Scientific Investigations Planned for the Lidar In-Space Technology Experiment (LITE)

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Abstract

The Lidar In-Space Technology Experiment (LITE) is being developed by NASA/Langley Research Center for a series of flights on the space shuttle beginning in 1994. Employing a three-wavelength Nd:YAG laser and a 1-m-diameter telescope, the system is a test-bed for the development of technology required for future operational spaceborne lidars. The system has been designed to observe clouds, tropospheric and stratospheric aerosols, characteristics of the planetary boundary layer, and stratospheric density and temperature perturbations with much greater resolution than is available from current orbiting sensors. In addition to providing unique datasets on these phenomena, the data obtained will be useful in improving retrieval algorithms currently in use. Observations of clouds and the planetary boundary layer will aid in the development of global climate model (GCM) parameterizations. This article briefly describes the LITE program and discusses the types of scientific investigations planned for the first flight.

1. Introduction

Lidar systems have now been used for remote sensing of the atmosphere for nearly three decades, providing a powerful means of studying the structure, composition, and dynamics of the lower and middle atmosphere. The present maturity of lidar techniques is reflected in the contribution of both ground-based and airborne systems to recent major programs. Among the more significant are FIRE (the First International Satellite Cloud Climatology Project Regional Experiment), studying the role of clouds in climate; the Antarctic Ozone Experiment and the Airborne Arctic Stratospheric Experiment, studying ozone depletion in the polar regions; and CEDAR (the Coupling, Energetics, and Dynamics of Atmospheric Regions initiative), investigating the dynamics of the middle atmosphere. The state of the art in lidar remote sensing is reviewed in recent special issues of the *Proceedings of the IEEE* (1989) and *Optical Engineering* (1991).

Spaceborne lidar systems offer improved capabilities with respect to current polar-orbiting sounders and occultation instruments. Lidar can provide better vertical resolution than passive sensors due to the short length of laser pulses and the use of more direct data-retrieval algorithms. Lidars can probe the atmosphere beneath optically thin clouds and, due to the small beam footprint, can probe between broken clouds. Passive instruments operating in the visible and near-infrared have temporal and spatial restrictions on their sensing due to their reliance on an external source of illumination such as the sun or moon. Lidar can operate continuously, providing daily global coverage. The many potential advantages of spaceborne lidar have led NASA to sponsor a number of design studies beginning in the early 1970s and including studies of the feasibility of flying a lidar as part of the Earth Observing System (EOS) (Curran et al. 1987). The Lidar In-Space Technology Experiment (LITE), which has grown out of these studies, is a system that has been designed to be carried into orbit by the shuttle, operated from the cargo bay, and returned to earth at the end of the mission. While no lidar instrument for measuring atmospheric composition has been chosen for EOS at this time, LITE will provide a platform

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with which to develop the required hardware and to explore the applications of such a lidar.

LITE is scheduled to fly on the shuttle in early 1994. Approval has recently been given for the first of several planned follow-on missions at 1- to 2-year intervals. The first mission will be used to develop experience in operating a lidar system in a space environment and to evaluate the sensitivity of the instrument for performing scientific studies on clouds, aerosols, and the middle atmosphere. Building on this experience, the second mission will have a stronger emphasis on scientific studies. On subsequent follow-on missions, LITE will be used as a test-bed for investigating more advanced measurement capabilities. In this paper we briefly describe the LITE instrument and mission scenario, review a number of scientific investigations planned for the first flight, and outline possible future directions for the program. Due to the limited duration of shuttle missions, the LITE investigations have a somewhat different focus than studies that might be performed using an operational system. The measurements to be performed, however, are typical of those that would be performed by an operational lidar and allow a realistic determination of the performance capabilities of the LITE instrument. The more important atmospheric parameters that will be derived from the lidar return signal are listed in Table 1.

TABLE 1. Primary atmospheric parameters measured by LITE.

Stratosphere

- Temperature and density profiles
- Tropopause height
- Aerosol backscatter cross section
- Aerosol scattering ratio

Troposphere

- Aerosol scattering ratio
- Aerosol backscatter cross section
- PBL optical depth
- PBL height

Clouds

- Top and base heights
- Number of cloud layers
- Geographic distribution
- Optical depth
- Extinction profile

2. Instrument characteristics and operational scenario

a. Instrument description

A brief description of the LITE instrument is presented here; the instrument has been discussed in detail by Couch et al. (1991). The LITE system consists of a laser transmitter module, a receiving telescope, an assembly mounted behind the telescope holding the receiving optics and electronics, and several electronics subsystems. These subassemblies are mounted to a spacelab pallet, which will be carried in the cargo bay of the space shuttle. LITE is not steerable, other than by attitude maneuvers performed by the shuttle.

The transmitter consists of two identical flashlamp-pumped Q-switched Neodymium:YAG lasers. The two-laser design provides redundancy in case of a failure in one of the lasers. By incorporating doubling and tripling crystals, part of the energy at the fundamental wavelength of 1064 nm is converted to the second and third harmonics at 532 and 355 nm. The receiving telescope is a Cassegrain design with a 38-inch-diameter primary mirror, originally built as a prototype for the NASA Orbiting Astronomical Observatory (OAO) spacecraft. Laser light backscattered by the atmosphere is collected by the telescope and directed onto photomultipliers, for the 532- and 355-nm channels, and an avalanche photodiode for the 1064-nm channel. The field of view is determined by a selectable aperture stop. A wide aperture for night use and a narrow aperture for daytime use are available. Narrowband interference filters can also be moved into the optical path to reject the bright sunlit background during daytime portions of the orbits. The lidar return signals are amplified, digitized, stored on tape on board the shuttle, and simultaneously sent to the ground using a high-speed data link. An electronic bandwidth of 2 MHz limits the range resolution to 35 m. The instrument is commanded from the ground over a low-rate telemetry link. Instrument parameters are shown in Table 2.

Since observations will be conducted with the laser beam pointed toward the earth's surface, it was nec-

TABLE 2. LITE instrument parameters.

Output wavelength (nm)	1064	532	355
Output energy (mJ)	486	460	196
Laser pulse length (ns)	27	27	31
Beam divergence (mr)	1.0	0.6	0.6
Detector QE	33	14	21
Field of view	Selectable: 1.1 mr, 3.5 mr, and opaque		
Sampling interval (m)	15		
Primary mirror diameter (m)	0.985		

essary to consider the potential for eye damage to an observer on the ground within the laser footprint. The system has been designed so that mean exposure levels at all three laser wavelengths are well below the maximum permissible levels defined by ANSI standards, even for a dark-adapted ground observer looking directly upward and using binoculars. Further, the probability of exposure levels instantaneously exceeding permissible levels due to scintillation effects has been shown to be negligibly small (Winchester 1990).

b. Sensitivity analysis

Simulation studies have been conducted to estimate the magnitude of the lidar return for the purposes of instrument design and experiment planning. A representative set of simulated signal profiles shown as a function of altitude above the earth's surface is given in Fig. 1. In the absence of clouds, the backscattered signal amplitude will generally increase down to the surface of the earth, from which a very strong return will be received. The stratospheric aerosol model used in this simulation is an estimate of the state of the stratosphere at the time of the LITE mission in 1994. The range of surface return strengths is indicated, as well as the effect of a layer representing the optical characteristics of Saharan dust in the midtroposphere. Much stronger returns will be received from clouds. A dense cloud will completely extinguish the transmitted laser pulse, preventing observations at lower altitudes. The pulse will penetrate most cirrus clouds, allowing the atmosphere and other cloud layers beneath to be probed.

The signal-to-noise ratio of the return varies by many orders of magnitude between the stratosphere and the earth's surface and will cause the error in the determination of the scientific parameters from a single lidar profile to vary from a few percent to hundreds of percent. Clouds and optically thick aerosol layers can be detected with a single lidar return, day or night, while the measurement of stratospheric aerosol requires averaging several hundred shots to achieve the required accuracy. As an example, Table 3 shows the number of laser shots required to detect and determine the altitude of subvisible cirrus, dense cirrus, Saharan dust, and the top of the planetary boundary layer. Multiplying the number of shots by 0.74 km gives the obtainable horizontal resolution.

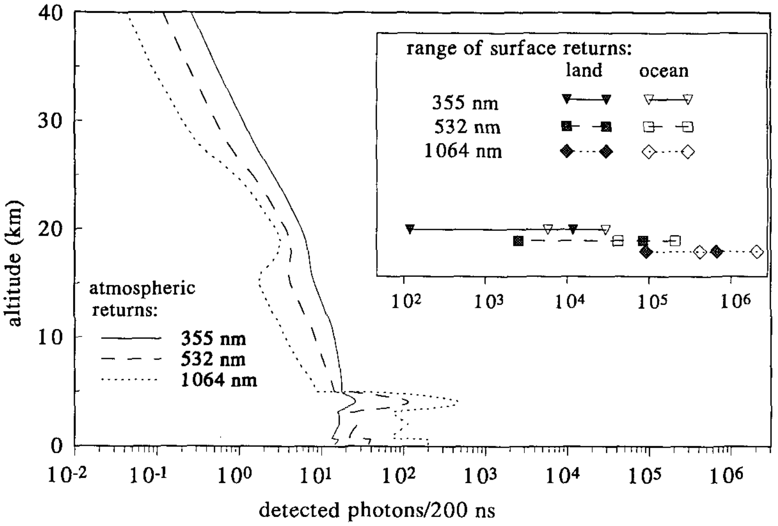

FIG. 1. Simulation showing the LITE atmospheric return signal and the range of returns expected from land and ocean surfaces in terms of the number of photons detected per system time constant. The atmospheric model includes a Saharan dust layer and the stratospheric aerosol loading at the time of the mission, estimated from the expected decay of the aerosol injected by the June 1991 eruption of Mt. Pinatubo.

c. Operational scenario

The first flight of LITE is scheduled for a standard 7-day shuttle mission. The planned orbit is near-circular with 57° inclination and 160 n mi (296 km) altitude. This altitude gives an orbital period of about 90 min and a ground track velocity of 7.4 km s^{-1}. As the shuttle orbits the earth, LITE is operated in a nadir viewing mode from the cargo bay as shown in Fig. 2a. When lasing, a series of circular footprints is drawn out on the surface of the earth, shown in Fig. 2b. The diameter of the footprints depends on the divergence of the laser beam at each wavelength.

Lidar observations are planned for a total of 45 h over 5 days of the mission: 9 hours per day, divided into two segments of three orbits each. As this will be the first lidar system operated in orbit, a significant portion of the mission will be concerned with testing the ability to command and configure the instrument and with verifying basic system operation. After instrument integrity has been established, observations will be conducted to support a variety of scientific investigations. A sampling of these investigations is outlined in the next section.

LITE observations will be conducted in conjunction with space-based, airborne, and ground-based correlative measurements to assist in measurement validation. These measurements are an integral part of the flight plan. Instrumentation employed in this effort will include 1) ground-based and airborne lidars, 2) solar spectral radiometers for optical depth, 3) in situ aerosol samplers for computation of aerosol optical properties, 4) multispectral visible and infrared satel-

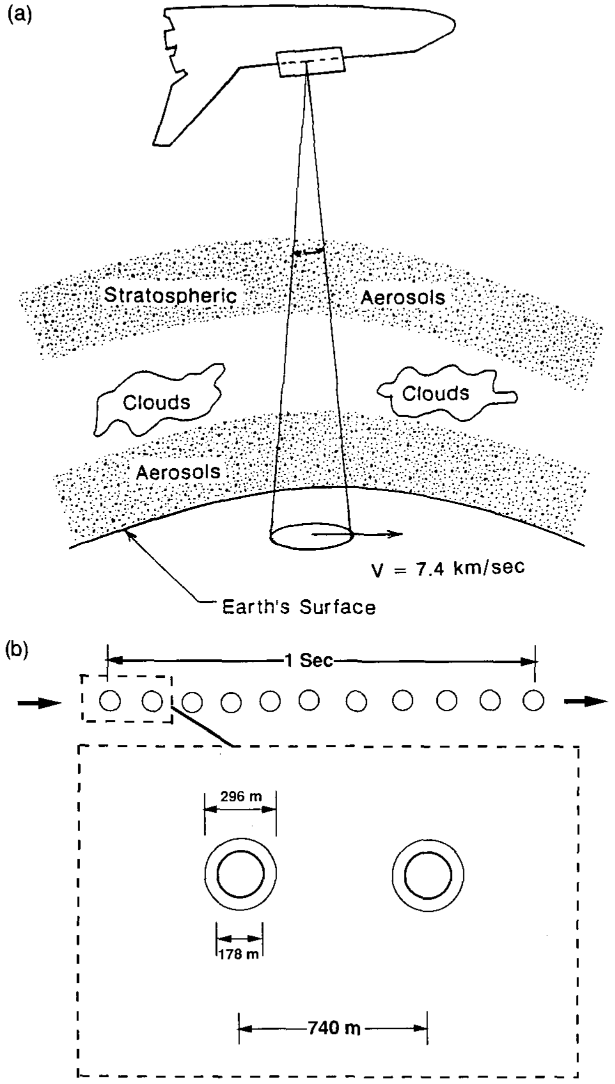

FIG. 2. (a) LITE orbital configuration, and (b) instrument footprint for 355- and 532-nm beams (thick line), 1064-nm beam (thin line).

lite imagers, and 5) coincident SAGE II measurements of aerosol extinction.

Planning of the correlative measurements program is under way. Researchers who feel that they could contribute to such a validation are encouraged to contact the LITE project scientist.

3. Investigations planned

Figure 3 shows the ground track covered in one day by a shuttle in a 57° inclination orbit. The orbit is highly precessing, providing the opportunity for diurnal studies. Successive orbits cross the equator at a separation of 2500 km. Figure 4 is a sketch of atmospheric phenomena that might be studied with LITE by observing their associated clouds and aerosols. The sketch shows a latitudinal section from about 60°N to about 60°S. LITE will obtain a cross section in less than 0.5 h as the space shuttle circles the earth. During a single 4.5-h observing period, three adjacent cross sections will be recorded on successive orbits, spanning 5000 km, allowing study of synoptic-scale phenomena.

Figure 4 shows possible tropopause gaps associated with polar jets (b) and subtropic jets (d). Above the tropical tropopause (e) are arrows representing the poleward transport of the stratospheric aerosol. The tropopause can often be identified through variations in stratospheric and upper-tropospheric aerosol layers, and is also often associated with visible and subvisible cirrus [(c) and (e)]. One can map the location, height, and distribution of marine boundary-layer stratocumulus (f), which can be difficult to detect at night using passive IR imagery. The slope of the trade inversion (h) is sketched near 20°N. The height of the inversion can be determined from a measurement of the heights of cloud tops and aerosol gradients. The intertropical convergence zone (ITCZ) is drawn at about 10°N and can similarly be located by observing the tops of the associated convective cells and, often, an extensive cirrus shield. Cumulonimbus tops overshooting the tropopause would also be observable. Other features of the large-scale circulation such as the Indian summer monsoon and the western Pacific Walker circulation would also be observable through their associated cloud systems. Frontal systems and storms [(g) and (j)] would be observable at midlatitudes. Throughout the Southern Hemisphere we would see a similar picture of the atmospheric structure, depending on season, and would be able to characterize north–south asymmetries.

The remainder of this section discusses areas where observations of clouds, tropospheric and stratospheric aerosols, and stratospheric density variations conducted during the first flight of LITE will improve our understanding of the atmosphere.

a. Clouds

Clouds are intricately tied into the processes that drive the global circulation and those that determine the global energy balance. The latent heat released by tropical weather systems combined with the radiative heating of cirrus shields represent the major energy sources for the general circulation of the atmosphere (Ramanathan 1987). In addition, the earth's radiation budget is largely governed by the distributions of water vapor and clouds. Clouds significantly influence both the incoming solar flux and the outgoing thermal emission. The net magnitudes of the solar and infrared effects are such that low clouds cause a surface cooling; cirrus, depending on optical depth, may produce warming or cooling at the surface (Ramanathan

TABLE 3. Aerosol detectability—number of shots required for 95% detection probability with 40-m vertical resolution. Surface albedo = 0.1 except for dense cirrus, where albedo = 0.8.

	Top height	Layer thickness	1064 nm		532 nm		355 nm	
	(km)	(km)	Night	Day	Night	Day	Night	Day
Boundary layer	0.6	0.6	1	6	1	55	224	>1000
Saharan dust	6	2	1	1	1	3	5	>1000
Subvisible cirrus	10	0.03	1	1	1	4	1	286
Dense cirrus	10	0.03	1	1	1	1	1	3

et al. 1989; Ramanathan and Collins 1991). Uncertainties in the role of clouds in climate change are among the most serious impediments to reliable prediction of the effects of increasing greenhouse gases. We cannot predict with any confidence what will happen when the climate is perturbed by an increase in CO_2 because we do not know how global cloud systems will respond to climate change. Even the radiative effects of clouds in the present climate are not known in any detail. Incorporation of cloud properties into numerical models of the atmosphere (global climate models or GCMs) is relatively crude, so that only approximate predictions can be made. In fact, a recent comparison of 19 GCMs using different cloud parameterizations did not agree even on the sign of the cloud feedback (Cess et al. 1990).

Modern cloud climatology datasets, such as those being produced by the International Satellite Cloud Climatology Project (ISCCP), are an enormous improvement over the best data available only a decade ago. A number of major experiments now under way have begun to further improve our understanding of the climatic effects of clouds (e.g., Minnis et al. 1990; Betts and Boers 1990). Nevertheless, serious uncertainties remain concerning the global distributions of some of the climatologically most important cloud types, such as thin cirrus and marine stratus. LITE will be able to unambiguously detect and characterize these cloud types for which retrieval is difficult using conventional methods, and accurately determine their heights. Additionally, LITE will measure base heights of optically thin clouds, a parameter critically important for the energy balance at the earth's surface that is not now available. LITE will provide a unique and complementary dataset on the distribution of clouds and will contribute to our knowledge of their optical properties and aid in modeling climate change.

These cloud observations are also essential to improving current cloud-retrieval methods. A particu-

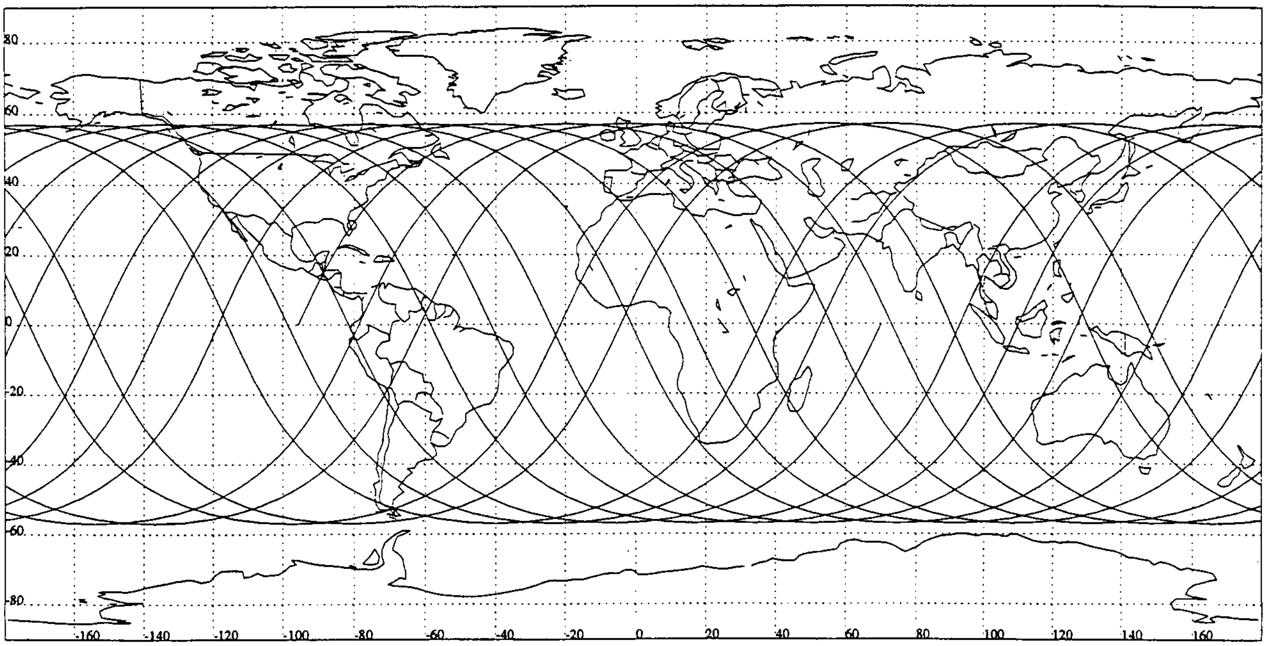

FIG. 3. Shuttle ground track for one day, assuming 57° inclination and 296-km altitude.

larly vexing problem in the retrieval of cloud properties from conventional satellite observations is the treatment of multilayered cloud systems. Multilayered and complex convective cloud systems make up the majority of cloud systems on the 250-km scale, and current schemes for analyzing such systems are, at best, simplistic (Coakley and Baldwin 1984; Minnis and Harrison 1984). By providing statistical distributions of the heights of clouds forming multilayered systems on the 250-km scale, LITE will provide new guidance for the development of realistic retrieval models on which to base the analysis of routine satellite observations.

Finally, LITE will allow estimates of cloud radiative properties such as emittance and optical depth. Cloud extinction derived from measurements of pulse penetration can provide verification for retrievals of hydrometeor size and cloud reflectivity and emissivity obtained from multispectral satellite imagery data (Spinhirne and Hart 1990).

b. Aerosols in the lower atmosphere

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. Evaluation of the impact of aerosols on the radiative budget is hampered by the lack of information on the global distribution and characteristics of natural and anthropogenic aerosols. The sources and sinks of tropospheric aerosols and the long-range transport of aerosols in the free troposphere are also poorly understood. We are aware of major features such as the transport of desert dust from the Saharan and central Asian deserts, but existing satellite technology lacks the vertical resolution necessary to study these properly.

Dust storms that originate in the Sahara affect the chemistry and radiative properties of the troposphere over the entire tropical Atlantic and the Caribbean (Prospero et al. 1981). These dust events extend over large regions of the Atlantic as they are transported in pulses occurring about every 5–7 days. This large-scale transport can be readily detected and tracked by LITE, which, over several flights, will lead to a better understanding of the geochemical cycle of material from the deserts of Africa to the Caribbean. These data can be combined with measurements from passive sensors to examine the importance of mineral aerosol deposition as a source of nutrients to the remote open ocean, trace gas photochemistry, and the long-range transport of aerosols and pollutants from industrial regions to the oceans (Harriss et al. 1984).

The PBL is the layer of the atmosphere where the coupling between the atmosphere and the surface of the earth occurs. Although the atmospheric general circulation is ultimately driven by solar radiation, most of the solar energy absorbed by the planet is deposited in the oceans. Turbulent fluxes of latent and sensible heat in the PBL remove this energy from the ocean and make it available for conversion to kinetic energy, which then drives atmospheric motion, from convective scales to the general circulation of the atmosphere. Studies of climate sensitivity therefore require careful consideration of the role of the PBL.

There have been few measurements of the properties of the PBL in the tropics. The turbulent fluxes of momentum, heat, and moisture that affect the PBL depth have typically been generated in GCMs using theoretical and semiempirical approaches. LITE provides the opportunity to test these predictions by measuring the marine PBL height directly, based on detection of the strong aerosol gradient that typically occurs at the top of the PBL. Over the ocean, aerosol optical depth of the PBL can be estimated from lidar surface return strengths (Reagan and Zielinskie 1991).

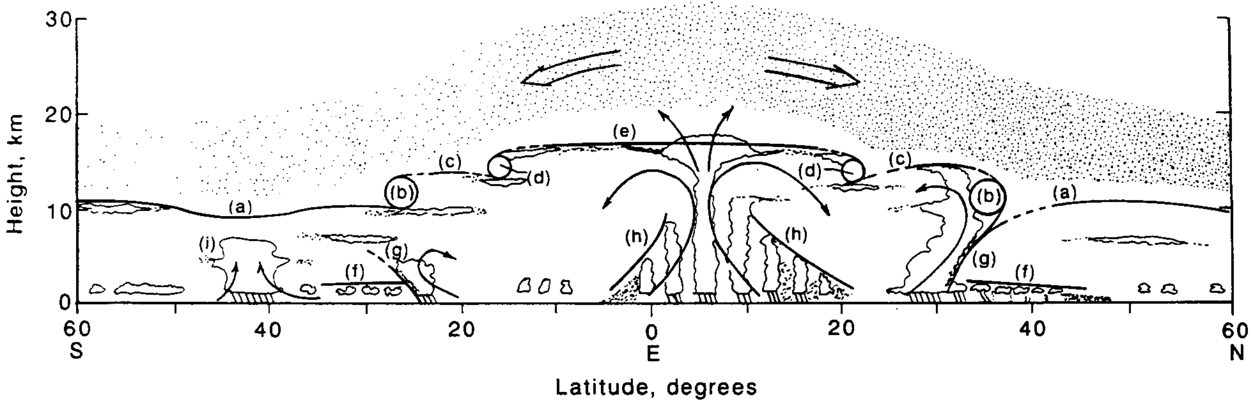

FIG. 4. Latitudinal cross section of the atmosphere depicting the locations of the (a) polar tropopause; (b) polar jet; (c) subtropical tropopause; (d) subtropic jet; (e) tropical tropopause; (f) convective PBL; (g) frontal systems; (h) trade inversion; and (i) midlatitude storms.

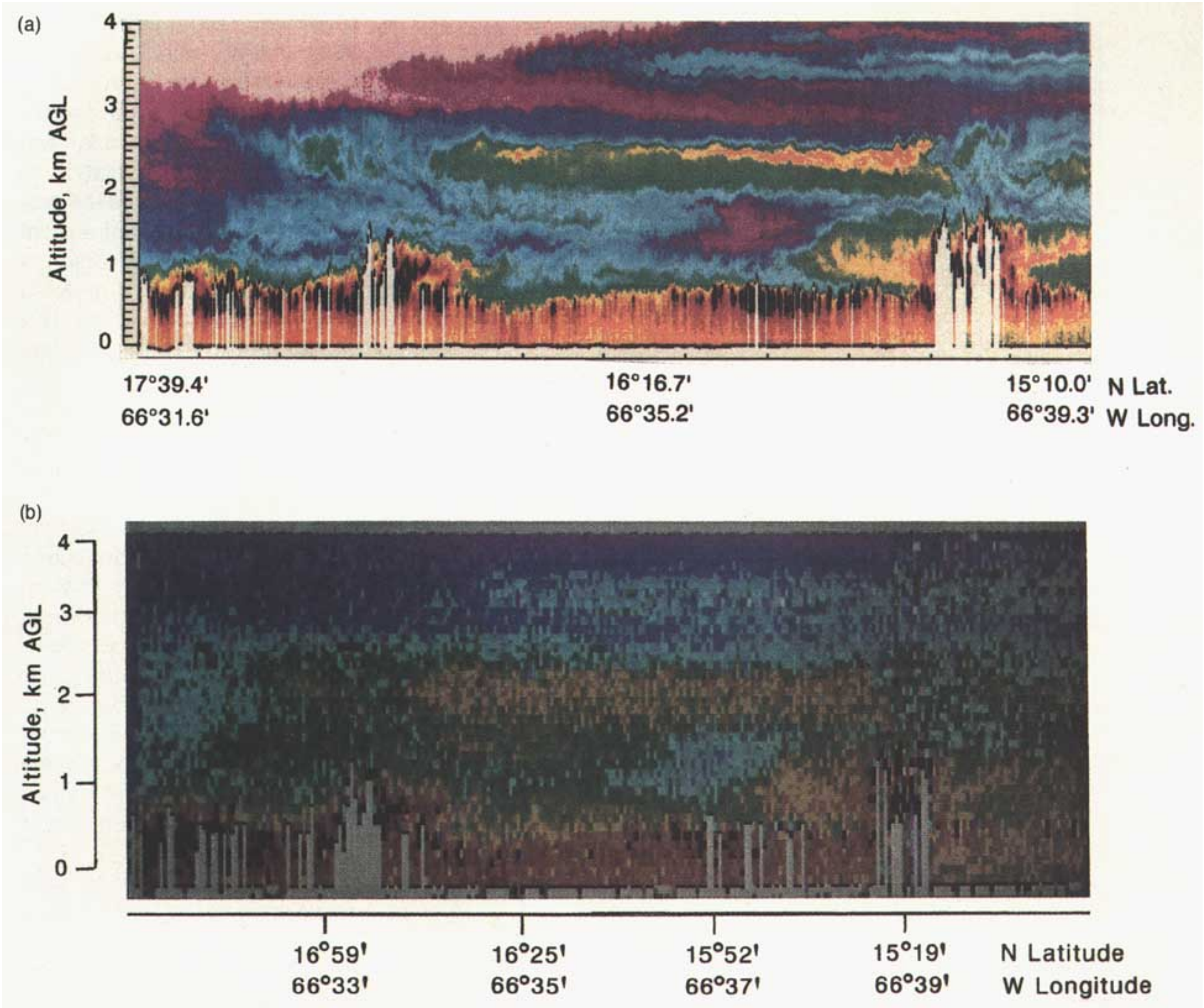

FIG. 5. (a) Airborne lidar measurements of relative aerosol backscatter during a flight south of Puerto Rico over the Caribbean on 12 July 1985 (Browell, unpublished data); (b) simulation of LITE measurements for data presented in (a).

LITE will be used to study the spatial and diurnal variability of the PBL, improving our ability to model the coupling between the ocean and atmosphere.

Figure 5a shows an example of the atmospheric structure observed with a downward-looking airborne lidar system over the Caribbean between Puerto Rico and Venezuela. The horizontal distance covered in the figure is about 240 km. The figure is a false color representation of the relative amount of atmospheric scattering detected by the lidar system, with a vertical and horizontal resolution of 15 and 100 m, respectively. The scattering ranges from low values in the magenta and blue to higher values in the orange, red, and black. The enhanced aerosol loading of the marine PBL can be readily seen in the figure (orange and black), with the depth of the PBL ranging from about 500 to 1000 m. Clouds can be seen forming at the top of the mixed layer with some cloud tops rising up to 1.8 km on the right-hand side of the figure. Since some of the clouds are optically thick, the lidar beam cannot penetrate through them and a shadow (white area) in the data is created beneath the cloud. In the free troposphere above the PBL, several different airmass regions can be seen. The region of enhanced aerosol scattering (yellow and orange) at about 2.3 km in the middle of the figure is from Saharan dust transported across the Atlantic, and the region of low aerosol scattering above 3.3 km in the upper left of the figure (pink) is clean air that was transported down from the upper troposphere.

To simulate the sensitivity of the LITE system, a portion of the data shown in Fig. 5a was scaled statistically and spatially to reflect the scene as it might be observed by LITE. Figure 5b shows the results of

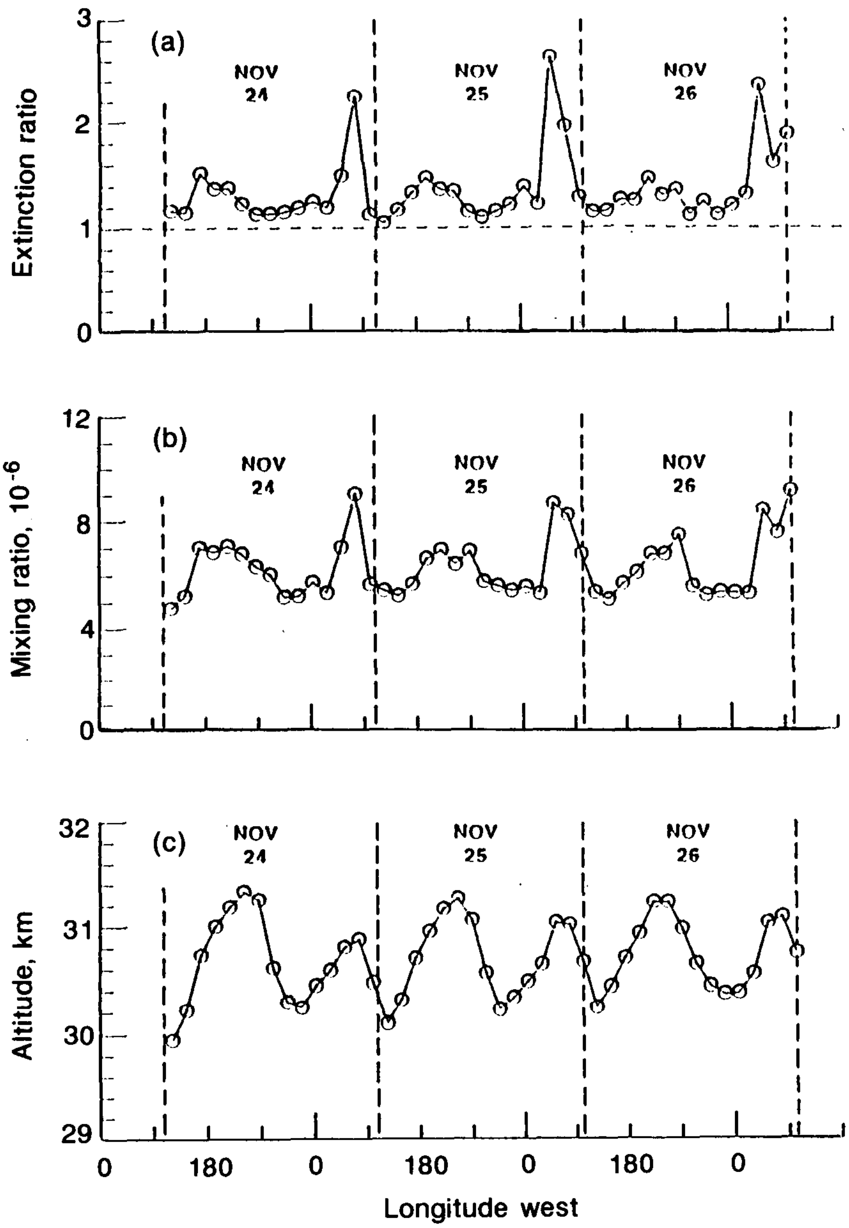

Fig. 6. Variation of aerosol extinction, ozone mixing ratio, and pressure altitude observed by SAGE II, 24–26 November 1985 (UT dates). Latitude is 46°–49°N. (a) 30-km aerosol extinction ratio; (b) 30-km ozone mixing ratio; (c) 10-mb pressure altitude.

this simulation at a resolution of 800 m (horizontal) by 100 m (vertical). Although LITE signal levels are significantly lower than for the airborne lidar, the large-scale structure is readily apparent.

c. Stratospheric aerosols

The stratospheric aerosol has been extensively studied with the SAGE I and II and the SAM I and II satellite instruments (McCormick and Wang 1987; Osborn et al. 1989; Wang et al. 1989). These are self-calibrating instruments able to measure aerosol extinction with good vertical resolution (1 km), which have provided a dataset suitable for deducing long-term trends. The basic limitation to studies using these data has been the relatively infrequent sampling over a given region of the globe, which is intrinsic to occultation instruments. LITE should provide a more detailed look at dynamic mixing and transport processes and give a better indication of spatial inhomogeneity of the aerosol. Simulation studies have shown the stratospheric aerosol scattering ratio can be retrieved to altitudes of 30 km at a resolution of 1-km vertical and 300-km horizontal under near-background conditions (Russell and Morley 1982; Russell et al. 1982). Due to the eruption of the Pinatubo volcano in June 1991, signal levels at the time of the mission will be much higher, providing even better resolution.

Stratospheric aerosol data obtained by the SAGE II satellite show evidence of strong dynamical changes. In winter, the stratospheric aerosol concentration is frequently controlled by planetary-wave activity. An example of this is shown in Fig. 6. Figure 6a shows the variation of the aerosol extinction ratio at an altitude of 30 km over a 3-day period in 1985. Figure 6b shows similar variations occurring in ozone mixing ratio, while Fig. 6c shows the variation in the 10-mb pressure altitude, indicating planetary-wave structure. All three variables are clearly correlated. Examination of the global map of extinction ratio values at these altitudes shows that the only region from which the high values shown in Fig. 6a could have originated is a low-latitude band centered on the equator. The variation seen here illustrates part of a seasonal global circulation pattern in which stratospheric material at low latitudes is transferred to middle and high latitudes.

Recent studies of the polar stratosphere in winter-time have led to an awareness of the existence of a region of strong potential vorticity gradient at high latitudes, which inhibits meridional motion (Juckes and McIntyre 1987). Some material is, however, transferred across this boundary by a process of erosion by planetary waves, where it is vigorously mixed to middle latitudes. Recently, M. E. McIntyre of the University of Cambridge has suggested that a similar potential vorticity barrier may exist at low latitudes, and SAGE II data have been examined to test the validity of this hypothesis (McIntyre 1989, personal communication). Using 1-μm-wavelength aerosol extinction as a tracer of stratospheric motion, a striking feature shown by this analysis is the partial confinement of material to a band between 20°S and 20°N. This confinement coincided with a potential temperature gradient and is consistent with a potential vorticity barrier at these latitudes (Trepte and Hitchman 1992).

The LITE mission offers an excellent opportunity to study these phenomena. SAGE II data indicate that a strong aerosol gradient persists from winter into summer in each hemisphere. Investigation of the changes that take place in the aerosol distribution on isentropic surfaces and comparison with SAGE II data will give additional insight into the dynamical mechanisms involved. Although longer observational periods are required to determine aerosol climatology, a mission of even a few days can give very useful information. We are at present ignorant as to the structure of the aerosol gradients at the boundary of the low-latitude band and the manner in which the latitude of maximum gradient changes with longitude and atmospheric dynamical conditions. LITE can provide a view of the entire equatorial region with measurements taken over just a few days.

d. Atmospheric density/temperature

Gravity waves, tides, and planetary waves play important roles in determining the large-scale circulation and structure of not only the stratosphere, but also the mesosphere and thermosphere. These phenomena are the dominant mechanisms for energy transport between the lower and upper atmosphere. Gravity waves and tides propagate upward into the stratosphere and mesosphere, where they exert a powerful drag force on the mean flow with strong secondary effects on the temperature distribution.

While LITE lacks the sensitivity for observations in the mesosphere, the effects of waves and tides on the lower atmosphere can be studied. LITE will begin to address the current lack of knowledge about this altitude region by measuring the horizontal variations of the density and temperature structure. Above 30 km or so, the aerosol concentration is low enough that laser backscatter becomes purely Rayleigh and can be related directly to molecular density, making measurements of density profiles and calculation of temperature profiles possible (Hauchecorne and Chanin 1980; Gardner et al. 1989). Two-wavelength measurements allow at least partial correction of aerosol effects, extending measurements downward into the stratospheric aerosol layer. Performance simulations indicate atmospheric density can be measured to an altitude of 40 km with accuracy similar to that of other sensors that have been operated from orbit, but with greatly improved vertical resolution. Atmospheric and wave parameters that can be deduced from density and temperature profiles include the temperature and height of the tropopause, temperature lapse rate in the stratosphere, stratosphere density and temperature variations, and the amplitudes and wavelengths of stratospheric waves.

4. Summary and future directions

The first LITE mission will be focused on the evaluation and characterization of the instrument and the development of space-based lidar remote-sensing techniques. Further flights of LITE will expand on the applications and capabilities of the current system. A second flight is planned to occur 1 to 2 years after the first, without major hardware modifications. Building on the experience gained during the first flight, the second flight will provide the opportunity for further studies of tropical and midlatitude phenomena.

The design approach of LITE allows new measurement capabilities to be added by upgrading or replacing one or more modules. A modification under consideration for flights beyond the second flight, for example, is the addition of a cross-polarization channel, allowing the discrimination of water and ice phases of clouds (Sassen 1991). Replacement of the current laser with a tunable laser based on Alexandrite or Ti-Sapphire would allow accurate water vapor profiling. A source at 589 nm would allow resonance fluorescence measurements of mesospheric atomic sodium, which is an excellent tracer of wave effects in the mesopause region. Through the remainder of the decade, LITE will provide a test-bed for development of the technology necessary for the ultimate goal of a free-flying lidar system in polar orbit, able to measure clouds, aerosols, and gases on a global basis.

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