CORRECTING THE SCAN ANGLE DEPENDENCE IN HARLIE DATA

Afusat Dirisu, Princeton University, Princeton, NJ (*aod323@webbox.com*)
Mentor: Dr. Geary Schwemmer, NASA GSFC, Code 912

Abstract. *HARLIE (Holographic Airborne Rotating Lidar Instrument Experiment) is a scanning lidar instrument that uses a Holographic Optical Element (HOE) to diffract laser light into the atmosphere and focus received backscattered into a fiber optic connected to the Data AcQuisition (DAQ) system. In order to be able to extract absolute profiles of atmospheric variations, instrumental effects as well as other non-desirable environmental effects need to be removed from the measured data. The scan dependence of the HARLIE is due to some physical factors of the instrument; hence it is an instrumental effect.*

The HOE used in the HARLIE has some manufacturing imperfections. One effect of these imperfections is to make the HOE sensitive to linearly polarized light (causing light passing through the HOE to be diffracted with varying efficiency, depending on the angle the fringes make with the polarization vector of the linearly polarized laser light). Other imperfections cause the focal spot of the received light to be distorted. This distortion enlarges the size of the focal spot beyond the diameter of the fiber core (which determines the Field Of View of the system) in a non-symmetrical fashion. These effects, combined with the fact that the instrument rotates, produce a factor that causes the intensity measured to vary with the angle of view. My objective is to find a method of extracting the scan dependence function from the data set in order to make corrections for it.

INTRODUCTION

Remote sensing involves the collection of reflected or emitted energy from an entity without being in direct contact, through the use of sensors. A remote sensing system involves the following:

i. Energy illumination: This is the source of the electromagnetic energy provided to the target of interest unless the target already emits enough energy that can be sensed remotely.
ii. Transport medium: This is the medium between the energy source and target. Radiation from the energy source can interact with other species in the medium.
iii. Interaction with the target: The radiation, upon contact with the target, may be absorbed, reemitted and/or scattered, depending on the properties of both the target and the radiation.
iv. Recording sensor: A sensor, not in contact with the target, is required to collect the scattered or emitted energy.
v. Processing and application: The collected energy is sent to a processing station for analysis. The information can be applied to study the target or for solving other particular problems.

The two types of remote sensing systems are passive and active. A passive remote sensing system is one that uses energy from a different source for illumination. These systems can only be used when the external energy source is available. An example is the sun photometer. It uses energy from the sun for measuring optical depth of the atmosphere. The disadvantage of passive system is the inability to take measurements anytime. An active remote sensing system, on the other hand, is one that provides its own energy source for illumination. It is capable of taking measurements anytime and also has control over how much illumination is sent to the target. An example of an active system is a laser fluorosensor. The disadvantage of an active system is that it requires large amount of energy to sufficiently illuminate the target.

BASIC LIDAR CONCEPT

LIDAR (**LI**ght **D**etection **A**nd **R**anging) is an active remote sensing technique that can be used in the measurement of atmospheric and oceanic properties. LIDAR is similar to RADAR except it uses optical frequencies such as infrared, visible and ultraviolet.

In a lidar system, a laser sends out laser energy into the medium of interest. The laser energy interacts with other species in the medium before reaching the target. The amount of the laser radiation that reaches the target is reduced through absorption and scattering by other species it encounters. The scattered energy from the target interacts again with species along the return path, so that the radiation collected by the receiver is very small compared to the amount sent out. A very sensitive detector may be required to detect the received radiation.

Range information can also be determined from a lidar system if a pulsed laser is used. The time between when the pulse was sent out and the reflected pulse was received can be measured. Since the speed of light is a known constant, the round trip distance can be calculated from, $2z = c * t_{total}$. The range information, z, is half the round trip distance.

Lidar techniques are classified as elastic or non-elastic. An elastic lidar measures the same frequency as that of the transmitted energy. An inelastic lidar measures a different frequency due to energy transfer between the laser radiation and the target. The various types of lidar includes, backscattering lidar, **DI**fferential **A**bsorption **L**idar (DIAL), Raman Lidar and Doppler Lidar.

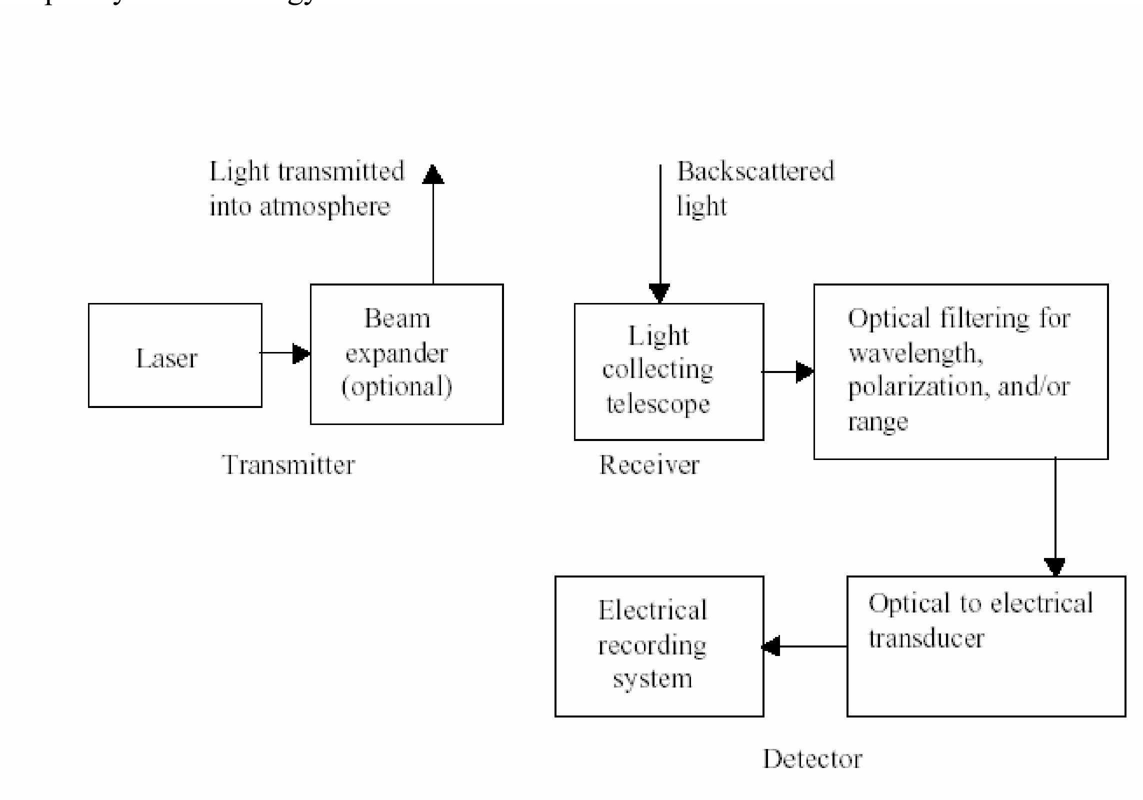

Figure 1: Block diagram of a generic lidar system

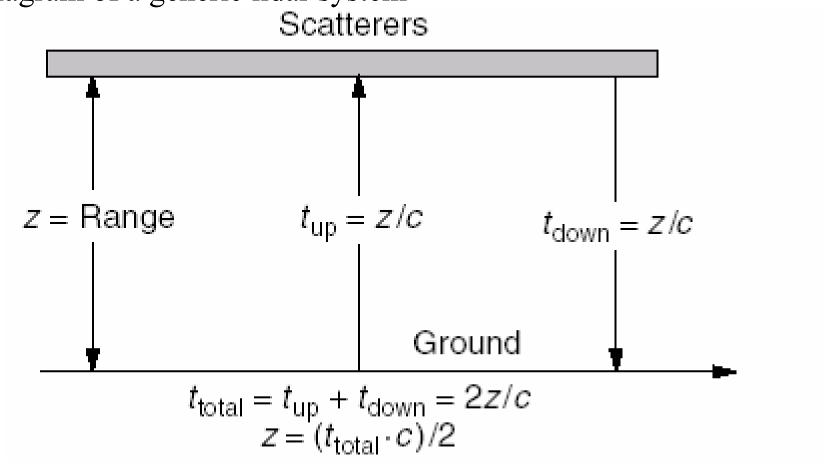

Figure 2: Determination of LIDAR range

HARLIE

HARLIE (Holographic Airborne Rotating Lidar Instrument Experiment) is a scanning backscattering lidar, which consists of a laser light source, a beam expander, steering mirrors, Holographic Optical Element (HOE), fiber optic, photo detector and data acquisition system.

An HOE is a hologram of a point source with the ability to focus light. It consists of a diffraction pattern or fringes produced from interference of mutually coherent light from a point source (object beam) and a collimated reference beam. This stores a hologram of the point source in the HOE as fringes and can be reconstructed by illuminating the HOE with a reference beam. In the HARLIE system, the backscattered laser light collected by the HOE acts as the reconstruction beam and is focused by the HOE.

The laser light is steered, by the steering mirrors to the center of the HOE. The HOE diffracts the light to be transmitted, at an angle of 45^o. The backscattered light is collected by the HOE, at an angle of 45^o as well, and focused onto the fiber optic (see Figure 3), which transports the collected light to the photo detector. The photo detector senses the desired frequency and sends the information to the data acquisition system for processing.

The HARLIE scans in a conical fashion, sweeping out the surface of a cone with half angle of 45^o. The relative intensity measured for all heights up to 20km in altitude (30km in range) is stored in bins, along with the angle of view, as a single profile of data.

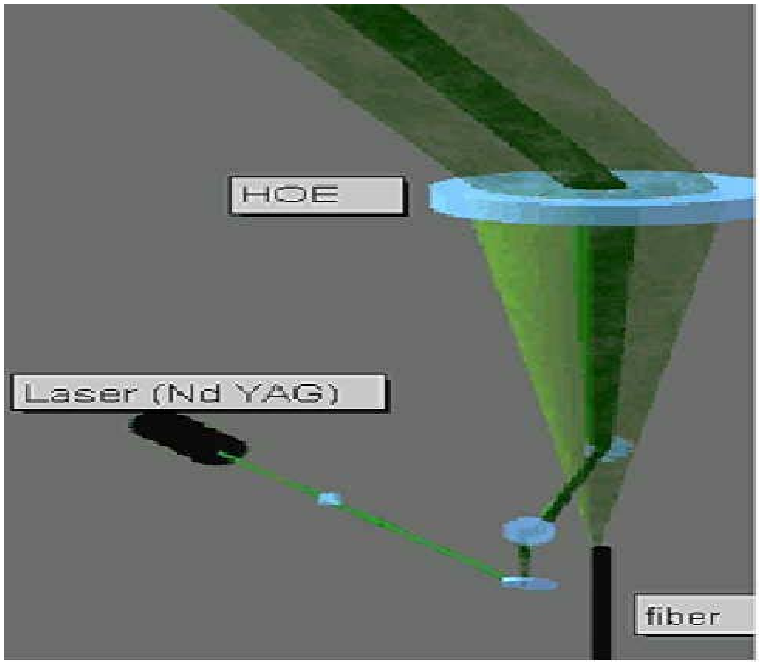

Figure 3: Schematic view of HARLIE transceiver

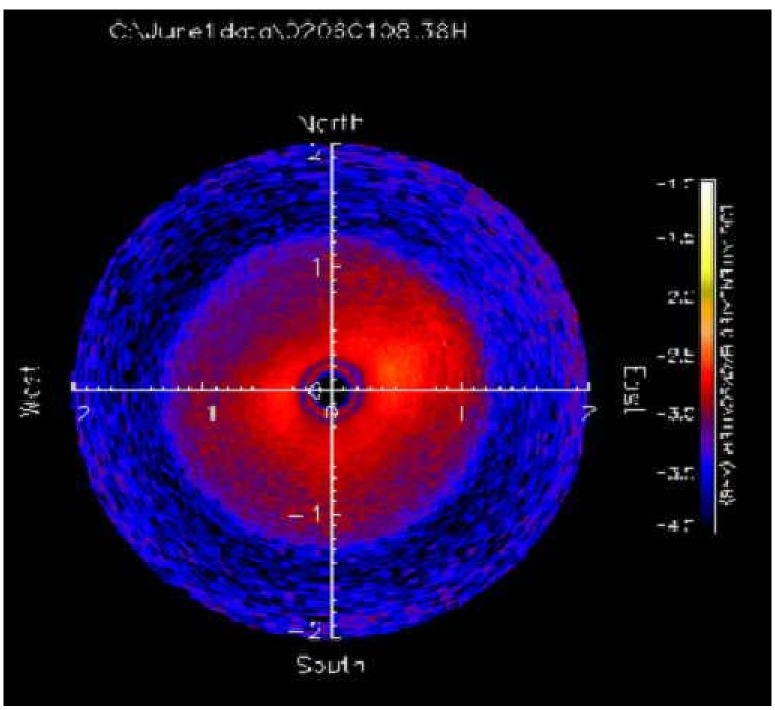

Fig 4: Top view of the conical of the relative backscattered signal collected with scan information from HARLIE system. The X and Y-axis are in units of Km. This Data was taken from IHOP field campaign in Oklahoma from May-June 2002.

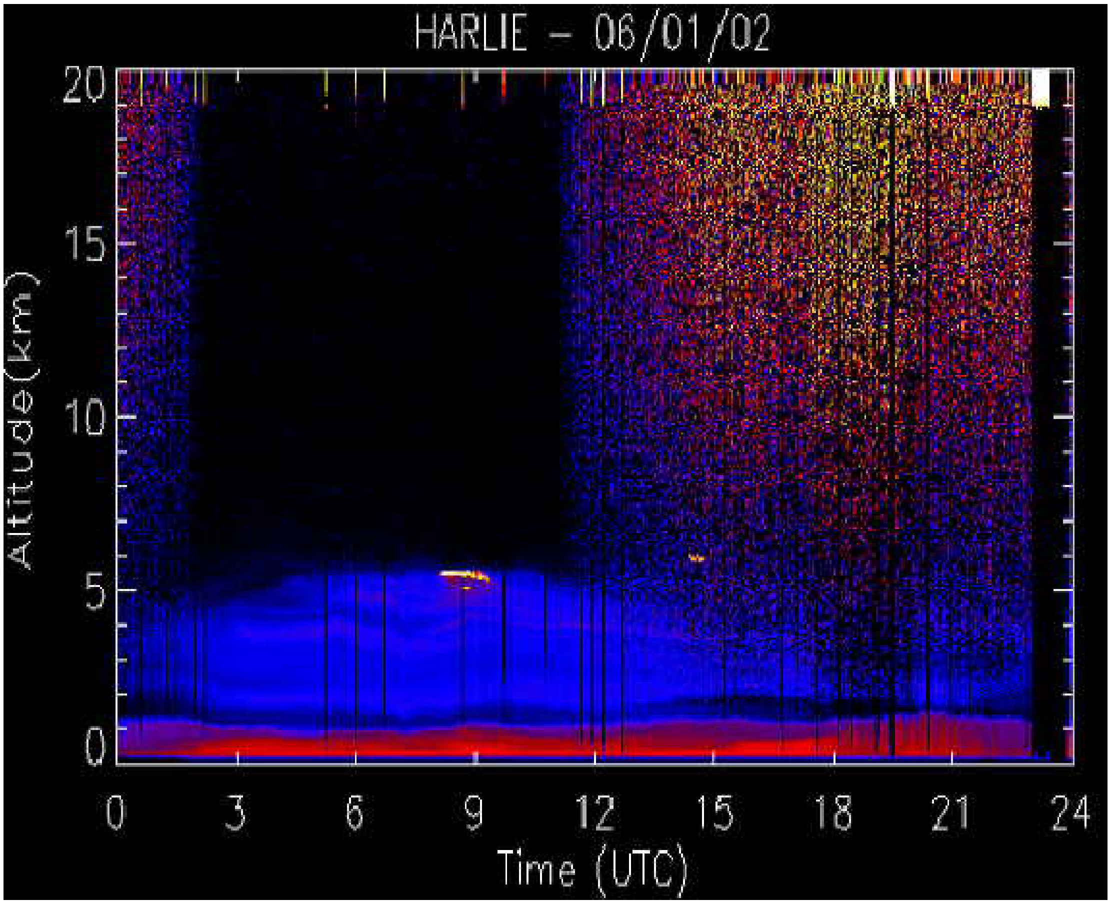

Figure 5: Vertical view of relative backscatter with scan angle averaged out. This shows the profiles from time 0 to 24 in UTC. This Data was taken from IHOP field campaign in Oklahoma from May-June 2002. Notice the cloud patches and bright daytime background speckles from the sun from 12-2.

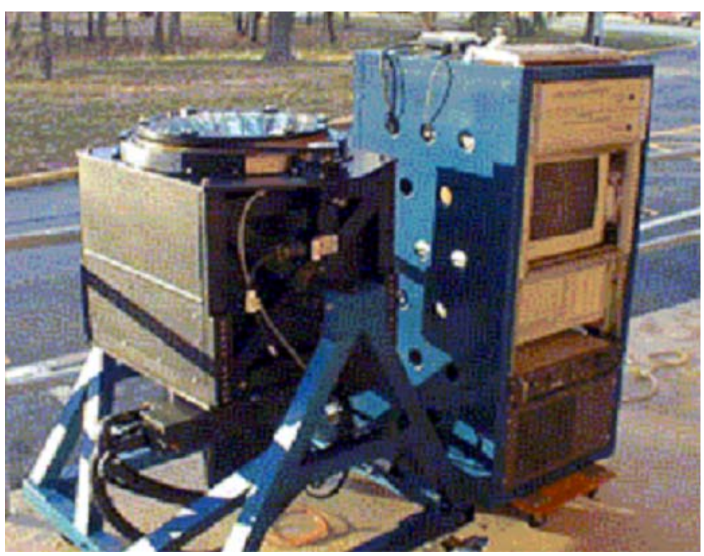

Figure 6: HARLIE transceiver on left, electronics rack on right

SYSTEM SPECIFICATIONS

Transceiver Assembly

- Weight: *118 kg*.
- Overall dimensions (in cm, minus mounting rails): *56 w x 69 l x 102 h*
- Transmitter: *diode pumped Nd:YAG, 1064nm wavelength, 1 mJ, 40 nsec pulse length, 5 kHz rep-rate, 100 µrad divergence*
- Receiver: *40 cm diameter, f/2.5 volume phase transmission HOE, 45° diffraction angle, effective collection area 1064 cm^2, 200 µrad field-of-view, 0.5 nm bandpass*
- Detector: *Geiger mode Silicon Avalanche PhotoDiode*

Electronics Rack

- Weight: *138 kg*
- Overall dimensions (cm): *56 w x 64 l x 127 h*
- Power requirements: *1000 W max. @110 Vac., 19 amps peak (2.2 kVA peak)*

Scanner

- Scan Modes: *Point and stare, 8 position step-stare, Continuous scan up to 30 rpm*
- Azimuth (scan) pointing resolution: *12.5 µrad*

Data System

- Two ping-ponged *24 bit x 8192 bin scalers*
- Range resolution: *30 m*
- Integration time: *100 msec*

SCAN ANGLE DEPENDENCE

Scan angle dependence factor is an instrumental artifact embedded in the data, which causes it to vary with the scan azimuth angle. This factor can obscure or falsify the effects of atmospheric variations that were supposed to be observed by the instrument. The primary cause of the scan dependence is due to manufacturing defects in the HOE. One effect of these imperfections is to make the HOE sensitive to linearly polarized light. This causes the light passing through the HOE to be diffracted with varying efficiency, depending on the angle the fringes make with the polarization vector of the linearly polarized laser light. The other effect causes the focal spot of the received light to be enlarged, in a non-symmetrical fashion, beyond the Field Of View (FOV) of the system. As the HOE rotates, the focal spot rotates as well, so that the intensity variation across the, large and distorted, focal spot moves in and out of the field stop (fiber core). Hence, scan angle dependence is exhibited in the data set measured by the instrument. If the focal spot was smaller than or at least the size of the fiber core, then all the light would be in the FOV of the system or if the intensity variation had been uniform across the focal spot then the fiber would collect the same intensity of light regardless of which portion of the spot is in sight.

In order to be able to obtain a fully calibrated data set, this dependence factor needs to be removed along with other non-desirable factors such as detector pile up and background noise (which are not the subject of this paper).

APPROACH

In order to make the corrections to the data set, the scan angle dependence factor needs to be extracted from the data set and used as the correction function. A full analysis of the data over several heights and several days was performed in both the time and frequency domains. The following assumption and observations were made:

i. The scan angle dependence was assumed to be a slow varying function compared to the random variations in the atmosphere. So that, averaging over many scans should suppress most of the atmospheric variations, leaving the scan function (see Figure 7).
ii. The scan function was observed to vary significantly at groups of heights above the 2km and below 500m. This observation was attributed to secondary effects such as laser power fluctuations especially for near field heights. (See Figure 7)
iii. The scan function varied significantly when the instrument was bore sight aligned. Bore sight alignment is for matching up the center of the focal spot with the axis of the fiber core so as much of the focal spot as possible is in the FOV. When bore sight alignment is performed the portion of the focal spot in the FOV is changed so that a different intensity variation pattern is measured.

$$f(\theta) = \sum_{n=0}^{N-1} a_n \cos(n\theta) + b_n \sin(n\theta)$$

Since the scan angle dependence function, obtained from averaging over many scans, is a sinusoidal function, a good approximation of it can be done using the Fourier series equation, where N is the number of strong peaks in the FFT magnitude spectrum used to approximate the correction function. Note that too few coefficients under estimates the function and too many over estimates it. The cosine and sine coefficients, a_n and b_n, can be extracted from the FFT information but since this is very noisy (see Figure 9), it was easier to, first, approximate the values of the coefficients and then perform regression analysis on the function to fit the data set that was used for the FFT analysis. The regression analysis was done using the SVDFIT procedure in IDL. The SVDFIT procedure performs a least squares fit to the user provided function and data set. The FFT analysis had to be done on the raw data, without averaging, but the regression analysis was done with the data averaged over scans and collapsed for the heights between 500m-1050m.

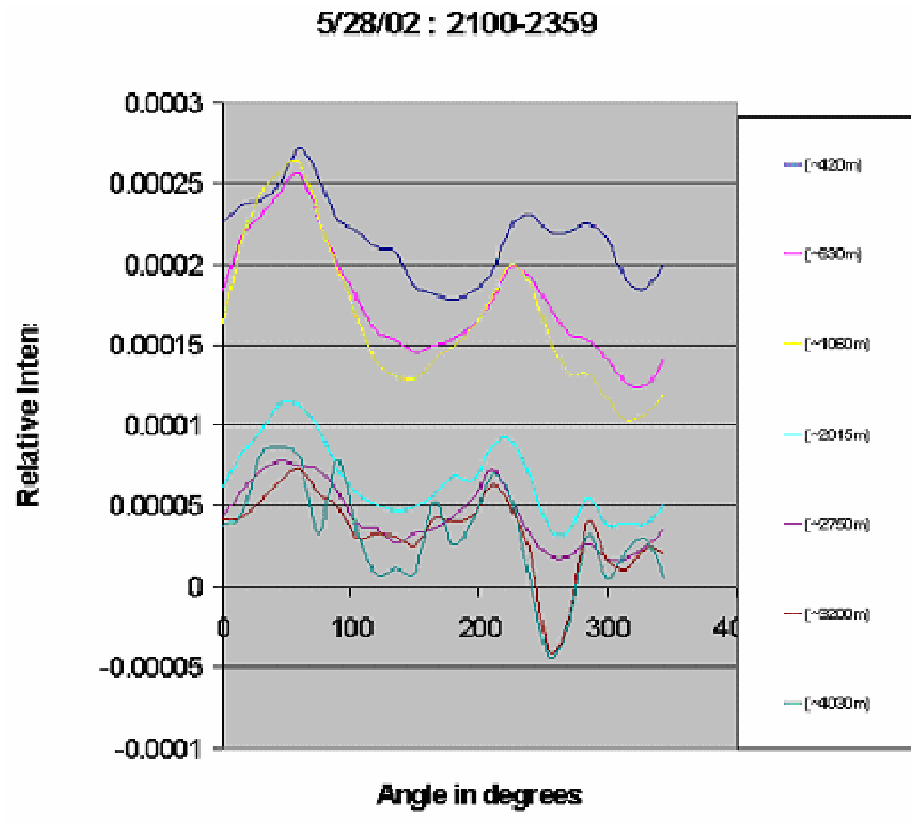

Figure 7: scan dependence function for a day in IHOP campaign averaged over many scans for different heights

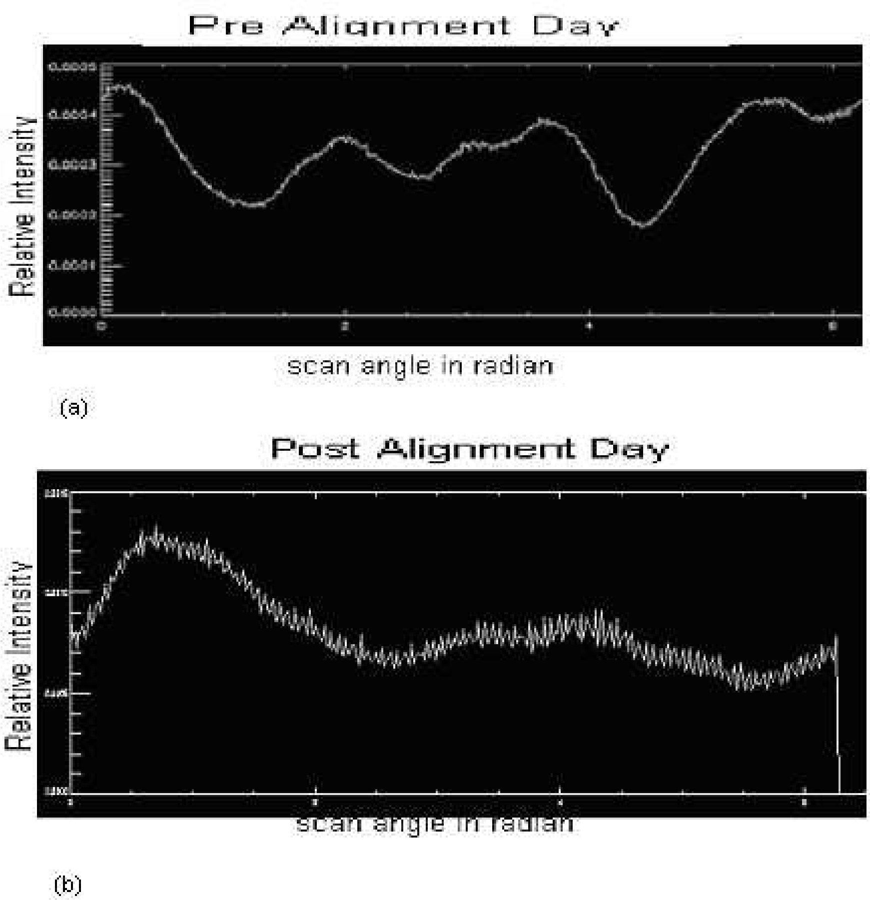

Figure 8: Plot of relative intensity versus scan angle collapsed between 500m-1050m over many scans (a) pre alignment day (b) post alignment day.

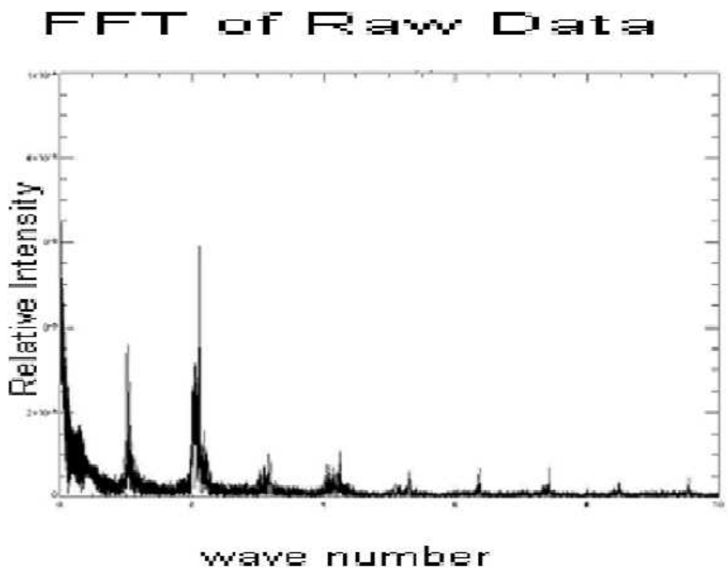

Figure 9: FFT (magnitude spectrum) of the raw data profiles over 12 hours. The wave number is the inverse of total number of scans in the data samples used. (N=10).

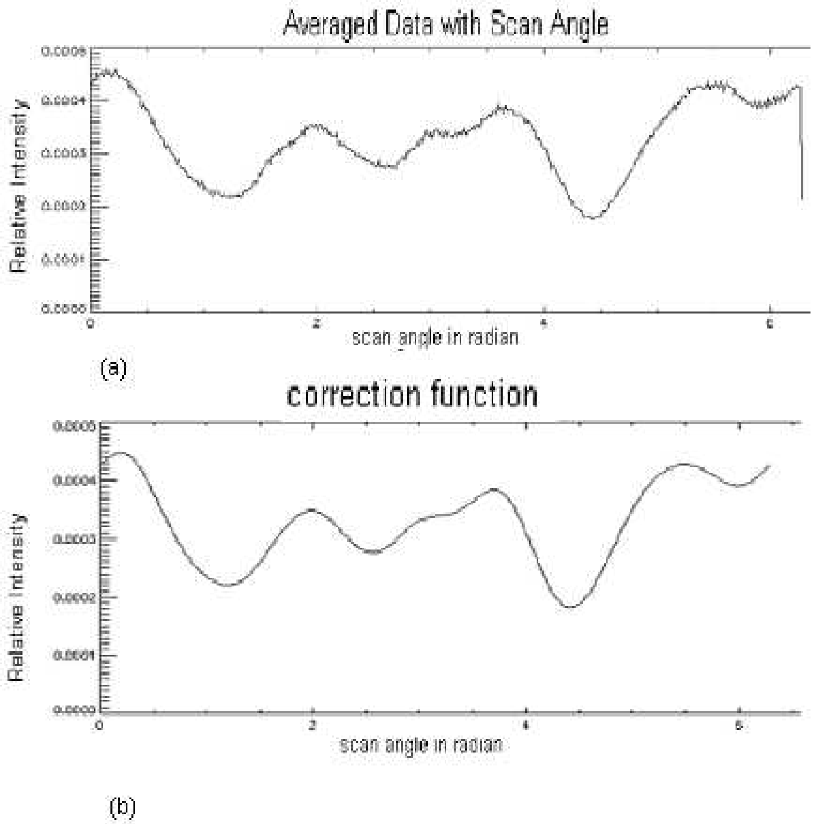

Figure 10: (a) averaged data vs. angle for a PRE ALIGNMENT day (b) correction function extracted from data set of (a).

RESULTS

The correction function extracted from the scan dependent data is shown in Figure 10(b) and Figure 11(b). Since the correction function was different for heights below ~500m, the correction in fact worsened the data (see Figure 14). For cases above ~1050m, the correction was not obvious since the data was quite noisy (see Figure 15).

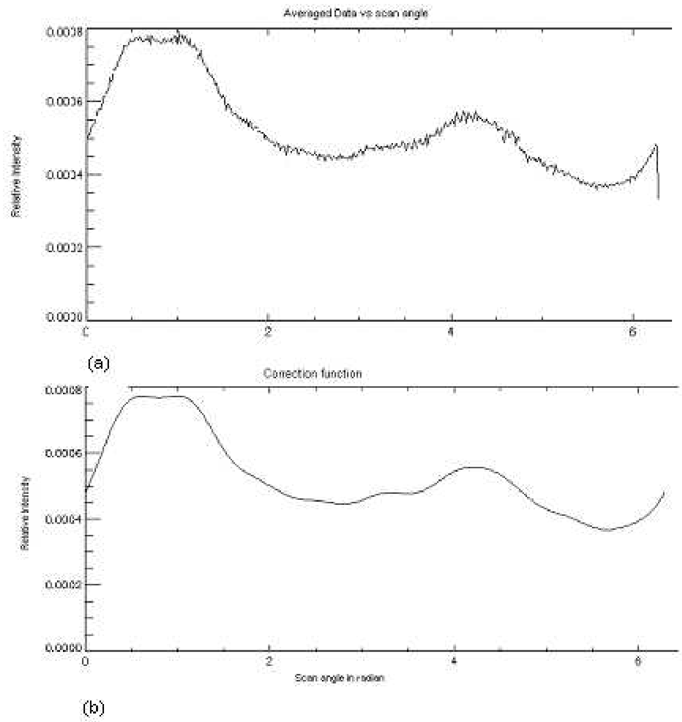

Figure 11: (a) averaged data versus angle for a POST ALIGNMENT day and (b) correction function extracted from data set of (a).

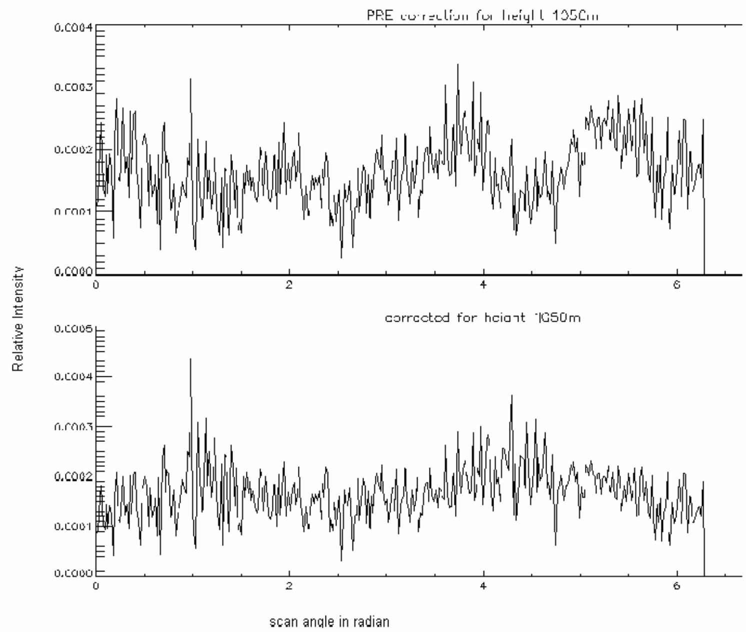

Figure 12: Pre Alignment day, May 18, 2002, top plot is before correction and bottom plot is after correction.

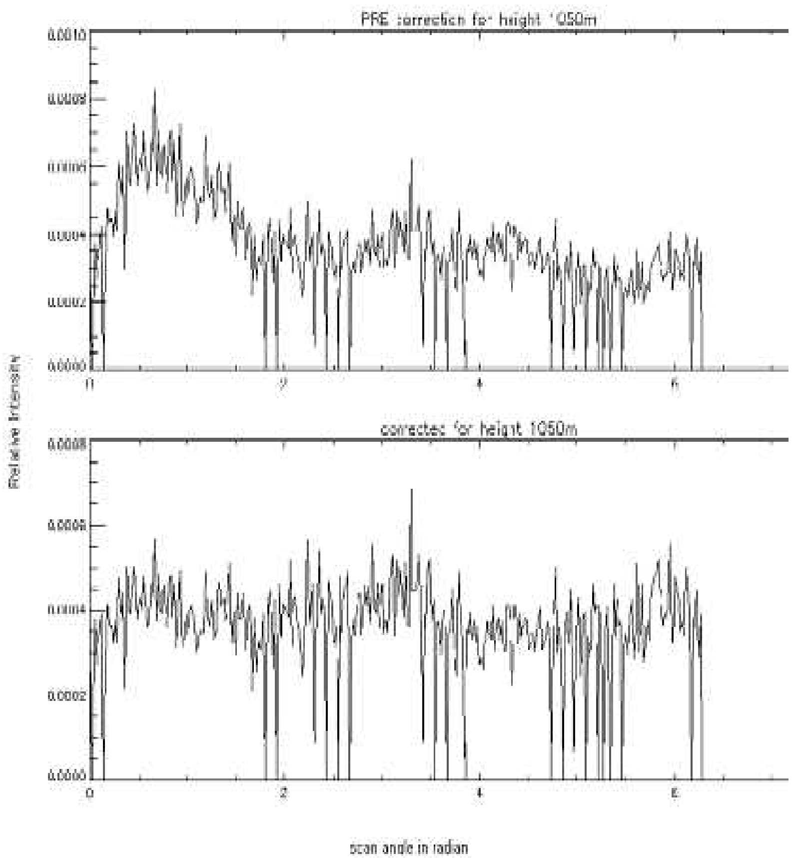

Figure 13: Post Alignment day, May 28, 2002, top plot is before correction and bottom plot is after correction

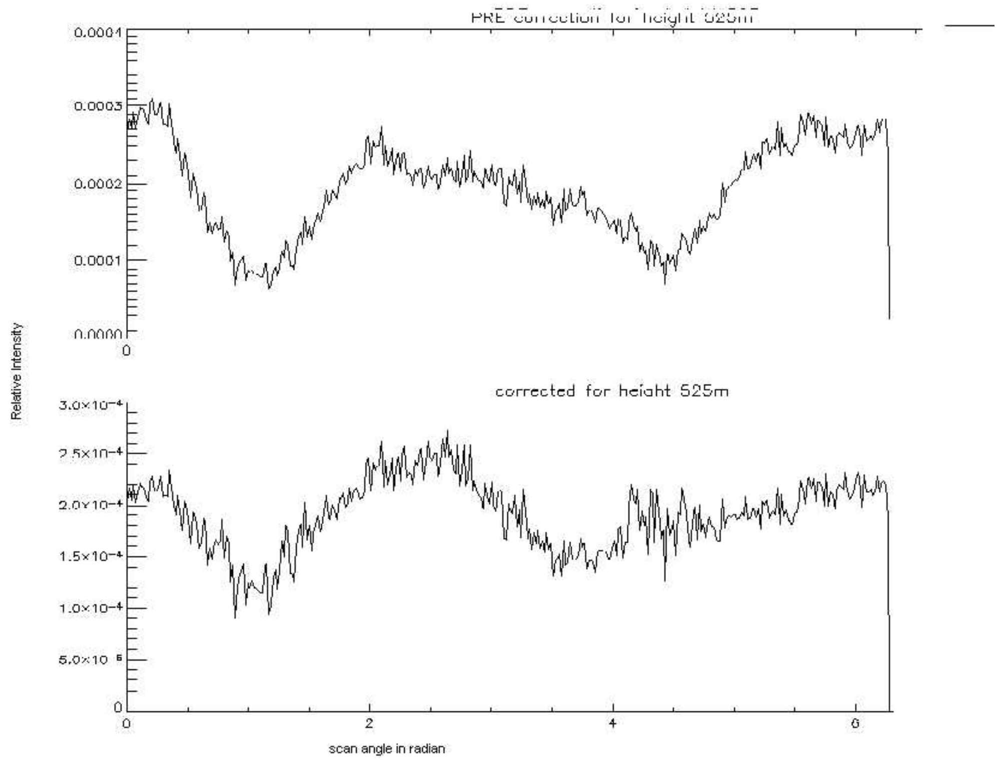

Figure 14: May 18, 2002, (pre alignment day), top plot is pre correction and bottom plot is post correction.

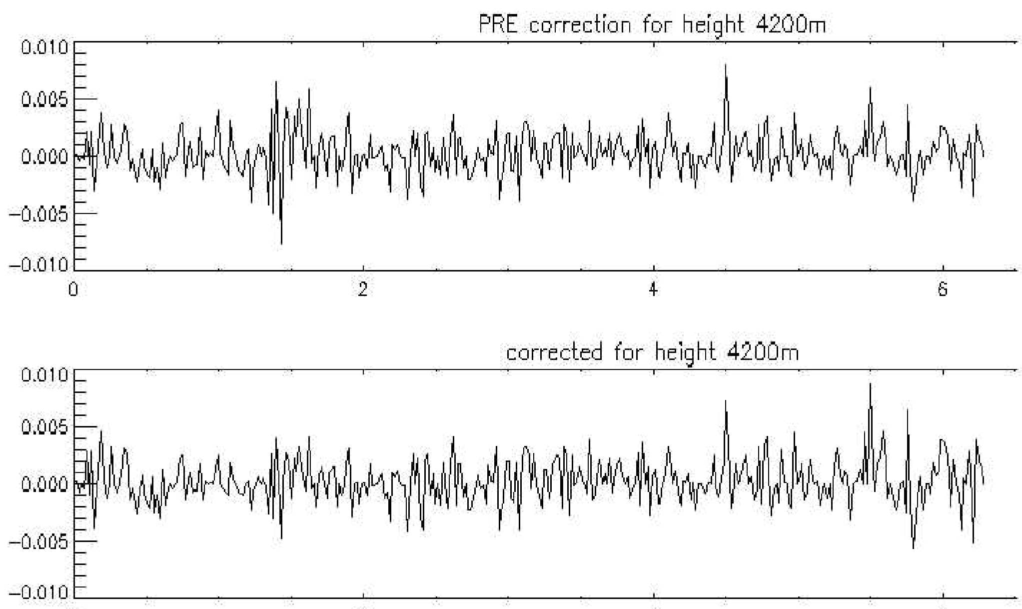

Figure 15: June 1, 2002 (post alignment day), top plot is pre correction and bottom plot is post correction

CONCLUSION AND FUTURE WORK

The scan angle dependence was quite persistent in the data and was well characterized by the Fourier spectrum and regression analysis techniques. It was observed to change substantially with height and bore sight alignment. It was also correctable, for a group of heights, while other heights were made worse or not affected much due to other secondary effects that need to be investigated

There is still more effort needed to be put in the extraction of the correction function for the HARLIE, especially for the group of heights that did not show much promise. It may be that more than one correction is required to correct the different groups of heights or a single correction with the secondary effects added may be devised. Overall, the correction will need to be optimized and applied for all HARLIE data, so that a full calibration can be done to extract the absolute profiles.

ACKNOWLEDGEMENTS

I would like to thank the following people for their individual and collective support. I was able to make substantial progress in my pursuit of a career in lidar remote sensing. I appreciate everyone, especially the holographic lidar lab team and my mentor (in charge of the lab), for all the ideas and help. Thank you all.

i. Mentor, Geary K. Schwemmer
ii. Holographic Lidar Team – Dave Miller, Sangwoo Lee, Prof. Sonia Garcia (visiting professor) and Rasheen Colleen (summer grad student)
iii. UMBC/GEST Graduate Student Summer Program (GSSP)