiation budget through their influence on incoming solar radiation as well as outgoing terrestrial radiation. Current satellite-based passive sensors have considerable difficulty accurately determining the structure of multilayered cloud systems and, in some cases, cloud height, both of which are factors influencing the net radiative effects of cloud systems. Observations of tropospheric aerosols will allow the first global-scale measurements of tropospheric optical depth. Tropospheric optical depth is also a measurement of great radiative importance which is beyond the capability of current passive sensors, at least, over land surfaces. Global measurements of the height of the planetary boundary layer will aid in global climate model parameterizations of flux transport between the oceans and the atmosphere. Measurements of the optical properties and transport of desert dust and biomass smoke will enhance our knowledge of the radiative and chemical effects of these aerosols. Finally, the experience gained from LITE and the analysis of its data products will provide important insight for the planning of future long-term spaceborne lidar missions. LITE ushered in a new era of remote sensing from space, that being active probing of the atmosphere. There is no doubt that at the beginning of the next millennium spaceborne lidars will play a major role in the measurement of global change.

References

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3. Winker, D. M., Atmospheric sounding With the Lidar In-Space Technology Experiment (LITE), Proceedings of Lasers '91, December 9-13, 1991, San Diego, CA, 1992.

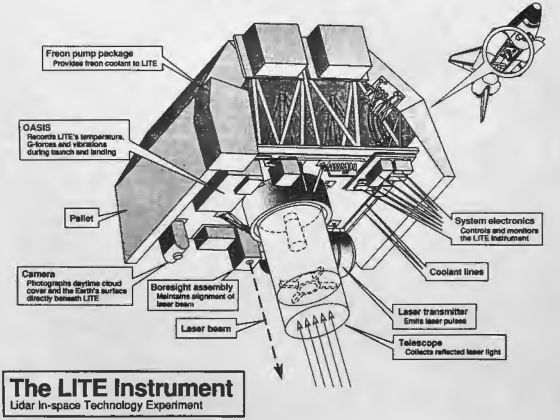

Figure 1. A depiction of the LITE instrument and its configuration aboard Space Shuttle Discovery

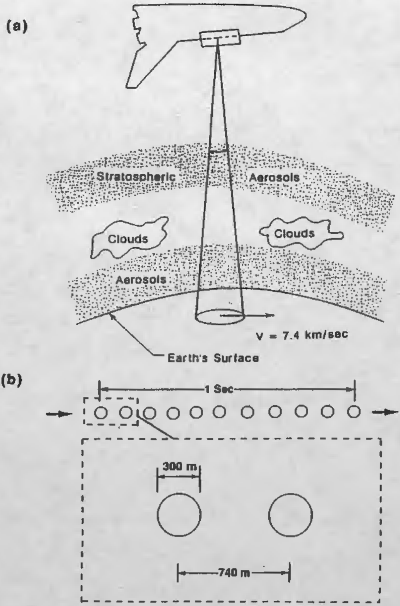

Figure 2. (a) LITE observational geometry, and (b) laser footprint at the Earth's surface.

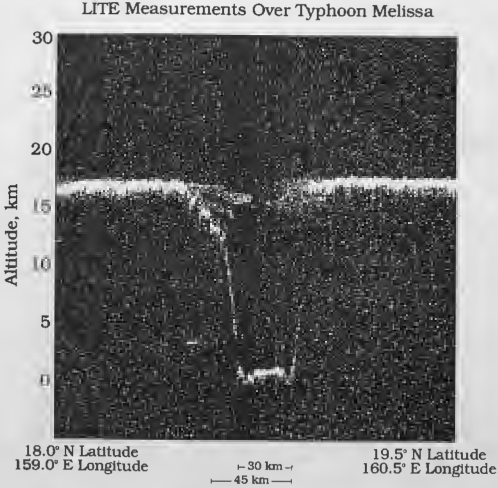

Figure 3. A gray-scale, altitude-time plot of daytime 532 nm data showing a cross-section of the eye of Super Typhoon Melissa taken on September 15, 1994, at 3:57:04 Greenwich Mean Time (GMT). Typhoon Melissa formed in the Pacific Ocean and, at the time of the LITE measurement, was centered at approximately 159.7° E longitude and 18.6° N latitude. Maximum sustained winds at this time were estimated at 140 kt with gusts peaking at 170 kt. The plot clearly shows the eye of Melissa, surrounded by a high level deck of cirrus cloud at 15-17 km altitude. Inside the eye of the typhoon, a wall of cloud extends from the upper level cloud layer to a lower level cloud deck near the surface of the ocean. The diameter of the eye varies from bout 45 km near 17 km altitude to about 30 km at the surface. (Large returns from clouds are shown in white. The dark areas correspond to low or no signal due to lack of significant scatter from the largely molecular atmosphere above the cirrus clouds or due to total extinction of the lidar signal in the optically thick region below the cloud tops.)

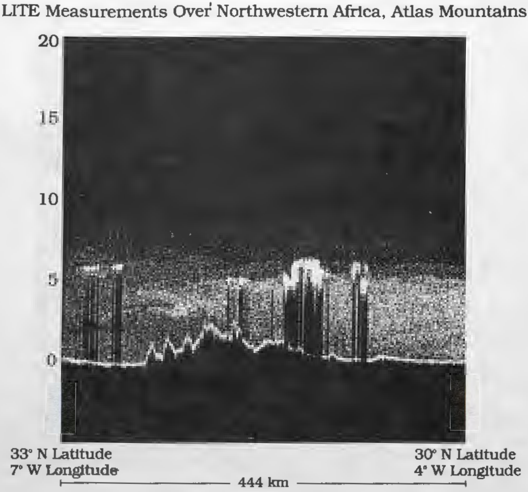

Figure 4. A gray-scale, altitude-time plot of nighttime 532 nm data taken over the Atlas Mountains in Northwest Africa on September 12, 1994, at 1:43:25 GMT. An aerosol layer consisting of dust (probably desert dust blown up from the desert floor) can be seen extending over and on either side of the mountain range (greatest concentrations lie to the southeast of the mountains). Optically thick clouds near 5 km in altitude (shown in white) in some cases prevent LITE from observing the surface below the clouds and create a shadowing effect beneath the cloud layer. (Larger signal levels are shown in lighter colors.)

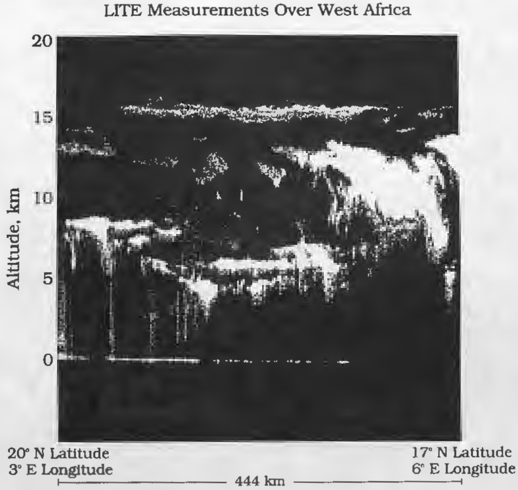

Figure 5. A gray-scale, altitude-time plot showing nighttime 532 nm data taken over Western Africa on September 12, 194, at 1:47:25 GMT. The plot shows the complex cloud formations over the intertropical convergence zone. (Larger signal levels are shown in lighter colors)