# A MULTISTATIC RECEIVER FOR THE MONITORING OF LOWER TROPOSPHERE AERSOSOLS AND PARTICULATE MATTER

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## ABSTRACT

A multistatic receiver has been developed to operate in conjunction with a monostatic Raman lidar. Composed of several CCD cameras, the receiver was used to measure and monitor aerosols and particulates in the lower troposphere, under 1 km. This paper discuses the physical configuration, operating characteristics and image collection procedures of the multistatic receiver. The receiver was successfully used during a field study conducted in Philadelphia during the summer of 2001 and examples of the data collected are presented. It was demonstrated that the multistatic arrangement could effectively monitor the evolution of the vertical distribution of aerosols and particulate matter.

## 1. INTRODUCTION

There has been increasing interest in the vertical distribution of aerosols and particulate matter. With most of the particulate matter, aerosols and molecules of the earth's atmosphere contained within the planetary boundary layer, (i.e., ~ below 1-2 km) [7], it is necessary to be able to monitor and measure the particulate matter, especially during air pollution episodes. While there are several instrument packages capable of long-term monitoring of aerosols in the atmosphere above 1 km (namely, tethered balloons and aircraft) a means is needed that can monitor aerosols with remote sensing equipment at altitudes below 1 km on a continuous basis. This paper discusses an approach using three CCD cameras, in conjunction with a Raman monostatic lidar unit, to monitor the spatial and temporal evolution of particulate matter and aerosols within the planetary boundary layer.

The foundation of this work is based on Stevens [3] who used a single linear diode array to image the scattering produced from a horizontally-directed lidar beam. Because Stevens conducted his experiments at Wallops Island, VA, a warm and humid marine environment, most of his data revealed the presence of a uniformly-mixed atmospheric path, thereby allowing retrieval of aerosol distribution parameters. However, in situations when a dry air mass was encountered, Stevens was unable to find a suitable fit to his data. During these periods, Stevens may have been unsuccessful because the particles may have been non-spherical, had an index of refraction sufficiently different from water, or the observed atmospheric path may have been non-uniform. Thus, Stevens had insufficient independent information with which to fit the data. A multistatic approach was conceived to address some of these shortcomings.

Because it was expected that the vertical distribution of aerosols and particulate matter within the planetary boundary layer would be much more variable in an urban environment such as Philadelphia as compared with a marine environment such as Wallops Island, it was decided that several imaging devices would be needed to provide overlapping coverage of the observed atmospheric path. Having several independent images of an atmospheric path provides a range of scattering angles at a given altitude for use in the retrieval of aerosol distribution parameters.

The next several sections discuss the specifics of the multistatic configuration, its operating characteristics and overall performance. Additionally, we describe the process of taking data images and the subsequent processing to determine aerosol profiles. While the analysis of the collected data for the retrieval of aerosol parameters is covered elsewhere [1], we do provide the reader with several data examples, including the capture of a sequence showing temporal evolution of an aerosol layer.

## 2. CONFIGURATION, CHARACTERISTICS AND OPERATION

Three commercially available, astronomy-grade CCD cameras were arranged as depicted in Fig. 1. Each camera used a 16-bit, 768 x 512 array and was commanded by a computer. As shown in Fig. 1, each camera used a different field of view (FOV) lens thus allowing the collection of scattering angles from 150° to 180°, corresponding to altitudes of 10 m to approximately 8 km. However, a theoretical investigation of the scattering model indicated that scattering angles between 175° and 180° do not

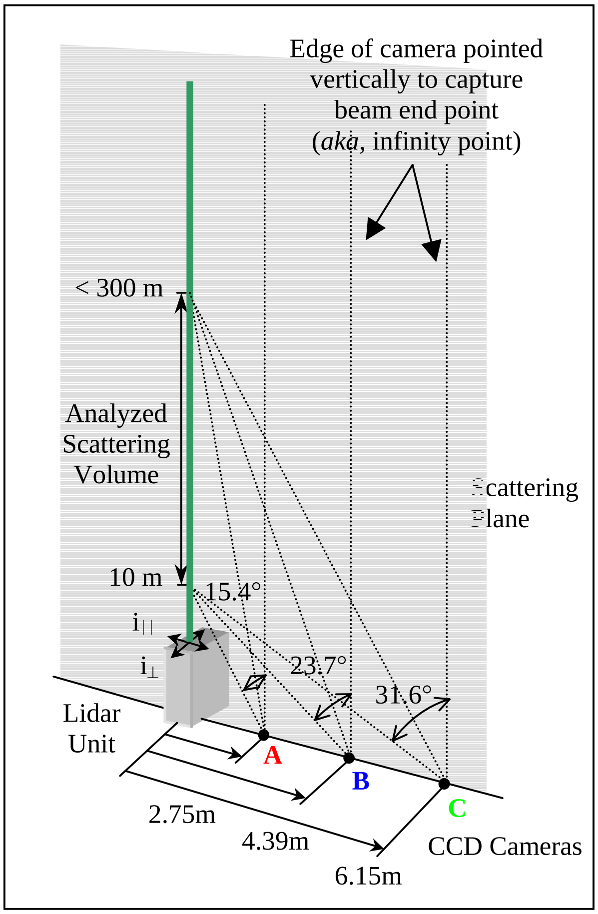

Fig. 1. Multistatic CCD camera arrangement.

provide useful information for the retrieval of aerosol parameters. Thus, the present investigation of atmospheric aerosols is centered on altitudes between 10 m and 100 m (Fig. 2).

To avoid high background signals on the CCD arrays, images were captured during the night. Additionally, to limit unwanted stray light from entering the cameras, 10 nm interference filters centered on 532 nm were fitted over the lenses.

Several tests were conducted to determine the operating performance of each camera. Such tests are necessary to determine how each camera operates with respect to the others. First, all cameras were equipped with thermoelectric coolers, thereby mitigating dark counts and noise. Further, by taking measurements with the lens aperture closed, it was found that average pixel count deviation for each camera was within a single count. Second, tests conducted to determine the polarization response of each camera's CCD array revealed no appreciable linear polarization dependence.

Once the cameras were properly configured to take images, the cameras had to be aligned to image the lidar beam onto the long axis of the CCD array. The first step was to focus the cameras to image far-field objects. Once proper focusing of far-field objects was achieved, the cameras were rotated to align the terminus point of the laser beam onto one of the last few pixels on the horizontal axis. An example of a properly aligned and imaged lidar beam is shown in Fig. 3.

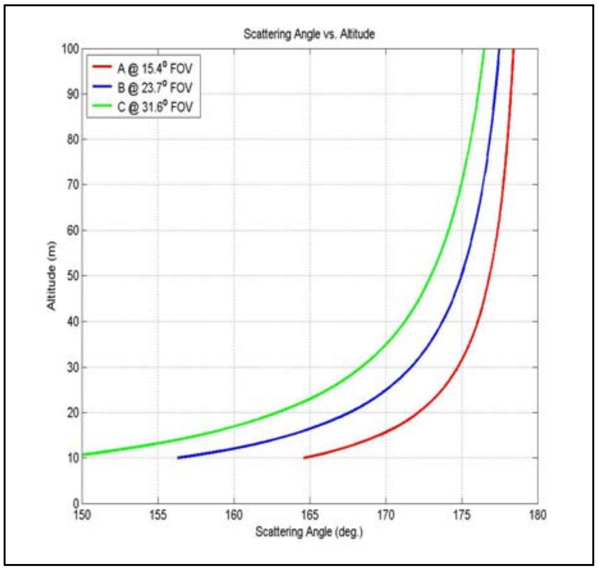

Fig. 2. Observed scattering angles of each camera.

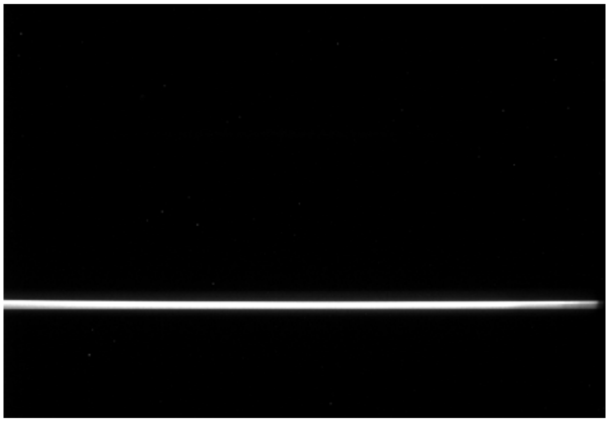

Fig. 3. Aligned lidar beam with the endpoint of the beam on the right side of the image.

It is known that taking absolute measurements of the scattering from aerosols in the atmosphere is not advisable primarily due to the nonlinearities introduced by the imaging device and due to differences in extinction along different atmospheric paths [1,3,5]. Thus, the principal analytical technique employed in the investigation of lower tropospheric aerosols described in this work uses a polarization ratio of the parallel and perpendicular scattering images [2]. In the data collection process, the first image taken was with the lidar's polarization oriented parallel to the scattering plane. As the parallel polarization image was being stored, the lidar beam was turned off, a polarization rotator was inserted into the beam's path and the lidar turned back on. An image of the scattering due to the perpendicular polarization orientation is then taken and stored. The polarization ratio is formed by simply dividing the parallel polarization image by the perpendicular polarization image, on a pixel by pixel basis. A background image and a dark count image were also taken. Thus, twelve images (four from each camera) compose a single data set for a given time. The total time to take a complete, twelve image data set (four from each camera) was under one minute (accounting for polarization rotation and image downloading). However, under windy conditions, where the vertical distribution of aerosols and particulate matter may change rapidly, shorter total image acquisition times are desirable.

## 3. IMAGE PROCESSING AND RESULTS

The main interest in the image data was to produce a polarization ratio of scattering angle versus altitude in order to extract aerosol distribution information and particulate composition. This section briefly describes the image processing used in this study and shows some results.

The imaging data can be processed to yield several pieces of information useful in describing the vertical distribution of aerosols and particulate matter. The first useful pieces of information are the polarization profiles. Fig. 4 shows an example of polarization profiles obtained from a field study conducted in Philadelphia, PA during the summer of 2001. There are six curves in the figure; three showing the parallel polarization and three showing the perpendicular polarization. Upon inspection of Fig. 4, an aerosol layer in the profiles is observed at an altitude of approximately 50 m. Inspecting the polarization profiles provides a useful means of determining when and where to concentrate efforts for the analysis of the polarization ratio.

By dividing the parallel polarization profile data by the perpendicular polarization profile, a polarization ratio is obtained. Thus, a complete data set for a given observation time reduces to three polarization ratios, one for each camera. Shown in Fig. 5 are the corresponding polarization ratios of the profiles from Fig. 4. Here, Fig. 5 displays the polarization ratio obtained from each camera as a function of scattering angle. Plots such as those shown in Fig. 5 were ultimately used in the aerosol parameter retrieval process. Although there is a high variability of each camera's polarization ratio value, the curve shape for each camera is similar. Thus, Fig. 5 indicates that the vertical atmospheric path, at the time of observation, contained the same aerosol distribution but was highly stratified.

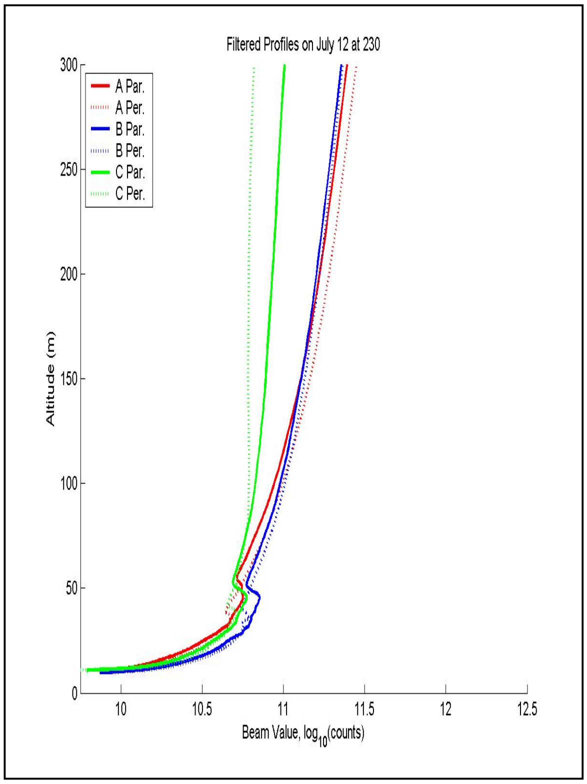

Fig. 4. Polarization profiles.

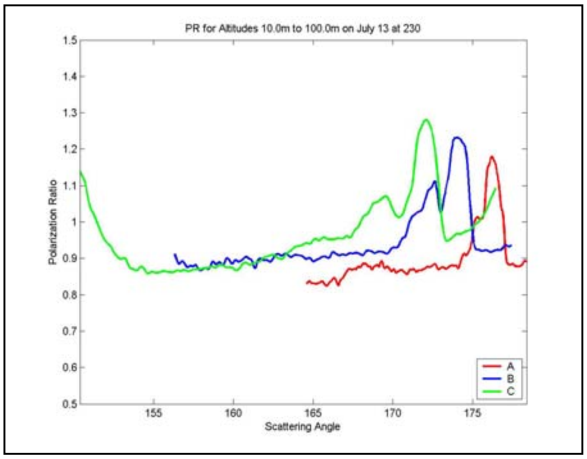

Fig. 5. Polarization ratio of Fig. 4.

Fig. 5 is part of a sequence taken on 13 July 2001. The sequence, Fig. 6, shows the growth, peak, and decay of an aerosol layer captured by the multistatic receiver.

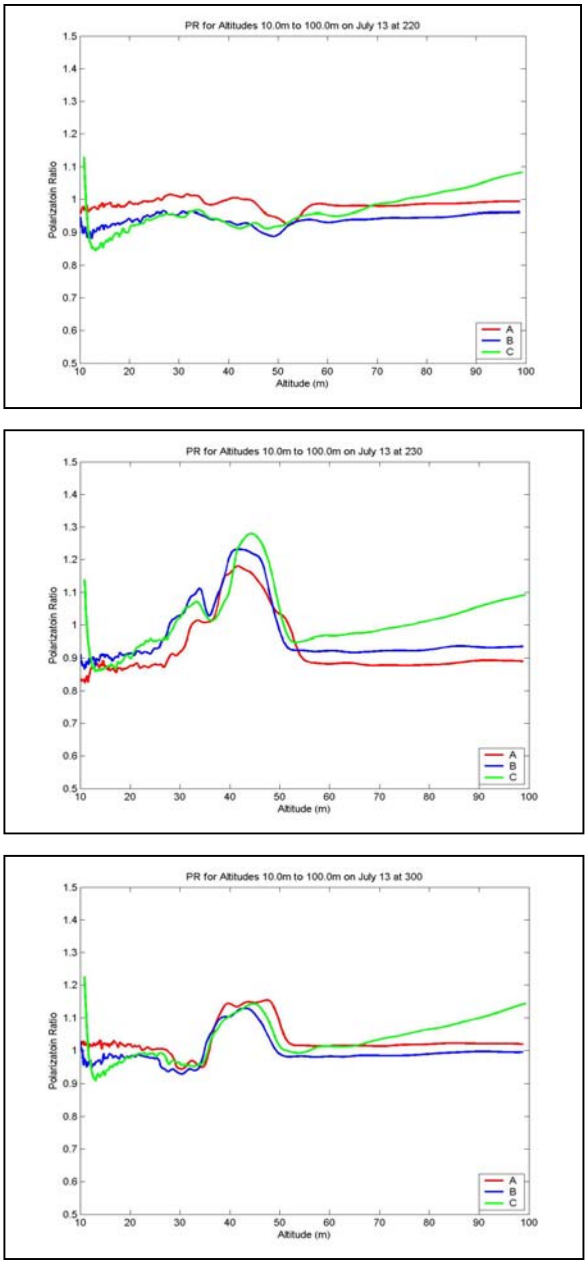

Fig. 6. Evolution of an aerosol layer.

## 4. SUMMARY

A multistatic receiver arrangement consisting of three CCD cameras was operated to augment a Raman lidar's ability to remotely sense aerosols in the lower troposphere, within the planetary boundary layer. The receiver, consisting of three CCD cameras, was configured to take a series of images of the vertical atmospheric path. Processed images of the scattering data yielded polarization profiles and the ratios used in determining the presence of aerosol layers and the retrieval of aerosol parameters. With the goal to monitor the vertical transport and evolution of aerosols continuously, the multistatic arrangement has been shown to provide effective access to the desired aerosol information.

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