Development of a Compact Lidar to Profile Water Vapor in the Lower Troposphere

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Introduction

The National Oceanic and Atmospheric Administration (NOAA) Environmental Technology Laboratory (ETL) in collaboration with the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and the National Center for Atmospheric Research (NCAR) is developing a small Differential Absorption Lidar (DIAL) system to continuously profile lower tropospheric water vapor. This lidar will be ground-based and will measure water vapor to an altitude of several kilometers with ~100-m resolution and ~15-minute averaging times.

Need for an Inexpensive Water Vapor Profiler

In recent years, continuous measurements of wind and temperature profiles have been made with automated ground-based remote sensors, such as wind profilers with radio-acoustic sounding systems (RASSs). The information from these new instruments has improved the understanding and modeling of both synoptic and mesoscale atmospheric phenomena. To date, however, an equivalent capability for continuous and widespread measurement of water vapor profiles has not been available.

Water vapor profiles are important for understanding and predicting moisture convection and horizontal transport. For example, Crook (1996) showed that the strength of convection is sensitive to the difference between the surface and boundary layer water vapor concentrations. Accurate partitioning of water vapor, along with associated temperature profiles, is necessary to characterize the atmospheric radiation balance. Understanding the transport of water vapor is also important for predicting cloud formation.

The systems currently available for continuous measurement of water vapor are not suitable for wide-spread deployment. Relatively inexpensive ground-based Global Positioning System (GPS) sensors can make continuous, all-weather observations of column-integrated moisture, but do not determine the vertical structure. Existing ground-based Raman Lidar (Whiteman et al. 1992) and DIAL (Wulfmeyer and Bösenberg 1999) systems can profile water vapor very accurately, but are generally quite large, expensive, and/or manpower intensive.

System Design

To address the need for profiles of lower tropospheric moisture concentrations, we are building a small, relatively inexpensive, unattended DIAL system. This system will have moderate temporal resolution (~15 min) and will focus on measurements in the lower troposphere (<3 km), which contains most of the atmospheric water vapor. These compromises in averaging time and maximum altitude enable us to use inexpensive, high pulse-rate diode laser sources along with photon counting and a PC processor.

This eye-safe DIAL will be ground-based and measure water vapor in the lower troposphere with ~100-m height resolution. The system uses a 37-cm telescope, and a state-of-the-art amplified diode laser transmitter at 825 nm that produces low-power pulses at ~6 kHz (Figure 1).

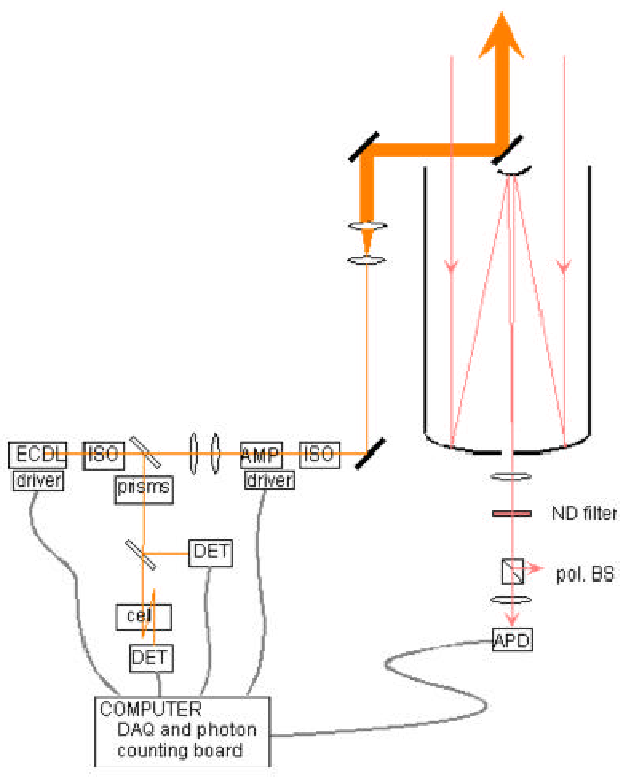

Figure 1. Schematic of DIAL System. Components include 60-dB optical isolators (iso.), the flared diode amplifier (AMP), a polarizing beamsplitter (pol. BS), detectors (DET), and a narrowband interference filter (NB filter).

Computer simulations (Machol et al. 1996) of this design indicate that measurement accuracies of better than 0.5 g/kg should be obtainable to ~2.5 km in the daytime and ~4 km at night (Figure 2). The simulation results agree with estimates of the measurement accuracies of this lidar made by applying scale factors to measurements made by the more powerful Max Planck Institute DIAL system (Wulfmeyer and Bösenberg 1999).

The transmitter for this system is based on an amplified single-frequency laser (Krainak et al. 1995) at 825 nm. For the initial version of this system, the single-frequency continuous wave (cw) source is an SDL 8610 external cavity diode laser (ECDL). The ECDL is locked to the water vapor line by monitoring the light transmission through a water vapor cell. The laser wavelength is dithered over ~0.5 pm to facilitate the on-line locking. The less-critical off-line wavelength is obtained by stepping the wavelength by ~20 pm (via a PZT-mounted grating in the ECDL). In the future, we may substitute for the ECDL a more compact seed laser such as single-frequency diode laser stabilized with feedback from a fiber grating.

The cw seed light is amplified in a single pass through a pulsed flared diode amplifier (from an SDL 8630). The peak power limit of the flared amplifier is 0.5 W, which corresponds to ~10 mW average power at kHz-repetition rates.

A 37-cm diameter telescope collects the atmospheric backscatter. The light is collimated to a 5-mm diameter beam and then passed through a ~250-pm narrowband filter (Barr Associates) and a polarizing beamsplitter cube to eliminate daytime background light. Although the initial system has only one optical receiver channel, we will probably add a dedicated near-field (wider field-of-view) channel in the future.

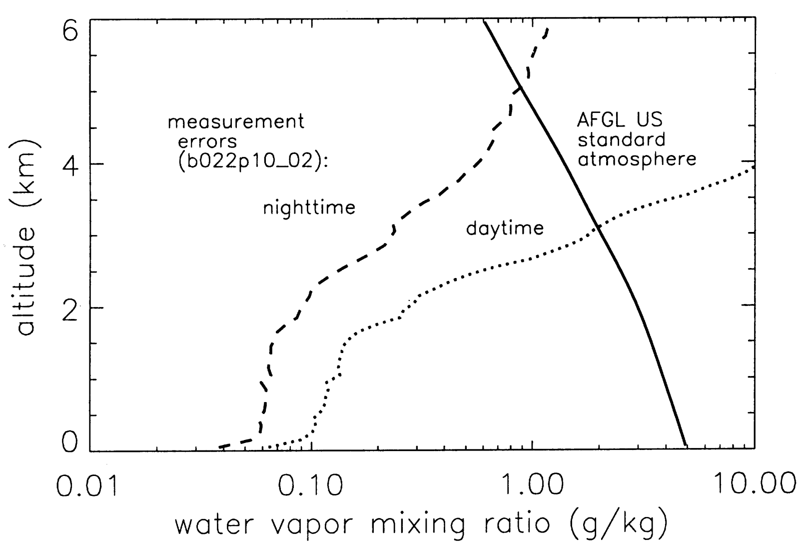

Figure 2. Computer simulation of DIAL retrievals shows daytime and nighttime errors. Errors of less than 0.5 g/kg should be obtainable to ~2.5 km in the daytime and to ~4 km at night.

The lidar detection system uses an EG&G photon-counting avalanche photodiode in conjunction with a photon-counting board (Grund and Sandberg 1996). With this setup, fast integration is done electronically on the photon-counting board, and then the summed data can be transmitted at a much slower rate (~10 Hz) to the computer.

Future

A breadboard version of the system should be ready for field testing late this fall. We will initially test with ground-based and tower-mounted in situ sensors. Ultimately we wish to deploy this system in conjunction with wind profilers and RASS to provide continuous low-level soundings of wind, temperature, and water vapor.

Acknowledgments

Funding has been provided by NOAA Office of Global Programs (OGP), NOAA ETL, National Science Foundation (NSF)/NCAR United States Weather Research Program (USWRP) and NASA GSFC.

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