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LIDAR INSTRUMENTS PROPOSED FOR Eos

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Introduction

Lidar, an acronym for light detection and ranging, represents a class of instuments that utilize lasers to send probe beams into the atmosphere or onto the surface of the Earth and detect the backscattered return in order to measure properties of the atmosphere or surface. Lidar have been used since the early 1960s, shortly after the invention of the laser, and have become quite useful in a variety of applications. The associated technology has matured to the point where two lidar facilities, Geodynamics Laser Ranging System (GLRS) (Ref. 1) and Laser Atmospheric Wind Sensor (LAWS) (Ref. 2), have been accepted for Phase B studies for Eos. A third lidar facility, Laser Atmospheric Sounder and Altimeter (LASA) (Ref. 1), with the lidar experiment EAGLE (Eos Atmospheric Global Lidar Experiment)* was proposed for Eos. The EAGLE experiment for LASA was not accepted because of the weight and power requirements, and the tunable solid-state laser technology required for gaseous species such as water vapor was judged not yet ready for a long-term space mission.

The generic lidar system has a number of components (Ref. 3). They include controlling electronics, laser transmitters, collimating optics, a receiving telescope, spectral filters, detectors, signal chain electronics, and a data system. Lidar systems that measure atmospheric constituents or meteorological parameters record the signal versus time as the beam propagates through the atmosphere. The backscatter arises from molecular (Rayleigh) and aerosol (Mie) scattering, while attenuation arises from molecular and aerosol scattering and absorption. Lidar systems that measure distance to the Earth's surface or retroreflectors in a ranging mode record signals with high temporal resolution over a short time period.

The overall characteristics and measurements objectives of the three lidar systems proposed for Eos are given in Table 1.

Geodynamics Laser Ranging System (GLRS) (Ref. 1)

GLRS is a lidar system being designed to measure the position of retroreflectors to an accuracy of <1 cm and Earth surface height along the nadir ground track to an accuracy of <10 cm (see Table 2). The retroreflectors will be placed in regions of known seismic activity with easy access for ground teams. Each region, such as along the San Andreas Fault in California, will have a number of retroreflectors whose positions will be measured at regular intervals or during times of seismic activity. It is important to measure the distance to as many retroreflectors as possible at a given time to help reduce errors due to uncertainty in orbit knowledge and variations in the atmospheric index-of-refraction. Two wavelengths will be used to help reduce errors because of refractive index variations.

Topographical measurements will be made primarily over polar ice fields, where it is expected that the smaller ground spot size (60 m) compared to microwave systems will lead to more accurate determinations of snow and ice heights, and hence, the stored water amounts.

In both measurement programs, optically dense clouds between the platform and the target region will render it impossible to obtain signals from the surface. Although there is consideration being given to using GLRS to study cloud properties in addition to the other

* E. V. Browell, Eos Atmospheric Global Lidar Experiment (EAGLE) Proposal, submitted to NASA Headquarters, July 15, 1988.

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measurements, when clouds do interfere, it would be better not to operate the lasers so as to prolong the instrument lifetime. The Principal Investigator of the GLRS instrument (S. Cohen, Goddard Space Flight Center) has expressed an interest in having the Information Sciences Experiment System (ISES) acquire and process cloud location data from any available source and relay to GLRS enough to allow GLRS to decide whether or not to attempt to make measurements.

Laser Atmospheric Wind Sensor (LAWS) (Ref. 2)

LAWS is a lidar system being designed to measure tropospheric wind fields (see Table 3). LAWS will use aerosol backscatter at 9.11 microns to determine the horizontal wind components. The lidar will be able to measure the Doppler frequency shift along the line-of-sight by measuring shifts from the local oscillator frequency and using surface returns to correct for the relative motion between the platform and the Earth. The lidar system will scan conically so that it samples a large swath around the ground track, and so that it can acquire returns in two pointing directions to provide enough information to calculate the horizontal wind components, assuming that the vertical component is zero or known. The vertical resolution of LAWS will be about 1 km, with very few photons being received in this interval. It would be useful for the analysis to add any information about the vertical and horizontal distribution of aerosols and clouds in the lower 20 km of the atmosphere in the region of the swath. Winds can change speed and direction with altitude, and regions with different winds may have different aerosol loading. In addition, it would be useful to have information concerning the existence of high-altitude cloud cover, because LAWS cannot penetrate clouds. This information could help extend the operational lifetime of LAWS, because it will probably be limited by the number of laser firings.

Eos Atmospheric Global Lidar Experiment (EAGLE) *

EAGLE was proposed to use the LASA facility for lidar measurements of water vapor, aerosol, and cloud profiles (see Table 4). It was not initially selected for Eos because of the weight and power requirements of the combined system and because the tunable, solid-state laser technology was deemed to be not sufficiently mature for an extended mission in space. However, EAGLE/LASA is discussed here for completeness. Eagle was proposed in a Differential Absorption lidar or DIAL mode for measuring water vapor. In this approach, one laser wavelength is tuned to an absorption line of the molecular species of interest, while the other is tuned nearby but away from absorption by that species. This generally ensures that the difference is due primarily to absorption by the species of interest, rather than to other species or changes in molecular and aerosol scattering with wavelength. A ratio of the backscattered radiation with range is used to determine the density of the species along the lidar line-of-sight. Of course, the non-absorbed wavelength can be used to measure aerosol properties, such as the aerosol vertical profile or cloud top and mixing layer height.

The lidar signal is received as photon counts versus time (range) for each wavelength. In processing the data, the background signal has to be subtracted, and corrections have to be made for range (the signal should decrease as $1/R^2$, where R represents the range to the scattering volume), for modeled atmospheric scattering and extinction. The data must also be checked for the cloud presence. These corrections can be made either on individual returns or on averages of a number of returns, depending on which leads to more accurate results. A number of signals have to be averaged in order to increase the number of measured photons and reduce the statistical error.

* E. V. Browell, Eos Atmospheric Global Lidar Experiment (EAGLE) Proposal, July 15, 1988.

References

1. LASA, Lidar Atmospheric Sounder and Altimeter, Eos Instrument Panel Report, Vol. IId, NASA, 1987.

2. LAWS, Laser Atmospheric Wind Sounder, Eos Instrument Panel Report, Vol. IIg, NASA, 1987.

3. R. M. Measures, Laser Remote Sensing: Fundamentals and Applications, J. Wiley & Sons, N.Y., 1984.

TABLE 1. Eos LIDAR* INSTRUMENTS

INSTRUMENT:	GEODYNAMIC LASER RANGING SYSTEM (GLRS)	LASER ATMOSPHERIC WIND SENSOR (LAWS)	Eos ATMOSPHERIC GLOBAL LIDAR EXPERIMENT (EAGLE) ATMOSPHERIC
PLATFORM:	NPOP-1	JPOP	TBD
WAVELENGTH REGION:	1.06 MICRONS 532 nm	9.11 MICRONS	725 nm
MEASUREMENT OBJECTIVE:	PLATE TECTONIC MOTION, EARTH SURFACE HEIGHT CLOUD-TOP HEIGHT	TROPOSPHERIC WINDS	WATER VAPOR, AEROSOLS
MEASUREMENT PRINCIPLE:	SIGNAL VS TIME OF FLIGHT	DOPPLER SHIFT	SIGNAL VS TIME-OF-FLIGHT, DIFFERENTIAL ABSORPTION
HERITAGE:	LAGEOS, MARS OBSERVER	GROUND, AIRCRAFT SYSTEMS	GROUND, LOW-ALTITUDE AIRCRAFT, LASE SYSTEMS

*LIDAR = LIGHT DETECTION AND RANGING

TABLE 2. GEODYNAMICS LASER RANGING SYSTEM (GLRS)

LIDAR SYSTEM PARAMETERS:

LASER:	Nd:YAG (1.06 MICRONS) FREQUENCY-DOUBLED Nd:YAG (532 nm)
PULSE ENERGY:	10 mJ
PULSE REPETITION FREQUENCY:	10 Hz
RECEIVER APERTURE:	30 cm
POINTING FLEXIBILITY:	+/ – 60 DEGREES
POINTING FOR SURFACE HEIGHTS:	NADIR

RETROREFLECTOR ACQUISITION ROUTINE:

INPUT PLATFORM POSITION, ATTITUDE

DIRECT LIDAR TOWARDS CALCULATED POSITION OF RETROREFLECTOR

FIRE LASER

SCAN LIDAR UNTIL RETROREFLECTOR RETURN SIGNAL FOUND

SCIENTIFIC OBJECTIVES:

PLATE TECTONIC MOTION

EARTH CRUSTAL DEFORMATION

POLAR ICE CAP THICKNESS, EXTENT

CLOUD-TOP HEIGHTS

ANCILLARY DATA REQUIRED:

CLOUD COVER

VOLCANIC, EARTHQUAKE ACTIVITY

SYNERGISM:

RADAR ALTIMETER

SAR

TABLE 3. LASER ATMOSPHERIC WIND SENSOR (LAWS)

SYSTEM PARAMETERS

LIDAR	
TELESCOPE APERTURE	1.25 m
FIXED NADIR LOOK ANGLE	45 DEGREES
WAVELENGTH	9.11 MICRONS
LASER	CO_2 WITH O-18 ISOTOPE
PULSE ENERGY	10 JOULES
PULSE REPETITION FREQUENCY	8 Hz
PULSE LENGTH	3-5 MICROSECONDS
TELESCOPE SCAN RATE	6 RPM
CROSS-TRACK REACH	700 km
WIND MEASUREMENT ACCURACY	1-3 m/SEC

USES OF DATA

IMPROVED NUMERICAL WEATHER PREDICTION

IMPROVED UNDERSTANDING OF MESOSCALE SYSTEMS

MORE ACCURATE DIAGNOSTICS OF LARGE-SCALE CIRCULATION AND CLIMATE DYNAMICS

IMPROVED UNDERSTANDING OF GLOBAL BIOGEOCHEMICAL AND HYDROLOGIC CYCLES

ANCILLARY DATA REQUIRED

LARGE REGIONS OBSCURED BY HIGH CLOUDS

AEROSOL VERTICAL DISTRIBUTION (FINE SCALE)

SYNERGISM

OCEAN SURFACE WINDS

STRATOSPHERIC WINDS

AEROSOL, MOLECULAR SPECIES TRANSPORT

TABLE 4. Eos ATMOSPHERIC GLOBAL LIDAR EXPERIMENT (EAGLE)

LIDAR SYSTEM PARAMETERS

LASER:	SOLID-STATE, DIODE-PUMPED
WAVELENGTH:	725 nm
PULSE ENERGY:	1 J
PULSE REPETITION FREQUENCY:	20 Hz
RECEIVER APERTURE:	1.25 m
POINTING:	NADIR

MEASUREMENTS:

AEROSOL VERTICAL PROFILE

MIXING LAYER, CLOUD-TOP HEIGHTS

WATER VAPOR VERTICAL PROFILE (1-km VERTICAL RESOLUTION BY 100–300 km HORIZONTAL RESOLUTION)

USEFUL INPUT DATA:

EXTENT OF CLOUD COVER

SYNERGISM:

MODIS, HIRIS - WATER VAPOR FOR CORRECTION OF SURFACE IMAGES

AIRS - WATER VAPOR VERTICAL PROFILE

LAWS - AEROSOL PROFILES, WIND FIELDS

STATUS:

AWAITING FURTHER TECHNOLOGICAL DEVELOPMENTS IN SOLID-STATE LASERS: LIFETIME, PULSE ENERGY, RELIABILITY, PULSE REPETITION FREQUENCY, BEFORE BEING CONSIDERED FOR A MISSION ON Eos.