CHAPTER 7

CONCLUSION

Measurements of aerosol have been used for decades from in-situ measurements through the use of balloons and sondes and globally through the use of satellites. These datasets have been used to determine radiative forcing changes on the earth such as the recent global warming hiatus inferred from the record. However, current generation instruments are aging and operating well beyond their lifetimes. New instrumentation to continue the long term global aerosol dataset is required to continue to monitor climate change. This work has been focused on developing a prototype instrument to capture images of polarized radiance from a limb scatter geometry in order to determine aerosol profiles in two dimensions. ALI is the proposed prototype instrument and was designed as an engineering test to be launched from a stratospheric balloon to determine aerosol extinction and microphysics.

ALI was designed and developed using an AOTF to spectrally filter measured radiance from 650 to 950 nm in two dimensional images with exposure times on the order of seconds. A simple three lens linear optical system using a telescoptic layout consisting of the telescope for the FEO and a focusing lens for the BEO to resolve the image was used for ALI. The system had a large FOV of 6◦ to image from a tangent point on the ground to float altitude (approximately 35 km). This resulted in significant aberrations being present in the last degree of the FOV, which was also partially outside of the acceptance angle of the AOTF. From testing and simulations in Code V optical design software the optical resolution of the instrument was a nominal 210 m both in the vertical and horizontal directions. ALI was calibrated accounting for DC offset, dark current, stray light, flat fielding, and relative spectral calibrations.

The test flight for ALI occurred in Timmins, Ontario from the CSA balloon launch facility. ALI was mounted on board the CNES CARMEN-2 gondola and the launch of the stratospheric balloon occurred at 05:35 UTC on September 19, 2014 and had a flight duration of 16 hours and 14 minutes. Float altitude was 36.5 km and ALI captured aerosol images for five hours resulting in 216 two dimensional spectral images of the atmospheric limb. The observed radiances appear to be of high quality and show both vertical and horizontal features of the cloud and aerosol layers. Aerosol extinction coefficient profiles were retrieved from the ALI data that show reasonable agreement with OSIRIS satellite measurements. Furthermore rudimentary particle size microphysics information was also retrieved from the ALI mission. Due to the limited spectral range of the prototype these retrievals was noisy but would still yield sensitivity to large particle size perturbations seen after a volcanic eruption similar to OSRIS or SAGE products and with the extended wavelength range into the NIR the precision could be increased. A satellite version of the ALI instrument would be able to supply global distribution of aerosol extinction and microphysics and assist in continuing the global aerosol record. Overall, the results are promising and work on a second iteration of the instrument has already begun as well as a space feasibility study.

This first prototype ALI instrument has allowed for the measurement of stratospheric aerosol through polarized images and with the continuation of the ALI project some recommendations for future work are suggested. First, an azimuth scan occurred during the flight to test the sensitivity of the measurement to aerosol and provide some verification for the simulation study. These measurements should be analyzed to better understand the correct orientation for the second generation of ALI. From the simulation study a future iteration of ALI that is vertically polarized should be orientated so that the SSA is in between 45-60◦ to avoid the problematic scattering angles of 80-100◦ that causes a bias in the retrieved aerosol profile or orientate the instrument to measure the horizontal polarization instead to avoid this problem.

Also, even with the baffle and the robust method of removing stray light with the cycling of the AOTF, some stray light was still observed in the obtained images. Impact and mitigation of this should be tacked in future iterations of the instrument. Glan-Taylor prism polarizers should replace the nanoparticle linear polarizers. The advantage to the Glan-Taylor prism is rather than attenuate the unwanted polarization it is reflected though total internal reflection approximately 90 degrees from the optical axis where it can be absorbed away from imaging plane reducing the stray light contamination improving the imaging quality. Further, the addition of a back end telescope between the AOTF and the camera could be used to help separate the desired diffracted signal from the undesired outputs (*i.e.* zeroth order beams) in physical space to reduce stray light further. Lastly, the addition of an absolute calibration would allow the direct determination of albedo which would remove some uncertainty and most likely improve the retrievals due to the highly dependent nature between polarized albedo and retrieved aerosol extinction. This is simply a matter of having access to the calibration equipment and preforming the necessary experiments.

Some recommendations for the camera could also improve the quality of the measurements. The addition of a shutter or masked pixels on the CCD would be useful to calibrate DC offset and dark current changes during the flight due to temperature changes. Additionally, a camera with faster readout would also greatly increase the number of measurements that can be made with the system and increase the amount of scientific information that could be acquired in a space mission.

Apart from aerosol future iteration of ALI could be used to possibly measure additional atmospheric species with modifications to the possible wavelength range. The current version of ALI was able to measure from 650-950 nm, and expanding out to the NIR and selecting an AOTF with a narrower bandpass the possibility of retrieving a water vapour profile using the water absorption bands around 930 nm would be possible. Further if the AOTF is replaced with a dual octave filter the wavelength range of the device could be expanded, for example 500-2000 nm, and replace the camera with an extended InGa array would allow the addition of an ozone retrieval while still maintaining the ability to retrieve high quality aerosol profiles. Furthermore, the addition of an ozone retrieval has an effect on aerosol retrievals at the shorter wavelengths which would improve the aerosol product at these wavelengths. Lastly, using an extended range AOTF would also allow a short wavelength normalization to the measurement vector like OSIRIS and SCIAMACHY for easier and consistent comparison between various instruments.

Since the goal of ALI is a future satellite mission it would be ideal to be able to test a version designed for a low earth orbit. However, the second version of ALI is scheduled for another stratospheric balloon launch and must also function from a balloon geometry. Both tests could be performed on the flight of ALI version 2 if it is designed for a low earth orbit geometry with the addition of a front end zoom lens that would be able to change the FOV from space to balloon geometry. Additionally the adaptation of a folded optics design will be required for a space platform and should be tacked in a future iteration. All of these improvements would help to improve the image quality, and space feasibility of the next generation instrument.

With the completion of ALI, a simulation study was underwent to determine if there was any advantage or disadvantage to measuring a linear polarization over the total radiance for a space mission. Overall it was determined that there is no distinctive advantage to measuring a linear polarization over the total radiance. However, a polarized measurement only observes a fraction of the signal compared to the total radiance case which would need to be mitigated in the optical design or operation. One exception to poor instrument performance is measuring the 90 degree SSA with the vertical polarization due to the extremely low signal levels.

Overall, the ALI mission had a successful first flight and determined aerosol extinction profiles and a moment of particle size information. These profiles compared well to OSIRIS measurements and the particle size parameters were noisy but within the expect values for background aerosol loading. A satellite version of ALI would be able to determine global aerosol profiles from a low earth orbit especially if the horizontal polarization was observed instead the vertical polarization. This success of this mission has allowed for the future development of the ALI platform with two projects currently underway. The first is a second version stratospheric balloon instrument to be flown in the spring of 2017, and the second is a space feasibility study of the performance of ALI from a low earth orbit mission.