COHERENT DOPPLER WIND LIDAR CONCEPTS FOR GLOBAL SCALE OBSERVATIONS

Robert T. Menzies
Jet Propulsion Laboratory, Pasadena, California

1. INTRODUCTION

Earth-orbiting Doppler lidar hrrs a unique potential for measurement of wind fields in the troposphere with the spatial resolution consistent with the needs of global scale models. Knowledge of the global tropospheric wind field is widely recognized as fundamental to advancing the understanding and prediction of weather and climate (Baker et. al., 1995). Numerous feasibility studies have concluded that it is possible to measure boundary layer and free tropospheric winds from space using Doppler lidar technology (Huffaker, 1978; Huffaker *et al.*, 1980, 1984; Menzies, 1986; NASA, 1987), and that the potential impact of these data on the performance of general circulation models is significant (Atlas and Emmitt, 1991; Baker et al., 1995).

In addition to wind measurements, a Doppler lidar can also provide information on the boundary layer aerosol backscatter coefficients and thickness, the attitudes of elevated layers of aerosols in the free troposphere, and cloud heights. Scanning at an off-nadir angle is necessary in order to obtain the horizontal component of the wind field. A conical "step-scan" is envisioned whereby a small number of pulses would be transmitted at several selected azimuth angles within a conical scan, at approximately 30-degree nadir angle. Consequently the cloud and aerosol data would be obtained in discrete, non-contiguous patches within a several hundred km width swath. This is in contrast to the situation with a nadir-pointing backscatter lidar, for which the 2-dimensional, contiguous cloud and/or aerosol profiles are obtained in a thin ribbon along the sub-orbital flight track.

2. HERITAGE OF THE TECHNIQUE

Coherent Doppler lidar has an extensive and growing heritage for wind measurement from both airborne and ground-based platforms. The coherent Doppler lidar technique was first demonstrated as a method for remote measurement of wind fields in the early 1970's. A low-energy airborne pulsed CO_2 lidar was used to study winds in the vicinity of severe storms and other dynamic processes during the 1970s and early 1980s (Bilbro *et al.*, 1986). The use of coplanar scanning allowed vector winds to be resolved from line-of-sight velocities determined at varying look angles for these and other field measurements. An airborne instrument featuring conical scanning about nadir, similar to the scanning approach envisioned for a satellite instrument, has been developed through a collaborative French-German effort (Werner *et* rd., 1989) and is scheduled for flight in 1997. A tutorial review of the coherent Doppler technique for measuring wind fields can be found in Menzies and Hardesty (1 989).

In 1986 studies of the comparative performance capabilities of various Earth-orbiting Doppler lidar concepts were undertaken, and the results pointed out the significant efficiency advantage of the coherent Doppler lidar approach (Menzies, 1986).

Also in 1986 NOAA scientists demonstrated a ground-based pulsed Doppler wind lidar employing coherent detection along with an injection-seeded TEA-carbon dioxide laser transmitter (Hardesty *et al.*, 1988). The NOAA system has been employed extensively to investigate a variety of atmospheric phenomena, including thunderstorm outflows (Intrieri *et al.*, 1990), upper-level winds associated with a strong frontal passage (Neiman *et* al., 1988), and sea-breeze evolution (Banta *et al.*, 1993).

Based on the success of the laboratory, ground-based, and airborne experiments with CO_2 Doppler lidar, the Laser Atmospheric Wind Sounder (LAWS) instrument (General Electric Astro Space 1992; Lockheed 1992) was recommended for inclusion in the NASA Earth Observing System (EOS) instrument suite in 1985. Budgetary pressure was a key factor in the de-selection of the LAWS instrument and science team from EOS in early 1994. Until the de-selection of LAWS, plans for a space-based wind lidar were being built around CO_2 laser technology, a mature technology with well recognized means for generating large pulse energies with relatively high "wall-plug" electrical efficiencies. In the early years of the EOS program the LAWS instrument characteristics were driven by the desire to obtain continuous wind profiles through all altitudes of the troposphere (in the absence of optically thick clouds), using the backscatter from the clouds and tropospheric aerosol to provide the signals. A rather large and expensive lidar design resulted. The vision of a transmitter with 20 J pulse energy and a collecting telescope (optical antenna) with a 1.6 m primary was replaced by several mission concepts that were < 1 J and had 0.5-0.75 m diameter telescopes. Observing system simulation experiments performed with simulated lidar data input indicated that the smaller Doppler lidar designs using coherent detection still provided sufficient wind data to significantly impact forecast model capability, particularly over the data sparse regions of the globe.

3. CURRENT TECHNOLOGY THRUSTS

Given the perceived utility of Doppler lidar designs much smaller than the original LAWS design, with lower transmitter pulse energies and smaller optics, the 2 micron solid-state laser technology posed several attractive alternatives to the CO_2 gas lasers and the need for cooled detectors at the 10-micron laser wavelength. Eye safety for an Earth-orbiting Doppler lidar using coherent detection is an important issue because the transmitter-receiver combination must operate in a diffraction-limited mode for optimum efficiency, analogous to a Doppler radar. Using receiver apertures of the size needed for operation from satellite altitudes, the corresponding transmitter footprint on the Earth surface is sufficiently small to require operation at a Wavelength longer than 1.5 micron, i.e., in the "eye-safe" region. For the past several years NASA has funded the development of 2 micron laser technology with the space Doppler lidar application in mind.

Recent advances in 2-micron solid-state lidar (Henderson *et al.*, 1993) make this technology an attractive competitor for such a mission, For a low energy (i.e.. ≤0.5 J per pulse) system, a solid state 2. micron lidar is lighter and more compact than a downscaled CO_2 instrument, and it should be capable of longer lifetime performance.

Two micron technology now has an airborne heritage, The first 2 micron aircraft wind and aerosol lidar measurements were made during four DC-8 flights in November, 1993, with a compact laser sensor package built by Lightwave Electronics, Inc. The diode-pumped laser was pulsed at 610 Hz, but errch pulse was relativel y weak (0.5 mJ). Larger pulse energies (2,5 mJ) were achieved in a different flight program in June 1994 by Lockheed and Coherent Technologies, *Inc.* (Robinson, 1994; Targ et al., 1993; Hawley et al., 1995). Recently, an airborne 2 micron system at 50 mJ successfully measured winds (Richmond et. al. 1995). The lidar was installed on the plane and in operation in three hours.

4. CURRENT PLANS FOR A SPACE MISSION

A group of lidar and atmospheric scientists have been pursuing mission opportunities which would launch a coherent Doppler wind lidar in the 2001 time frame. This would be either a shuttle flight or a flight on a small kc-flyer orbiting at an altitude between 400-500 km. The transmitter pulse energy would be in the 200-500 mJ range, with total instrument power draw in the 250-503 W range. Wind data with accuracy of 1-2 m/s would be obtained using the relatively high lidar back.scatter "targets" in the atmosphere, e.g., clouds, boundary layer aerosols, and elevated aerosol layers formed from such sources as arid continental regions, pollution, and cloud dissipation processes. Currently the NOAA Integrated program Office (IPO), the NASA Ncw Millennium program Office, and the USAF Space Test Program have interest in a flight of such an instrument, to demonstrate the technology, the data analysis, and the data assimilation into numerical models. A demonstration mission such as this would be the major step toward the flights of Doppler wind lidars on the operational satellites later in the first decade of the twenty-first century.

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