DEVELOPMENT OF A LARGE-APERTURE TRANSPORTABLE LIDAR SYSTEM

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ABSTRACT

A new large-aperture transportable lidar system for atmospheric measurements is being developed in the Atmospheric-Optics Laboratory at Dalhousie University. The lidar will ultimately employ an array telescope with an equivalent aperture of 1.6 m, and will be housed in a 12 m transportable observatory. The core systems of the lidar have been implemented, and observations using a 25 cm telescope have been obtained. A prototype node for the telescope array is under construction, and nears completion. The lidar system will be used for measurements of clouds, aerosols, water vapour, and middle atmospheric temperatures and waves.

1. INTRODUCTION

Lidar systems have proved to be versatile instruments for atmospheric studies, and can obtain measurements of clouds [1], aerosols [2], water vapour [3], and middle atmospheric temperatures and waves [4,5], amongst others. Measurements made in the middle atmosphere and using Raman techniques benefit from the use of a large-aperture telescope. These systems cannot normally be conveniently moved to other sites of geophysical interest.

A new large-aperture transportable lidar system is under construction in the Atmospheric-Optics Laboratory at Dalhousie University. Central to the lidar's design concept is the development of a large-aperture telescope array, constructed using sixteen 40 cm telescope primary mirrors, to yield an equivalent aperture of 1.6 m. Compared to other telescopes of equivalent size, the telescope array is expected to be relatively lightweight and cost-effective.

The core components of the lidar have been assembled in the Atmospheric-Optics Laboratory at Dalhousie University, and await installation in the transportable observatory, which is currently under construction. The observatory is being built from a 12 m shipping container, and will have a retractable roof, a climate-controlled laser room, and a separate lidar control room.

Measurements using the core lidar systems have recently begun, and have focused on observations of clouds and aerosols. First deployment of the transportable system is expected in July 2004 at Chebogue Point, Nova Scotia, during the International Consortium for Atmospheric Research on Transport and Transformation ($ICART^2$) campaign.

2. INSTRUMENT DESCRIPTION

A schematic for the lidar system is given in Fig. 1, and the instrument specifications are given in Table1. The lidar uses a powerful frequency-doubled Nd:YAG laser in the transmitter, and collimates the beam at 4 cm across to reduce the divergence. The laser output at 532 nm is directed into the sky, and at this time the output at 1064 nm is discarded. A 25 cm telescope is currently employed to collect the backscattered signal, and the laser beam is directed into the telescope's field of view using a steering mirror. The photons collected by the telescope are channeled into two optical fibers according to polarization. The width of the fiber defines the field of view of the telescope; a selection of fibers can be used to produce the different fields of view.

Light from the fibers is directed into a four channel receiver, which uses dichroic mirrors and interference filters to separate the signal according to wavelength. Channels for the polarized elastic component at 532 nm wavelength, and the nitrogen Raman backscatter at 607.3 nm have been implemented; installation of a water vapour Raman channel is expected by the end of the year. Signal detection is achieved using photomultiplier tubes and fast pulse-counting computer electronics. System timing is performed with the use of a precision signal generator.

Although not shown in Fig. 1., the lidar is also equipped with a 6 kW Furuno radar, which is used to detect aircraft overhead. The radar was modified to use a

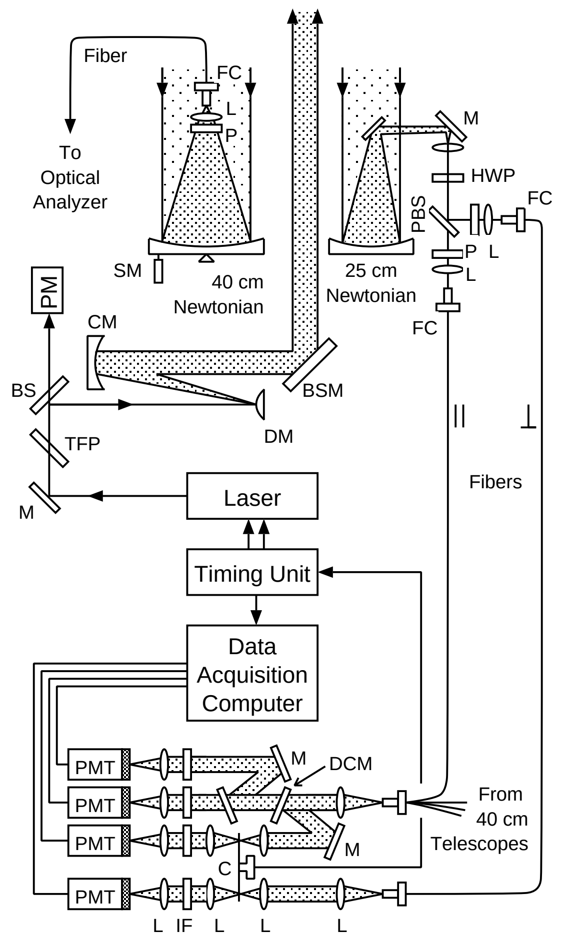

Fig. 1. Schematic for the lidar system. The transmitter consists of the laser, mirrors (M) to fold the beam, a thin film polarizer (TFP), a 99/1% beam splitter (BS), a diverging mirror (DM) and collimating mirror (CM), and a beam steering mirror (BSM). A 25 cm Newtonian telescope directs received photons into a polarization separator, which uses a half-wave plate (HWP), polarizing beam splitters (PBS), polarizers (P), lenses (L), and fiber couplers (FC), to channel light into two optical fibers. The optical fibers direct light into a four channel receiver, which uses dichroic mirrors (DCM) and interference filters (IF) to separate the received photons according to wavelength. An optical shutter implemented using a rotating bow-tie chopper (C) is used to remove the intense low altitude signal. Light levels are also controlled through the use of telescope masking, irises and neutral density filters (not shown). The chopper sets the trigger for all system timing, which is coordinated by the timing unit (a precision signal generator) Signal detection is performed using photomultiplier tubes (PMT) and a GHz counter board housed in the data acquisition computer. For the array telescope, a prototype 40 cm telescope is under construction.

Table 1. Lidar system specifications

Transmitter

Laser	Continuum 8020 Nd:YAG
Wavelength	532 nm
Power	11 W
Rep rate	20 Hz
Pulse length	8 ns
Beam diameter	4 cm
Divergence	0.1 mrad

Receiver

Telescopes	25 cm Newtonian; sixteen 40 cm Newtonians (planned)
Field of view	0.75 to 1.5 mrad
Channels	Four (parallel polarized elastic, perpendicular polarized elastic, nitrogen Raman and water vapour Raman)
Bandwidth	1 nm per channel
Detectors	Photomultiplier tubes
Rise time	≤ 2 ns
Counter board	FAST ComTec P7888
Counter speed	1 GHz

vertically pointing gain horn so that the radar beam fills a cone of space 10 degrees across around the laser beam, and automatically disables the q-switch of the laser should an aircraft be detected. The radar's performance was evaluated using both a helicopter and a jet aircraft, and was found to perform exceptionally well at both low and high altitudes.

3. MEASUREMENTS

Measurements with the lidar system have been obtained since December 2003. Fig. 2. presents observations of some optically thin clouds observed above Halifax on 3 February 2004, obtained during sunset. To reduce the signals to manageable levels, the telescope aperture was reduced to 8 cm, and a neutral density filter with optical density 2 and a narrowed iris were used in the receiver .

Fig. 2 shows that the lidar is well able to measure the cloud location, extent, and structure as a function of time. Background noise in the system due to sky light was found to be very low.

Fig. 3 shows a measurement of depolarization ratio obtained on 11 December 2003. The measurement on 11 December 2003 shows both high and medium altitude layers, which are due most likely to sub-visual clouds. The depolarization for the lower layer was very small, suggesting cloud droplets in the liquid phase.

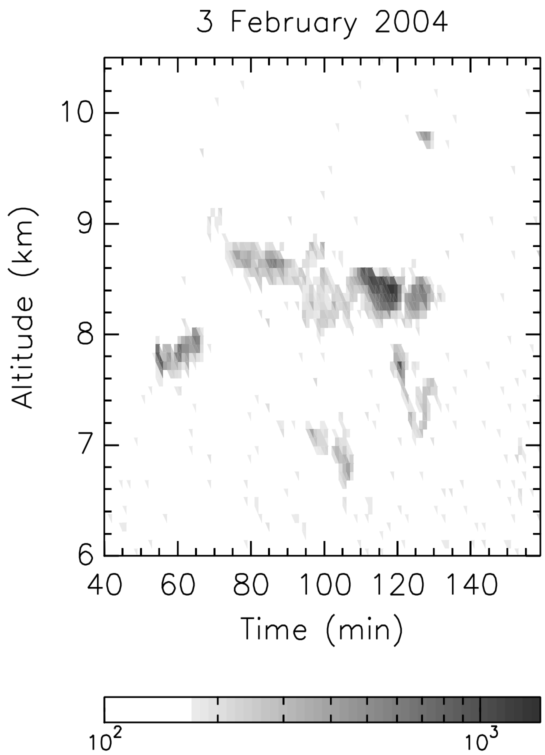

Fig. 2. A measurement of range-squared corrected backscatter obtained on 3 February 2004. The measurement shows the extent and structure of a high-altitude cloud.

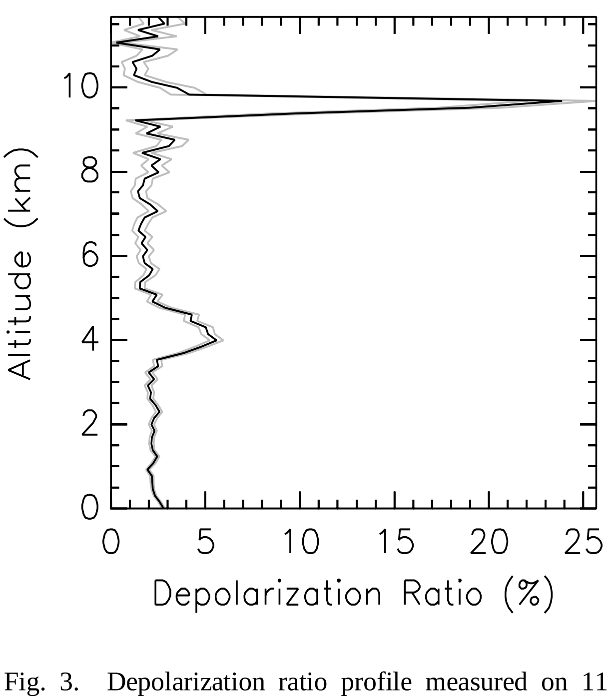

Fig. 3. Depolarization ratio profile measured on 11 December 2003.

The higher depolarization in the upper layer is indicative of a cirrus ice-crystal cloud.

3. LIDAR SYSTEM DEVELOPMENT

Development of the lidar system is continuing. In March 2004 an optical shutter was installed into the receiver, and used to reduce the low-altitude signal during high-altitude measurements. Earlier, masking of the telescope, neutral density filters and aperture-limiting irises were used to reduce these signals to manageable levels, which significantly degraded the high-altitude signal quality. With the optical shutter, measurements of middle atmospheric temperatures have been achieved.

Installation of the nitrogen Raman channel into the receiver was completed in March 2004. The Nitrogen Raman channel has allowed for measurements of cloud and aerosol backscatter and extinction.

To increase the overall power of the lidar, a large-aperture array telescope is being developed. The telescope will employ sixteen 40 cm telescope primary mirrors, each of which will couple into an individual fiber optic. Each telescope is seated on a pivot, and alignment with the transmitted laser beam will be achieved by tilting the telescope with stepper motors. Coordination of the sixteen telescopes will be computer automated. The fibers leading from each telescope will be collectively bundled and connected into the receiver.

There are several advantages to using an array telescope over more traditional single-dish instruments. Relatively inexpensive commodity telescope primary mirrors may be used to assemble a large-aperture instrument for non-imaging applications. Array nodes can be used in cooperation, or employed separately: the telescope may be divided up for pointing in many directions or for use by multiple lidars. Finally, because each component in an individual node is relatively lightweight, large-aperture transportable lidar systems are possible.

The first array node is nearly complete, and will be extensively tested. The construction of the remaining nodes will continue through the summer of 2004 and at intervals during the next few years.

To take advantage of the expanded collecting power of the array telescope, a water vapour Raman channel will be installed in the receiver within the next year. The ability to measure water vapour will greatly complement the current measurements of clouds and aerosols.

In April/May 2004 the lidar system will be installed in a transportable observatory, which is currently under construction. The observatory is being built by refitting a 12 m long shipping container, and will have its own electrical distribution and climate control. A 4.5 m long open section with a retractable roof will be used to house the telescopes. The remaining enclosed space will be insulated and divided into a laser room and a lidar control room. The observatory will be mounted atop its own flatbed trailer, and will require rental of a truck for relocation.

4. PLANNED ACTIVITIES

The lidar will be a capable instrument for a wide range of studies relevant to air quality, climate, and dynamics. Use of the various receiver channels will allow measurements of cloud and aerosol backscatter, extinction, depolarization, and structure, in addition to measurements of water vapour, and middle atmospheric temperatures and waves.

The first field deployment of the lidar will be in July 2004 at Chebogue Point, Nova Scotia, as part of the International Consortium for Atmospheric Research on Transport and Transformation ($ICART^2$) campaign. The $ICART^2$ campaign is a a multi-instrument field study complete with multiple field sites and aircraft measurements; its main focus is the study of pollution transport from the Eastern seaboard and out over the Atlantic. This transport often carries pollutants over Nova Scotia, and so this lidar system's home location is sometimes referred to as “The tailpipe of North America”.

Nova Scotia is also directly beneath a major flight corridor between North America and Europe, and contrail-induced cirrus clouds from commercial aircraft are frequently observed. Contrail cirrus have received increased scrutiny due to their observed effect on weather patterns following the grounding of commercial aircraft over North America in the days following 11 September 2001 [6]. We plan to document the characteristics of cirrus clouds above Nova Scotia, and compare them with cirrus observations in more pristine environments. It will be particularly interesting to evaluate the prospects for regional climate change due to the substantial anthropogenically induced cirrus overhead.

Studies of middle atmospheric temperatures and waves will be an important goal. The lidar will be transported to a variety of regions of geophysical interest, and comparative measurement campaigns in the lee of the Rocky Mountains and on the flat Canadian Prairies will be valuable for assessing the relative contributions of mountain and atmospheric internal sources to the stratospheric gravity wave spectrum. An Arctic research programme is also anticipated following the experiences gained from these earlier studies.

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