UNDERGRADUATE LIDAR EDUCATION AT GEORGIA TECH

L.L. West[(1)], A. K. Garrison [(1)], G. G. Gimmestad[(1)], D.W. Roberts[(1)], J. M. Stewart[(1)], J. W. Wood[(1)], A.L. Bowling[(2)]

[(1)] Georgia Tech Research Institute, Georgia Institute of Technology, Atlanta, GA 30332 USA,
E-mail: leanne.west, allen.garrison, gary.gimmestad, david.roberts, john.stewart, and jack.wood all @gtri.gatech.edu

[(2)] Department of Physics and Astronomy, Agnes Scott College, Decatur, GA 30030 USA,
E-mail:abowling@agnesscott.edu

ABSTRACT

The Georgia Tech Research Institute teamed with a local undergraduate women's institution, Agnes Scott College, to develop an eyesafe lidar for atmospheric remote sensing as a unique hands-on research experience for undergraduate students. The students constructed the lidar with guidance from Georgia Tech researchers after receiving classroom lectures and doing hands-on laboratory work on the technologies required to design and build the system. Coursework included geometrical and atmospheric optics; lasers and eye safety; radiometry; optical detection; materials, coatings, and filters; digital signal processing and data analysis; and mechanical structures. The course succeeded in making lidar technology accessible and appropriate for undergraduate students, and it is intended to serve as a model for other schools. EARL (the Eye-safe Atmospheric Research Lidar) research projects include studies of the planetary boundary layer, tropospheric aerosols and clouds, and the stratospheric aerosol layer. Partner schools for similar projects are being sought, and a web-based network is planned among participating colleges and universities.

1. BACKGROUND

In 2001, a Major Research Instrumentation grant from the National Science Foundation enabled researchers from the Georgia Tech Research Institute (GTRI) to develop an atmospheric lidar for Agnes Scott College (ASC) [1]. The program was later expanded to include students from Georgia Tech. The lidar, named EARL (the Eye-safe Atmospheric Research Lidar), was developed specifically for undergraduates and is housed in a dedicated lidar facility on the Agnes Scott College campus, which is located about 6 miles east of downtown Atlanta in Decatur, GA.

2. LIDAR FOR UNDERGRADUATES

Two key features make lidar technology appropriate for undergraduates. First, most of the physical and engineering principles that are required to understand, design, and build a lidar are fairly basic and can be taught at the level of introductory courses. Secondly, the data presentation is easy to understand with the basic skill of reading graphs. Data analysis can be as simple or as involved as is appropriate for the participating students.

The choice of laser wavelength is one of the first design decisions, and a visible-light laser was chosen for three reasons. First, a visible beam of light is much easier for a novice student to grasp conceptually than an invisible ultraviolet or infrared beam. Second, visible light is important for safety because students are more aware of the beam near their eyes, skin, or clothing. Third, visible light allows students to make measurements such as beam width and divergence easily without additional equipment such as ultraviolet or infrared cameras.

However, eye safety is another important requirement for an undergraduate lidar. The laser beam emerging from the lidar transmitter must be eyesafe for use in the university setting, where people will be present who are not familiar with laser safety. Additionally, the use of lasers outdoors is controlled by the Federal Aviation Administration (FAA), and there are fewer FAA restrictions on the operation of an eyesafe lidar as opposed to a hazardous lidar. The need for both visible light and eye safety lead to the micropulse lidar (MPL) approach introduced by Spinhirne [2].

The lidar must also be simple and rugged in design, easy to operate and maintain, and it must have a straightforward data interpretation. To meet these requirements, we avoided common optics by using short range and long range channels to span the dynamic range, and we employed analog signal processing. With these design choices, there are no corrections to the data, such as a geometrical overlap function or a photon count rate correction. In addition, EARL has large fields of view for ease of alignment and ruggedness. The easier it is for students to understand, operate, and maintain, the more confident and willing they will be in operating the lidar and the more it will keep their interest. A system that is too complex will lose student attention faster than one that is easy to understand.

3. CLASSROOM EXPERIENCE AND BUILDING THE LIDAR

During three consecutive semesters and before the students constructed the lidar, GTRI researchers taught the basic physics and engineering topics needed to design and build a lidar. The 2-credit-hour course included topics from fields such as geometrical optics, atmospheric optics, lasers and eye safety, optical filters and detectors, radiometry, and structural engineering. The weekly classes included one hour of classroom presentation followed by one hour of hands-on experiments and demonstrations to reinforce what was just taught in the classroom.

After the classroom work on basic principles was finished, the class became even more hands-on with the students being assigned to design teams. Three teams were created, with each team responsible for a different part of the lidar. With guidance from a GTRI researcher, the Transmitter team performed tasks including designing the optical layout for the transmitter based on an 8" Celestron C8 telescope, measuring laser beam characteristics such as divergence and beam width, creating an optical component list from catalogs and websites, preparing drawings for and interacting with the machine shop for special components, performing the calculations necessary to fill out the FAA forms for eye safety and operation based on ANSI standards, and assembling the transmitter. In addition to the Transmitter team, there were also the Receiver team and the Structure team, each with corresponding responsibilities for their own parts of the overall project. Fig. 1 and Fig. 2 show EARL at the beginning of assembly and after completion.

Fig. 1. Structure team assembling EARL.

Even though the GTRI team leader was guiding student choices, students were given some freedom to make actual decisions *and* mistakes. For example, if a specialty component had to be fabricated by the machine shop, students were allowed to create the design on their own. Some ideas were excellent, but others did not turn out quite as planned, being heavier than anticipated or having sharp edges. Seeing what was actually fabricated from their designs was a real-world learning experience for the students. Understanding why you would not do something a certain way again is perhaps more valuable than doing it correctly the first time.

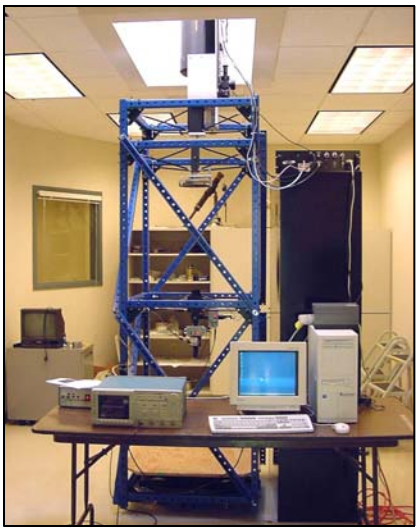

Fig. 2. EARL soon after completion.

Lastly, the students experienced the real-world frustration of waiting on parts that are continually delayed and having to make do with other parts in the meantime. For example, the laser had a delivery time of four months. However, seven months later, the Transmitter team was borrowing a similar laser for testing because the ordered laser had still not been delivered. Once the laser did arrive, only a draft copy of a users' manual was supplied, giving the students the real-world experience of documentation not always being exactly what is expected.

Overall, 12 students were involved in the classroom, design, and building experience, and many more will be involved with ongoing research projects. All students who started the project stayed with it until their graduation.

4. FUTURE VERSIONS OF EARL

The GTRI lidar team hopes to conduct similar projects with other interested colleges and universities and to create a network among participants. To do so, we intend to create a package that will include classroom materials, a laboratory manual, the lidar system in kit form, and suggestions for research projects. The classroom materials will include lecture materials and homework problems. The laboratory manual will include instructions and equipment lists for hands-on experiments in all aspects of lidar technology as well as instructions for assembling and testing each subsystem of the lidar.

The network will be a key component in the success of the effort to make lidar technology appropriate as a teaching and research tool for undergraduates. The network will give the students the opportunity to collaborate with students at other schools who have similar interests and to learn from each other, which professional researchers do regularly. The network will also allow students to learn about air quality issues outside of their own region. For example, Atlanta has high levels of air pollution, whereas the Hawaiian Islands experience constant streams of volcanic ash. Each air quality issue is unique to its region and the network will offer the students the opportunity to learn about specific problems across the country.

Future versions of EARL will be based on the original EARL as well as another eyesafe micropulse lidar currently being developed by the GTRI team specifically for astronomy. The astronomy lidar is a collaborative effort with the University of New Mexico (UNM). The transmitter, short-range receiver, and data system of the future undergraduate system will be very similar to those of the UNM lidar.

The lidar will be configured as two equal-sized telescopes joined together, with the smaller short-range receiver fastened onto the transmitter tube. A concept drawing is shown in Fig. 3. The main tubes will be 30 cm in diameter and 1.2 m long.

Fig. 3. Artist's conception of the next version of EARL

The transmitter aperture will be 25 cm in diameter, which will allow the lidar to transmit 52 μJ per pulse at 2000 pulses per second, which is about half of the full power available from the laser. For comparison, the commercial MPL transmits 8 μJ per pulse. The receiver area of our lidar will be about twice that of the MPL, so the power-aperture product will be more than ten times higher. The high power-aperture product is necessary for daytime operation, because the undergraduate lidar's large fields of view, while good for alignment stability, admit a large amount of sky background. Polarization switching will be available as an upgrade. Preliminary design parameters of the lidar are given in Tables 1 and 2.

Table 1. Transmitter Parameters

Parameter	Value
Wavelength	527 nm
Pulse Energy	52 μJ
Pulse Repetition Frequency	2 kHz
Aperture Diameter	25 cm
Beam Divergence	90 μradians
Average Fluence at Aperture	1 x 10^{-7} J/cm^2

Table 2. Receiver Parameters

Parameter	Value	
	Short-Range Receiver	Long-Range Receiver
Aperture Diameter	95 mm	254 mm
Effective Focal Length	800 mm	800 mm
Field of View	1.2 mradians	400 μradians
Bandwidth	0.5 nm	0.15 nm
Optical Efficiency	0.46	0.38
Transmitter-Receiver Distance	215 mm	320 mm
Detector Type	Photomultiplier	Photomultiplier
Data System	2-channel, 14-bit, 10 MHz A/D Converter	

In addition to the new configuration and higher power, the future version of EARL will differ from the current version in one other major way – it will be designed for disassembly. The GTRI team will develop laboratory exercises around its subsystems and components to give the students hands-on experience with almost all of the technical areas covered in the lectures, and to give them an in-depth understanding of the lidar's design considerations and tradeoffs. Once the students thoroughly understand all of the components, they will be able to reassemble the lidar, align it, and perform a checkout procedure to verify that it is operating properly. The lidar will be designed from the start for this type of training, while being mindful of safety and potential damage problems.

5. EARL DATA

As an example of aerosol data, Fig. 4 shows the range-corrected lidar signal acquired by EARL on September 30, 2004. At the start of the day, the figure clearly shows layers of high aerosol concentration at 550 m and 1000 m that are left over from the day before. Starting around 1030, as the earth warms up and convective mixing starts, the aerosols begin mixing down into the air we breathe. The dark color between

1000 and 1500 km at 1230 – 1300 hrs, 1415 hrs, and again around 1500 – 1600 hrs indicates clouds. Clouds typically block the signal from above them, hence the signal dropouts represented by darker vertical stripes above the clouds. Note the bumpy appearance of the top of the mixing layer due to individual convective cells passing through the lidar's field of view.

A white line has been drawn to highlight the envelope of the mixing layer. The mixing layer thickness is one of the three main parameters that determine the air quality. Data such as that shown in Fig. 4 are fascinating to the students because almost none of the structure and dynamics of the mixing layer that it reveals is apparent to the naked eye.

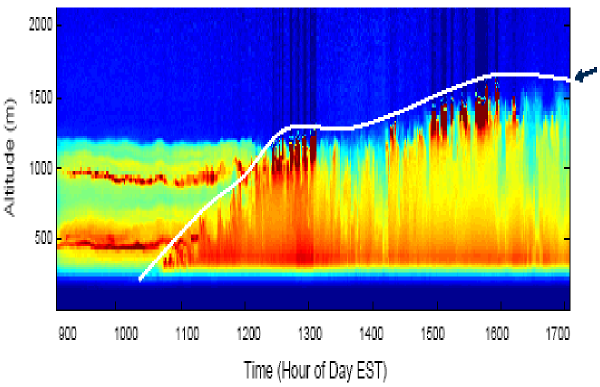

Fig. 4. Aerosol extinction on 30 Sept 2004

During summer 2005, a depolarization capability was implemented by mounting a polarization analyzer in front of the receiver and then rotating the polarization of the transmitted laser beam 90 degrees during alternate one-second intervals with a Pockel cell. Fig. 5 shows an example of depolarization data taken on November 3, 2005. The data are plotted in two ways: as range-corrected apparent backscatter X(R) with no other corrections and as a depolarization ratio with noise removed. The depolarization ratio is defined as $X(R)_{\perp}/X(R)_{\|}$. Noise removal was accomplished by examining the parallel channel and setting the depolarization ratio to zero for range bins with a signal-to-noise ratio less than 5. The noise was removed for aesthetic reasons only, to eliminate a distracting pattern of random colored speckles from the plots.

National Weather Service balloon sonde data taken nearby at 1900 EST showed that the temperature ranged from -40 °C at the bottom of the cloud to -50 °C at the top. Supercooled water in the atmosphere exists only at temperatures above -40 °C, so the entire cloud consisted of ice crystals. The depolarization ratios measured in the cloud are in the range 0.1 – 0.4, which is consistent with ice crystals.

The spatial distribution of the depolarization ratio values in the cloud has a very non-uniform appearance, with bands of high depolarization and large areas of lower depolarization. The differences are presumably due to inhomogeneous shapes and size distributions of the ice crystals within the cloud. The overall turbulent structure of the cloud is apparently driven by wind shear. The balloon data show that the wind speed was about 16 m/s at the top but only 12 m/s at the bottom.

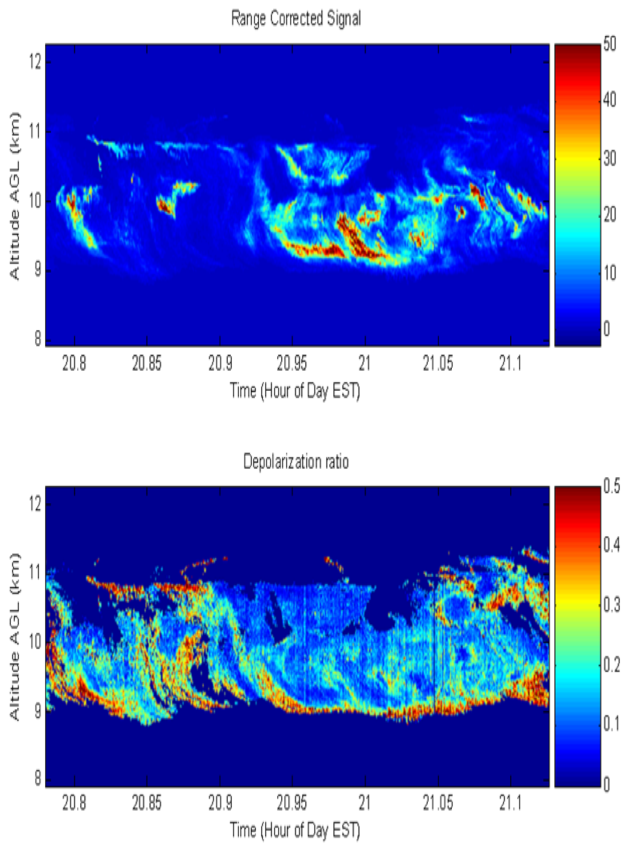

Fig. 5. Cirrus cloud measurements on 3 Nov 2005

ACKNOWLEDGEMENTS

The undergraduate lidar project was funded by the National Science Foundation, Grant No. 0116039. Additional support was provided by Agnes Scott College and Dean of the College of Engineering at Georgia Tech. The system software was written by Peter Haugen, who is now with Lawrence Livermore National Laboratory.

REFERENCES

1. Gimmestad, G.G., Roberts, D.W., Stewart, J.M.,West, L.L., Wood, J.W, and Bowling, A.L., A Simple and Rugged Micropulse Lidar, Proc. 22nd International Laser Radar Conference, Matera, Italy, 163-166, 2004.

2. Spinhirne, J.D., Micro pulse lidar, *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 31, 48 –55 (1993).