ADVANCES IN LASER REMOTE SENSING, EDS. A. DABAS, C. LOTH AND J. PELON, 73-76, 2001.

Monostatic Lidar at f/200: A New Instrument at Millstone Hill / MIT Haystack Observatory

THOMAS J. DUCK, DWIGHT P. SIPLER, JOSEPH E. SALAH
MIT Haystack Observatory, Route 40,Westford, MA 01886, USA

JOHN W. MERIWETHER
Department of Physics and Astronomy, Clemson University, Clemson, SC 29634-1911, USA

ABSTRACT

A lidar for middle atmospheric research is being developed at Millstone Hill / MIT Haystack Observatory (42.6°N, 71.5°W). The lidar obtains temperature profiles between 30 and 90 km in altitude during the night and up to 70 km during the day by using the Rayleigh lidar technique. A 1.2 m, f/200 steerable telescope is used in both the transmit and receive stages in this monostatic instrument. The long (240 m) focal length is advantageous for daytime use because of the naturally narrow field of view. The lidar will be suitable for studies of mesospheric temperature inversions and gravity waves.

1. Introduction

A lidar for middle atmospheric research is being developed in the Firepond Optical Facility at Millstone Hill / MIT Haystack Observatory (42.6°N, 71.5°W). The lidar complements a rich cluster of instruments that includes an incoherent scatter radar for upper atmospheric research (*Buonsanto et al.*, 1992; *Goncharenko et al.*, 1998), an F-region Fabry-Perot interferometer (*Sipler et al.*, 1991), an all sky Dopper interferometer (*Biondi et al.*, 1995), a meteor wind radar (*Clark and Salah*, 1991), an image intensified imager (*Baumgardner et al.*, 1993) and a CCD imager (*Smith et al.*, 2000). The lidar measures temperatures between 30 and 90 km in altitude at night by using the standard Rayleigh Lidar technique. Temperature measurements during the day currently reach 70 km in altitude, a limit imposed by the bright sunlight background.

The lidar will be used to address a variety of topics regarding middle atmosphere dynamics. Of particular interest to our measurement program is the detection of mesospheric inversions layers. Temperature inversions are observed at midlatitudes near the mesopause and in the lower mesosphere (*Meriwether and Gardner*, 2000). Sodium layer temperatures measured during both day and night by *States et al.* (1999) and *Chen et al.* (2000) have indicated that chemical heating contributes to the mesopause inversions. Temperature inversions at lower altitudes are caused by other mechanisms, and may be related to the diurnal tide (*Meriwether and Gardner*, 2000). Measurements throughout the diurnal cycle will most clearly reveal the tidal effect, and hence we have constructed this new lidar. We should be able to address the temperature inversion issue during winter when lower mesospheric inversion layers appear between 55 and 70 km in altitude (*Whiteway et al.*, 1995).

Gravity wave observations will also be a focal point of our studies. Previous investigations at Eureka (80ºN, 86ºW) revealed strong interactions between gravity waves, the wind background, and the large-scale thermal structure (*Whiteway et al.*, 1997; *Duck et al.*, 1998, 2000a, 2000b). Our new measurements will be valuable in comparison with airglow measurements obtained on site and also with the rest of the instrument cluster especially during Lower Thermosphere Coupling Experiment (LTCS) campaigns.

2. Instrumentation

A schematic depicting the configuration of the lidar is presented in Figure 1 and the system specifications are given in Table 1. The lidar uses a pulsed Nd:YAG laser transmitting in the visible at 532 nm. The laser beam is expanded into a 1.2m, f/200 steerable telescope through the Coudé path and directed into the sky. The 1.2 m telescope is also employed as a “monostatic” receiver. A smaller 60 cm, f/5.5 telescope, co-mounted and aligned with the 1.2 m telescope, is used as a versatile “bistatic” receiver. A photograph of this telescope system is shown in Figure 2.

Because the monostatic transmitter and receiver share a common path through the 1.2 m telescope, the two signals must be separated at some point through the use of a transmit/receive (T/R) switch. The T/R-switch has been implemented by arranging a polarizing beam splitter and quarter waveplate in an “optical isolator” configuration. In the transmit phase, the p-polarized light from the laser passes through the polarizer and is converted to a circular polarization by the quarter waveplate. Backscattered circularly polarized light collected by the receiver is converted to s-polarized light by the quarter waveplate and directed into the detector by the polarizer.

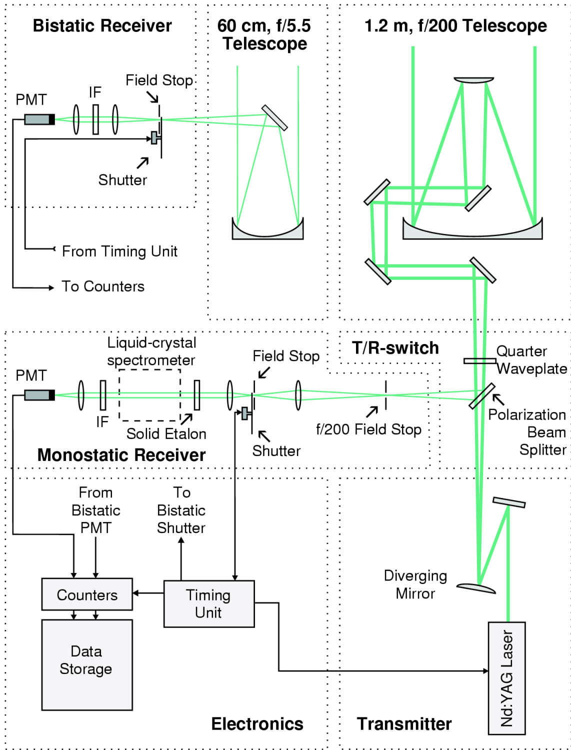

FIG. 1. Schematic for the lidar at MIT Haystack Observatory.

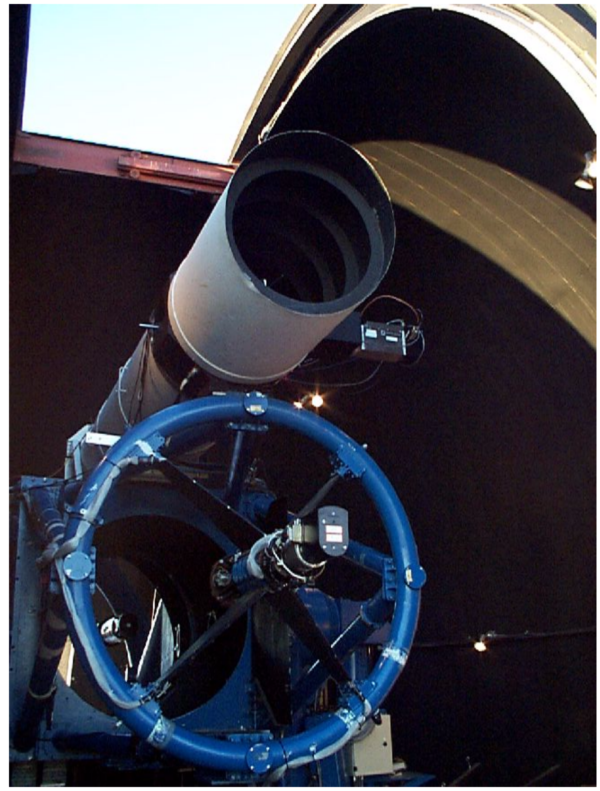

FIG. 2. The dual telescope system housed at the Firepond Optical Facility. The structure for the main 1.2m f/200 telescope is painted blue, and the primary mirror can be seen in the bottom left corner. The 60 cm, f/5.5 telescope is perched atop the main telescope, and is painted in white.

Low altitude signal is eliminated through the use of a mechanical chopper (a rotating bow-tie) which is synchronized with the transmitted laser pulse. The background light away from the laser's wavelength is reduced through the use of a broad band interference filter and a medium resolution solid Fabry-Perot etalon that is tuned by angular adjustments. A space has been left in the monostatic receiver for a high-resolution Fabry-Perot spectrometer that will be installed at a later date (see section 4). Signal detection is performed by using bialkali photomultiplier tubes (PMTs) and fast counting electronics.

3. Measurements

A sample nighttime measurement of 4.7 hours duration, obtained during the LTCS campaign on 28 September 2000, is given in Figure 3. As is shown in the upper panel, the signals start at 30 km in altitude (where the detector is fully exposed) and then decay exponentially to 100 km in altitude. Note that the background noise is so low that the top altitude is still signal limited after 282 minutes of measurement. A temperature profile derived from the signal measurement is given in the lower panel of Figure 3. A temperature inversion is evident in the upper mesosphere.

Figure 4 shows a temperature measurement obtained during daytime on 28 September 2000. The measurement extends up to 70 km in altitude, which should be sufficient to observe inversion layers during winter. In the stratosphere the uncertainties remain small because the signal levels are as strong as during the night; the background level only contributes a small amount of uncertainty where the signal to noise level is high. Thus, gravity wave measurements of consistent quality are obtainable throughout the diurnal cycle.

4. Planned Enhancements

As part of continued development, we have planned certain additions and enhancements to this lidar. An important goal is to obtain measurements to the highest possible altitudes during the day, and so the background light will need to be reduced as much as possible. In this respect, the 1.2m, f/200 telescope is already of particular use. With an effective focal length of 240m, the telescope has a naturally narrow field of view (<0.1 mrad), which reduces the background light significantly.

In order to lower the background even further, two types of Fabry-Perot interferometers have been acquired.

Transmitter Specifications	**Receiver Specifications**
Laser: Seeded Nd:YAG, Spectra Physics GCR-6 24 W, 800 mJ/8nS pulse	**Monostatic Telescope:** 1.2 m, f/200 Newtonian
Wavelength: 532 nm (frequency doubled Nd:YAG)	**Bistatic Telescope:** 60cm, f/5.5 Newtonian
Pulse rate: 30 Hz	**PMTs:** Bialkali, Hamamatsu R2496P
	Counters: EG&G Turbo MCS
	Interference Filter: 2 nm passband
	Solid etalon: 0.75 mm effective spacing
	Liquid-Crystal Fabry-Perot: Scientific Solutions Inc., 1.5 cm effective spacing

TABLE. 1. Specifications for the lidar at MIT Haystack Observatory.

The first, a "medium resolution" Fabry-Perot, is a solid etalon that has already been placed in front of the PMT in the monostatic receiver (see Figure 1). The etalon is tuned by angular adjustments to maximize the incoming laser light while eliminating a large portion of the background noise counts. Our success with this approach has provided the impetus to try other solid etalons of differing thickness.

The second Fabry-Perot is a new liquid-crystal etalon that may be tuned by adjusting the voltage across its interior (which changes the liquid-crystal index of refraction). The stability of the laser / liquid-crystal etalon pair will be monitored by directing a small amount of the laser light through the etalon into a fast photodiode detector. The narrow bandwidth of the Fabry-Perot will maximize the signal-to-noise ratio for daytime measurements; however, it will be a challenge to ensure sufficient throughput so as to improve upon our current altitude limit. Regardless, the liquid crystal etalon is expected to allow line-of-sight Doppler measurements of winds when the telescope elevation is lowered from the vertical. Measurements of wind are useful in the gravity wave studies since atmospheric waves are strongly affected by the background conditions through which they propagate (*Whiteway et al.*, 1997; *Whiteway and Duck*, 1999; *Duck and Whiteway*, 2000).

5. Conclusions

The lidar at Millstone Hill / MIT Haystack Observatory is now operationally measuring temperatures during day and night. These measurements complement the already extensive observational capabilities at the observatory. The lidar will be useful for evaluating issues regarding mesospheric temperature inversions, and for measurements of atmospheric gravity waves.

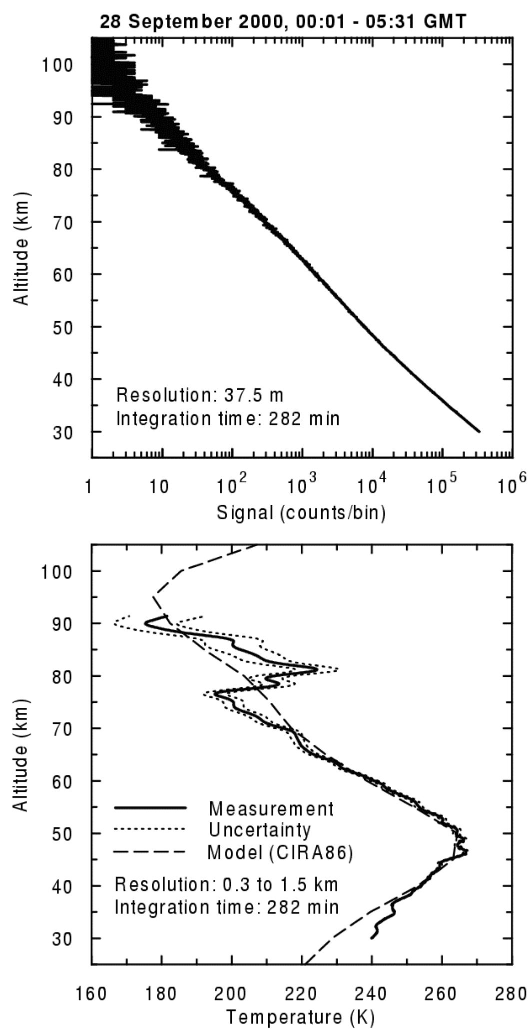

FIG. 3. A measurement obtained on 28 September 2000. The raw signal profile is given in the upper panel and the derived temperature profile is shown in the lower panel; the solid line represents the measurement, and the dotted lines give the uncertainties. The dashed line is a climatological temperature profile for March (*Fleming et al.*, 1990).

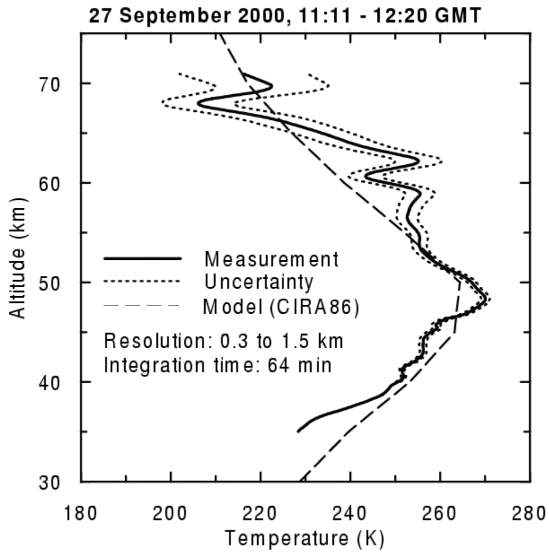

FIG. 4. Daytime lidar observations for 27 September 2000.

Acknowledgements. This development was supported by the National Science Foundation under grants ATM-9714728 and ATM-9724200. Cost-sharing support for equipment by MIT and facility access to the Firepond Facility by Lincoln Laboratory are gratefully acknowledged. The technical and operations support provided by T. Gallardo, C. Farrell, R. Woodland, and many others at the observatory are greatly appreciated.

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