CHAPTER 1

INTRODUCTION

The atmosphere of the Earth is a dynamic, evolving system dependent upon its composition. The concentration of various atmospheric species is dependent upon altitude, geographical location, season, and time of day. These species interact with the incoming sunlight to absorb, scatter, and re-emit the incoming radiance originating from the sun. Using spectroscopy, concentrations of different species can be determined to discover the composition of the atmosphere. Over a period of time, changes to the composition caused by natural and anthropogenic sources can be used to infer changes and trends, some of which are related to climate change. One important species in determining the radiative forcing effect is stratospheric sulfuric aerosol. These aerosols are submicron-sized droplets of sulfuric acid that scatter solar irradiance away from earth causing a cooling effect to the surface temperature. The source gasses that form these aerosols arise from the burning of fossil fuels, biomass burning, marine processes and form what is often referred to as the “background” aerosol layer. A large unpredictable perturbation of this layer occurs after large volcanic eruptions that can inject large quantities of sulfur directly into the stratosphere.

Instrumentation has been deployed over the past decades to monitor the atmospheric state from the ground, sky, and in space using many different methods. The evolution of the atmosphere needs to be monitored in the future and to do so, new instrumentation is required. Using the techniques from current generation instrumentation combined with advancements in technology, the capabilities of the next generation of satellite instruments will be able to monitor the earth with greater efficiency and higher resolutions.

Aerosol has been monitored globally from satellite platforms since the 1970s. The most notable method used is known as solar occultation, such as the NASA SAGE missions. These instruments acquired vertical aerosol profiles, however they were limited to the number of measurements that can be acquired per day due to each measurement requiring a sunrise or sunset. Following occultation, other techniques were implemented onboard satellites with the ability to measure aerosol. One such technique is limb-scatter geometry, such as OSIRIS onboard the Odin spacecraft, which achieves greater global coverage since it only requires sunlit atmosphere and also maintains vertical resolution. Stratospheric aerosol monitoring has continued to the present day from various platforms, including the previously mentioned as well as others, which has allowed a long global time series to determine trends in aerosol extinction over the past few decades. However, the current instruments are ageing and many are operating past their estimated lifetimes with few, if any, scheduled to replace the ageing instruments.

The continued atmospheric monitoring of stratospheric aerosol is essential since it is an important component of the climate equation due to its overall nature to cause cooling of the planetary surface. Recently, increases in stratospheric aerosol have been linked to the so-called “global warming hiatus” and the gradual increase in stratospheric aerosol has been attributed to small volcanic eruptions. Continued global coverage of stratospheric aerosol is essential to continue to monitor the climate. Additional missions and instrument prototypes are required for the near future.

In this work, the design and test of a new passive satellite-based remote sensing instrument, named the Aerosol Limb Imager (ALI), is presented, which images the polarized limb radiance of the atmosphere to determine stratospheric aerosol profiles using a novel filtering technology. ALI measures the atmosphere using two dimensional imaging to acquire cross-track and vertical profiles giving additional measurement resolution. Current limb instruments do not measure the cross-track profile and only the vertical. The addition of the cross track will allow for more spatially dense measurement points which will allow better determination of atmospheric species such as aerosol and how it dynamically interacts with its environment. This instrument, although a prototype for a satellite instrument, has been tested on a stratospheric balloon flight and was designed specifically for this platform. Slight alterations to the design are needed for deployment on to a satellite platform mission.

In this work, Chapter 2 outlines the background physics of the atmosphere on which this project is based including an overview of stratospheric aerosol. This includes its discovery and discussion about the importance of aerosol in the atmosphere, the effect on climate, sources of aerosol, and microphysical properties. Following, an overview of the different techniques used to measure aerosols is presented. This includes techniques used in in-situ measurements like optical particle counters and nephelometers and satellite based methods such as occultation and limb scatter. Then a brief overview of radiative transfer theory is covered starting with the scalar representation and moving into the more complete polarized, or vector, theory needed for this work. Lastly is a brief discussion of the SASKTRAN-HR model used within this work and inverse methods to determine atmospheric parameters from radiance measurements.

Chapter 3 starts with an overview of Acousto-Optics Tunable Filters (AOTF), which is the novel filtering device at the core of the ALI system. The background physics and practical application of this device are covered with a focus on the advantages and disadvantages to using this filter in remote sensing applications. Following is a discussion of the possible optical layouts for ALI and the testing and underling choice for the optical system design. Chapter 4 discusses the calibration and testing of the final instrument as well as the control software used during stratospheric balloon flight.

Chapter 5 is a presentation of the ALI test flight on a stratospheric balloon in Timmins, Ontario in 2014. The results from the measurements recorded from the flights are also presented including calibrated images, retrieved aerosol profiles, precision estimates, and particle size estimation. These results are compared to current satellite measurements and a discussion about the quality of the ALI retrievals is presented.

Since ALI is inherently a linearly polarized instrument to be used in a future space monitoring mission, a study was undertaken to determine the full effect of the polarized measurement on the aerosol retrieval capability. Furthermore, the optimal geometry for a limb scatter polarized instrument was also determined in this same study. This was done by probing the solution space with a large range of input parameters, and the results of this study are the focus of Chapter 6.