Dictionary Learning Approach To Lidar Sensing Of The Atmosphere

A thesis submitted
in partial fulfillment for the award of the degree of

Doctor of Philosophy

by

Varanasi Satya Sreekanth

Department of Avionics
Indian Institute of Space Science and Technology
Thiruvananthapuram, India

December 2023

Abstract

Extending temperature measurement range, and sustaining the system performance is an important requirement for Rayleigh lidar remote sensing of the atmosphere. Power aperture product enhancement is one way to achieve the desired measurement range. The second way is the Dictionary Learning approach. This work aims to retrieve atmospheric temperature profiles using denoised photon counts using the penalized maximum likelihood Dictionary Learning technique. The proposed algorithm for temperature retrieval provides an acceptable level of temperatures at higher altitudes and reduces the **Standard Error(SE)** in temperatures. In the proposed method, uncertainties in temperature profiles are estimated using Monte Carlo Simulations. The observational data for evaluating the proposed algorithm was acquired with the help of a Rayleigh Lidar System at the National Atmospheric Research Laboratory, Gadanki, India. It has been measured that the SE of the temperatures retrieved get reduced by **5K** at the altitude of 84 km and the measurement range has been extended by 6 km.

The Atmospheric Gravity Waves are studied based on temperature perturbations obtained from the measurements of Rayleigh Lidar. Background sources must be removed when studying gravity waves. In the analysis of Gravity Waves from temperature perturbations derived from Rayleigh Lidar, the presence of wind in the horizontal plane causes the frequency spectrum to shift and power spectral density get change than the actual. A methodology named Multi-Resolution Dictionary Learning combined with Instantaneous Frequency Estimation is proposed for removing background wind effects in both the temporal and spatial domain for analyzing the behavior of Atmospheric Gravity Waves accurately. An in-depth study on the seasonal changes of frequency shift due to background wind is discussed.

The temperature perturbations without the presence of background wind are used to detect Gravity Wave breaking. Middle atmospheric circulation is heavily influenced by the Atmospheric Gravity Waves. Gravity Waves get trapped at the altitude where their horizontal phase speed is equal to the horizontal background wind speed, causing a critical layer to form. We focus on the **mesosphere(50-90km)**, where Gravity Waves get attenuated due to non-linearity. To enhance the study of Global Circulation, Kernel functions are included for the first time in Deep Dictionary Learning techniques. As a result of the introduction

of **Kernel functions in Deep Dictionary Learning,** it is possible to detect sudden transient events, like the breaking of a Gravity Wave. It discusses how Deep Kernel Dictionary Learning techniques can detect Gravity wave-breaking events and the false detection rate of those events.