Multi-Instrument Analysis of Nocturnal Low-Level Jet Influence on Air Quality over the Mid-Atlantic United States

Maurice Roots[a, b], John T. Sullivan[c], and Belay Demoz[a, b]
[(a)] *University of Maryland, Baltimore County (UMBC), Baltimore, MD, 21250, U.S.A.*
[(b)] *Goddard Earth Sciences Technology and Research (GESTAR) II, Baltimore, MD 21250, U.S.A.*
[(c)] *NASA Goddard Space Flight Center (GSFC), Greenbelt, MD, 20771, U.S.A*
Lead Author e-mail address: mroots1@umbc.edu

Abstract: Understanding the diurnal and seasonal variations of Nocturnal Low-Level Jets (NLLJs) and their influence on atmospheric constituents is crucial for elucidating regional atmospheric dynamics, air quality, and climate impacts. In this study, we investigate the influence of NLLJs on aerosol and ozone layers in the U.S. mid-Atlantic region using a comprehensive observational dataset from ozone and aerosol lidar profiles. We leverage data from radar wind profilers, ceilometers, and the GSFC Tropospheric Ozone Lidar (TROPOZ) system to characterize NLLJ dynamics, aerosol properties, and ozone concentrations. Through analysis of wind profiles, we examine the diurnal variations and seasonal trends of NLLJs, focusing on their intensity, frequency, and vertical structure. Concurrently TROPOZ ozone lidar data provide high-resolution vertical profiles of tropospheric ozone concentration, allowing for detailed investigation into ozone distribution and its relationship with NLLJs.

1. Introduction

Decadal-scale observations have indicated a decreasing trend in surface ozone (O3) concentrations attributed to regulatory efforts like the National Ambient Air Quality Standards (NAAQS). However, the Mid-Atlantic region of the United States experiences recurrent high pollution events, particularly episodes of elevated O3 levels. Many of these events are influenced by complex interactions between surface terrain and meteorological phenomena [1 - 11].

Meteorological drivers such as Nocturnal Low-Level Jets (NLLJs), downslope winds (DSW), and long-range transport play pivotal roles in shaping pollutant distributions within the Mid-Atlantic region. NLLJs contribute to advection and vertical mixing, altering the chemical budget of the region. These jets, observed typically between 00:00 and 08:00 Eastern Time at altitude between 400 m AGL – 2000 m AGL, exhibit a potential to disperse pollutants over mesoscale distances parallel to the Appalachian Mountains [6, 12 - 14]. The turbulence associated with NLLJs coupled with aloft reservoirs of pollutants, induce nocturnal increases in surface pollutant concentrations through turbulent downbursts mixing pollutants from the residual layer into the stable boundary layer and surface layer [14].

Furthermore, NLLJs are often followed by DSW drainage flows, redistributing pollutants perpendicular to the sloping terrain of the Appalachian Mountains. This orographic effect aids in pollutant removal and storage for subsequent entrainment by the convective boundary layer [14]. Additionally, long-range transport of pollutants towards the Mid-Atlantic region, especially during the North American fire season, can significantly impact air quality, with smoke plumes occasionally acting as reservoirs of aerosols, ozone, and ozone-precursors [5, 10, 11, 15, 16].

Despite extensive studies on pollution episodes in the Mid-Atlantic region, a systematic and coordinated long-term investigation into the influence of Mid-Atlantic NLLJs on air quality is lacking. Understanding the characteristics and impacts of NLLJs is crucial for accurate meteorological predictions and effective environmental management strategies. Thus, this study aims to analyze the influence of NLLJs on aerosol and ozone layers using the available networks of profilers and surface monitors in Maryland operated by the Maryland Department of Environment (MDE). Through comprehensive observational analysis, we seek to elucidate the complex interactions between

NLLJs and atmospheric constituents, providing insights into regional air quality dynamics and their implications for environmental management and public health.

2. Data & Methods

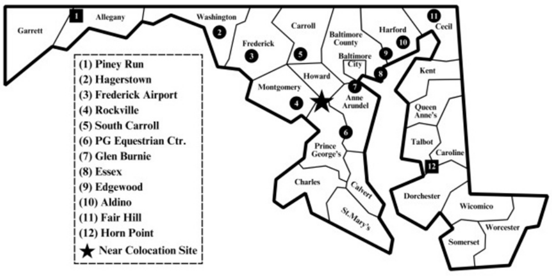

Figure 1: Study Site Map. Rectangles are locations with radar wind profilers; circles are locations with MDE surface monitors, and the star is the near colocation site with radar wind profiler, ceilometer, and ozone lidar.

This study utilizes a combination of observational datasets to investigate the influence of Nocturnal Low-Level Jets (NLLJs) on aerosol and ozone layers in the Mid-Atlantic region of the United States. The primary datasets include 915 MHz radar wind profiler (RWP) data, offering vertical profiles of wind speed and direction; 1064 nm ceilometer data, offering vertical profiles of aerosol backscatter; and GSFC DIAL Tropospheric Ozone Lidar (TROPOZ) data, offering vertical profiles of tropospheric ozone concentrations. Supporting datasets include surface meteorological data, and surface pollutant measurements are leveraged from in-house and state-managed networks.

Data preprocessing steps are applied to ensure the quality and reliability of the observational datasets. This includes quality control, calibration, and data fusion to harmonize measurements across different platforms. NLLJs are identified and characterized based on RWP observations of vertically resolved wind speed and wind direction. NLLJs events identified are then referenced with datasets on atmospheric constituents to analyze NLLJs influence.

Vertical distribution and transport of aerosols are determined by ceilometer backscatter. Tropospheric ozone profiles obtained from TROPOZ lidar measurements are analyzed to assess ozone distribution and vertical mixing by NLLJs. Diurnal variations and seasonal trends in ozone concentrations are examined to understand the role of NLLJs in ozone dynamics.

The observed patterns and trends in aerosol and ozone distributions are integrated and interpreted in conjunction with surface meteorological data and pollutant measurements. Statistical methods are employed to quantify relationships between NLLJs and atmospheric constituents and to assess the significance of observed trends and variability.

3. Results & Discussion

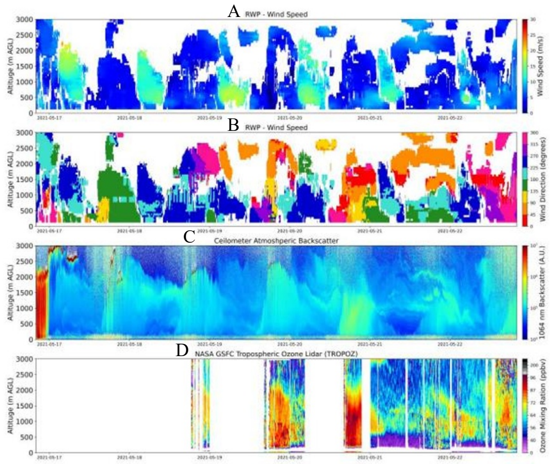

Figure 2: Near Colocation Site Profilers. (A) wind speed profile; (B) wind direction profile; (C) ceilometer backscatter profile; (D) ozone lidar profile.

We present the correlation between NLLJ cases and elevated nocturnal and diurnal surface pollution. This is represented by Figures 2 and 3, which demonstrate a week of NLLJ cases that coincide with overpassing aerosol layers and elevated ozone layers which were both mixed down and lofted pollutants for next-day diurnal entertainment. Note that the aerosol layers can be assumed by the ceilometer 1064 nm backscatter in which we observe the layers near the jet core to be descending near the stable boundary layer and the layers close to the top of the NLLJ we observe the lofting of those layers for subsequent entrainment by the convective boundary layer. The ozone profiles from the TROPOZ system in this scene (Figure 3) aren't sufficient to analyze the vertical structure of ozone during the NLLJ onset, however, we note that the surface ozone increase coinciding with the NLLJ onset is indicative of aloft layers of elevated ozone that were mixed down into the stable layer. This demonstrates the necessity for further study of NLLJ's influence on air quality as it constitutes a concomitant factor in mitigation and management of public health and environmental stability.

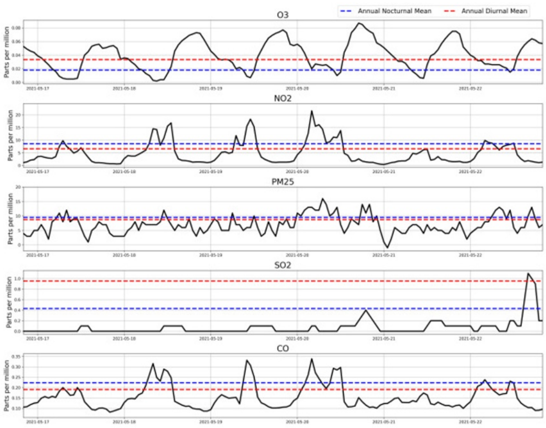

Figure 3: Surface measurements from near colocation site.

4. References

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