26B2 **COMPACT LIDAR SYSTEMS FOR SURFACE, SHIP-BASED, AND AIRBORNE REMOTE SENSING OF THE ATMOSPHERE**

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INTRODUCTION

Although lidar systems have been used to achieve many notable observational results over the past three decades, in almost all cases the progress has come about via the deployment of complex, relatively-expensive instruments that require significant attention from highly skilled operators. This increases the cost of deploying many lidars, effectively limiting the range of cost-effective applications and pricing the technology beyond that affordable for all but large, well-funded applications.

At NOAA's Environmental Technology Laboratory (formerly the Wave Propagation Laboratory), a concerted effort has been underway for the past 2 years to develop compact, robust, easily-deployed lidar systems for atmospheric observations. We are currently testing and improving small systems to measure wind and turbulence properties, chemical species and water vapor concentrations, aerosol profiles, cloud base heights, and ozone profiles. Although performance of these new-generation instruments is generally more limited than larger, more traditional lidars, the advantages of easy operation make them well-suited for many research and operational measurement applications.

LIDAR DESCRIPTIONS

Table 1 shows the operating characteristics and measurement applications of four of the compact systems developed at ETL. Each of the instruments has unique characteristics and capabilities. The radio frequency-excited CO_2 lidar employs a master oscillator/power amplifier (MOPA) configuration to obtain high repetition-rate pulses with very good frequency stability for high resolution wind measurements. Originally, the system employed a Q-switched reference oscillator laser, a separate local oscillator laser, and a single laser amplifier (Pearson and Rye, 1992). The instrument was used in this configuration to measure wind profiles and vertical motion below stratocumulus cloud decks during the summer 1992 Atlantic Stratocumulus experiment in the eastern Atlantic.

Since then, the instrument has been redesigned to make it more suitable for dual wavelength probing of clouds and chemical species (Fig. 1). The major change involves replacing the Q-switched reference oscillator with dual, chopped, continuous-wave reference lasers. Energy from one or the other of these lasers is directed into the laser amplifier by means of an acousto-optic modulator. Because these lasers operate continuously, a portion of their energy can be picked off and used as the local oscillator in the heterodyne receiver. This configuration enables relatively easy switching of wavelengths while retaining the sensitivity advantages of heterodyne detection. However, because the output energy of the chopped,

Table 1: ETL compact lidar systems

APPLICATION	SYSTEM	WAVELENGTH	CHARACTERISTICS
Turbulence, vertical motion water vapor profiles, chemical species	Radio-frequency excited, high pulse rate CO_2 lidar; simultaneous dual wavelength capability	line selectable between 9 and 11 μm	5 mJ output will provide ranges to 5 km for aerosols, and 15 km for clouds
Small-scale structure, wind measurement in marine environments, water vapor profiles	Diode-pumped, injection-seeded Tm:YAG lidar	2.022 μm (etalon tunable)	200 Hz pulse rate, compact, will include stabilization system for ocean-going measurements
Lower tropospheric ozone and aerosol profiling for air quality	Ultraviolet DIAL lidar employing Nd:YAG lidar (quadrupled and Raman shifted to transmit two UV wavelengths	simultaneous 266 nm 289 nm 532 nm 1.06 μm	compact; seatainer mounted; produces ozone profiles to 3 km with 100 m resolution
Continuous, unattended surface-based cloud climatology; cloud base height; aerosol backscatter profiles	Nd:YLF laser transmitting 40 μJ per pulse at 2 KHz pulse repetition rate	523 nm	Will be lodged in temperature-controlled, weather proof housing; will measure cloud base heights for all tropospheric clouds

continuous-wave lasers is considerably less than when they are operated in Q-switched mode, additional amplifiers are necessary to boost pulse energy output. We envision using requiring two or three amplifiers to obtain the 5 mJ design goal.

A second compact Doppler system developed at ETL and operating in the near infrared at 2.02 μm is currently being used to study the role of boundary layer eddies in modulating surface fluxes in the Canadian boreal forest. This lidar employs a diode-pumped Th:YAG transmitter to produce pulses of 2-5 mJ at pulse rates of up to 200 Hz. Operation at the shorter wavelength (relative to CO_2 laser wavelengths) provides better range resolution (to 50 m) enabling more complete mapping and characterization of turbulent eddies. The Th:YAG lidar system has been designed to permit easy mounting and operation on a medium-size aircraft. Because radiation at 2.022 μm is only weakly absorbed by water vapor, this lidar will be particularly useful for studies of winds and turbulence in marine regions. Plans call for the instrument to be operated aboard a ship for marine boundary layer studies in the spring of 1995.

Both of the compact systems described above have been installed in modified shipping containers for easy transport. In an effort to introduce some standardization of components, both systems employ virtually identical Doppler processing and display systems and scanner-control hardware.

Also listed in Table 1 are the characteristics of a compact lidar designed for continuous, unattended profiling of cloud bases and aerosol backscatter through the troposphere. The instrument concept is similar to that suggested by Shipley et al (1983) and initially implemented by Spinhirne (1993). Low-energy pulses and long integration times are used to achieve eye safety while still providing the sensitivity to observe clouds and aerosols throughout the troposphere. Because the NOAA system is aimed at providing calibrated aerosol measurement, significant design effort has been aimed at achieving linearity and easy calibration. Future plans will include the addition of a Pockels cell in the transmitted beam to enable depolarization studies of cloud properties. The lidar will be mounted in a sealed environmental housing, including an air-to-air heat exchanger for thermal management.

A fourth ETL lidar designed specifically for profiling tropospheric ozone in air quality studies is described elsewhere in this volume (Zhao et al, 1994).

APPLICATIONS

Each of the individual lidar systems described is intended for use in a multitude of applications. The compact, MOPA CO_2 lidar will be employed to study differential scattering effects from ice clouds at the Department of Energy's Clouds and Radiation Testbed site. Calculations indicate that measurements at thermal wavelengths provide information on particle size, phase, and orientation. The Doppler capability of the instrument will be important in characterizing vertical motions, especially in thin cirrus clouds that are not well-observed by mm-wave radars.

The 2 μm Doppler system will be deployed in a wide variety of upcoming studies. During the summer 1994 boreal forest study, the excellent range and velocity resolution of the instrument will enable fine-scale probing of turbulent eddies and their effect on surface-atmosphere exchange. This work will be extended to shipboard measurements in the marine boundary layer in spring 1995 (a shipboard stabilization system for the instrument is currently under development). Further on, the instrument will undergo test flights on a NOAA P-3 aircraft to assess its capability to make airborne measurements of wind fields in regional scale dynamics studies.

One research objective to be investigated during the next year is the measurement of vertical fluxes of ozone and water vapor using eddy-correlation techniques. By combining Doppler wind measurements and DIAL species measurements, we hope to be able to investigate transport of pollutants and moisture between the boundary layer and free troposphere.

Several applications are projected for the stand-alone aerosol lidar. Initially, it will be used to provide information on cloud presence for surface radiation studies. Other uses will include arctic boundary layer characterization, correction of satellite-measured surface quantities, and aerosol profiling in support of investigations of the effect of aerosols in countering global warming trends.

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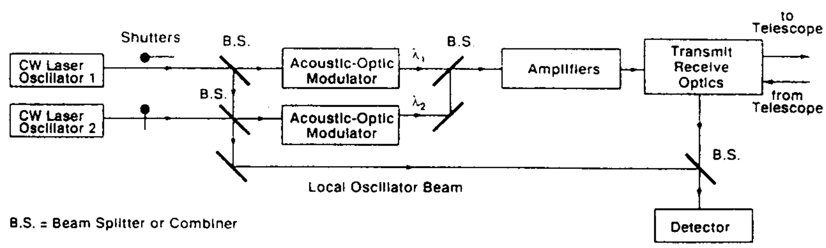

Fig. 1: Schematic of dual wavelength, high prf CO_2 MOPA Doppler lidar