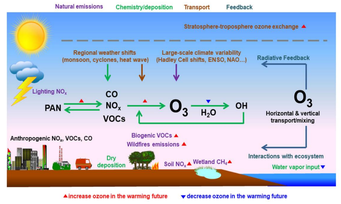
Characterizing Low-Level Jets in the Mid-Atlantic States: Impact on Boundary Layer Evolution and Composition

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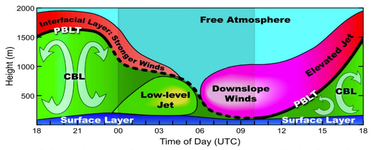
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Background

The Environmental Protection Agency (EPA) has set regulations for ozone and its precursors under the National Ambient Air Quality Standards (EPA NAAQS: https://www.epa.gov/criteria-air-pollutants/naaqs-table). Surface ozone concentrations are generally decreasing, however, in domains with urban centers adjacent to complex surface terrain (like large bodies of water) ozone concentrations continue to be observed in excess of the **2015 NAAQS of 70 ppbv** (Maximum Daily 8 Hour Average: MDA8).

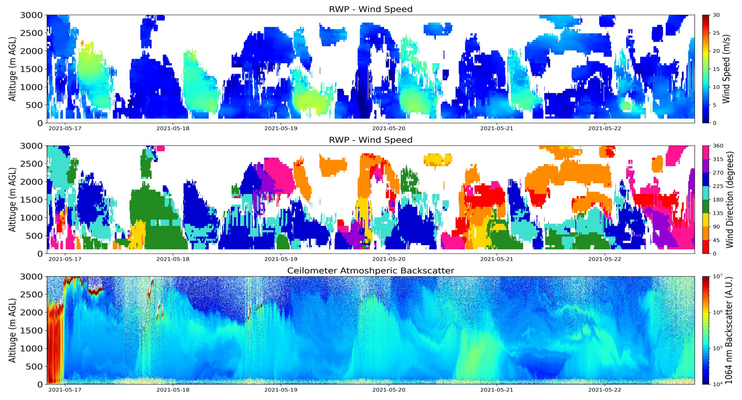


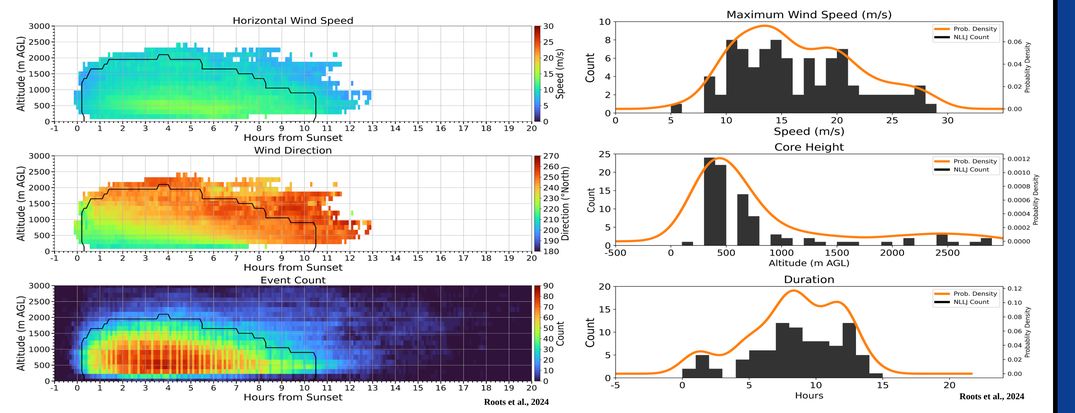
Tropospheric ozone (O_3) sources and sinks. Primary photochemical sources are outlined: nitrogen oxides (NO_x) and volatile organic compounds (VOC) (Lu et al., 2019).



Schematic of 3-Stage Mid-Atlantic Atmospheric Boundary Layer Evolution as modeled by Rabenhorst et al (2014) and adapted from the classic Stull (1988) model. Note the addition of the low-level jet and downslope winds.

Meteorological drivers (i.e., atmospheric dynamics phenomena) can have large impacts on not only the evolution of the PBL but also the variability of its constituents therefore having drastic implications towards air quality (Banta et al. 2010, Sullivan et al. 2017, Oyola et al. 2017, Moghani et al. 2018, Lu et al. 2019, Moeini et al. 2020,). The meteorological drivers that are relevant to this study and largely dictate distributions of pollutants within the **Mid-Atlantic region of the U.S. are nocturnal low-level jets (NLLJ), downslope winds (DSW), and long-range transport (LRT),** which bring advection and/or vertical mixing.



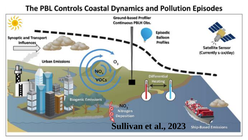


We conducted an *analysis of **90 Mid-Atlantic South-Westerly NLLJ events**, focusing on wind speed, core height, and event duration.* Maximum wind speeds ranged from 5 to ~30 m s^{-1}, with most events falling between 10 and 15 m s^{-1}, indicating a likely consistent formation mechanism. Core heights were predominantly around 500 m AGL, as shown by a sharp peak in the probability density, aligning with the expected confinement near the nocturnal boundary layer. Heights above 1000 m AGL were rare and likely due to noise in the dataset. Event durations displayed a multi-modal distribution with peaks at approximately 8 and 12 hours, suggesting additional regional factors like baroclinicity influencing the timing of the jet's maximum wind speed. We created a composite of the 90 NLLJ events to show a general representation of the structure and evolution based on observations at Beltsville, MD. *Horizontal wind speeds peaked (~15 m s^{-1}) at ~500 m AGL and persisted from sunset to ~11 hours after. The vertical extent remained steady (~1500 m AGL) until the NLLJ core arrives around 4 hours after sunset, after which it began to decay.* The composite wind direction, shows a clear transition between the dominance of the meridional (South to North; Southerly) and zonal (West to East; Westerly) winds and is indicative of the dynamic atmospheric processes that govern the behavior of the Mid-Atlantic NLLJ. The progression to more westerly winds across the night reflects the diurnal wind shift and underscores the influence of large-scale atmospheric circulation patterns on the NLLJ. *This shift in wind direction is often related to the Coriolis force acting on the regional air mass over the night. As the land cools after sunset, the pressure gradients adjust, and the NLLJ develops, initially following the temperature gradient.* As the night progresses, the Coriolis force begins to turn the flow toward the right in the northern hemisphere, resulting in the NLLJ acquiring a more westerly component.

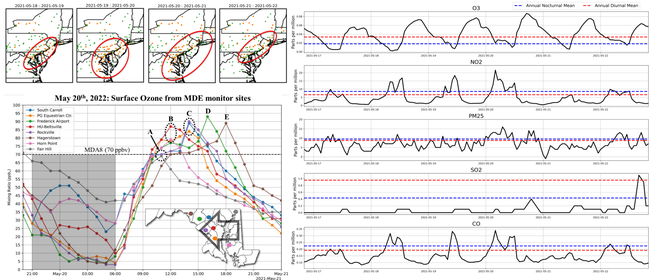
Integrated Monitoring System Datasets

This is a continuation of Roots et al., 2023 which leveraged multiple datasets together as an integrated observation system including vertically profiles of ozone, aerosols, and winds along with measurements of surface chemistry in addition to simulations of air mass transport. In addition to ground-based and satellite simulations of airmass trajectory by NOAA's Hybrid Single-Particle Integrated Lagrangian Transport (HYSPLIT) were used. The Near-Colocation Super Site refers to the **HU-Beltsville – NASA GSFC (< 10 km) which houses the TROPOZ trailer, Beltsville RWP, and MDE surface monitors**.

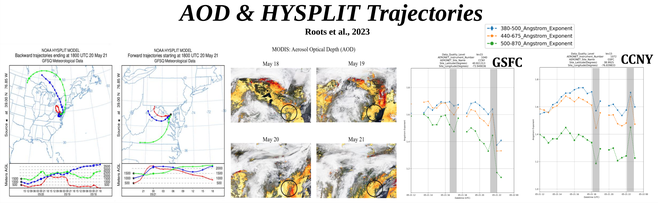




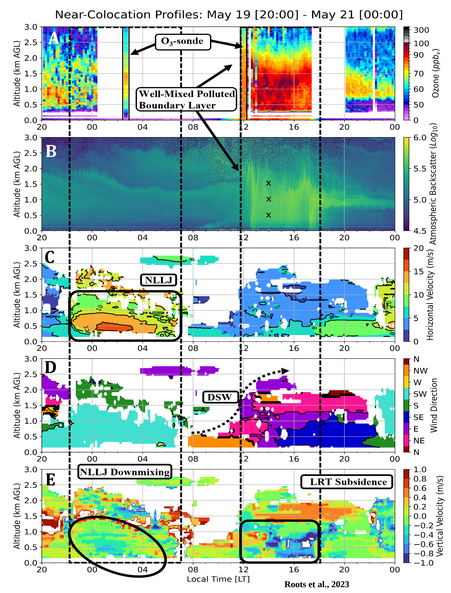
In-situ Surface Observation



AOD & HYSPLIT Trajectories



Vertical Profiles of Ozone, Aerosols, and Wind



- The vertical profiles of **ozone (A) and aerosols (B) depict a well-mixed polluted boundary layer observed from 12 LT - May 20th, 2021,** evidenced by increases in ozone concentration shown by the TROPOZ ozone lidar.
- The **vertical velocity (E)** from the Beltsville, MD RWP shows **strong downward velocities (~0.5 m/s)** observed during the onset of the jet **introducing smoke and ozone-precursors** from a polluted reservoir
- *Well-mixed polluted airmass transported nearly **90 ppbv of ozone** from the East to the West. The smoke airmass was brought with it ozone polluted air which mixed near Horn Point and advected across Maryland to be downmixed at from 14 LT to 18 LT at Piney Run and HU-Beltsville with downward velocities near 1 m/s*
- It is important to note that the transport of pollutants from East to West paired with the entrainment those left in the residual layer during 12 LT – 18 LT is met by the downmixing resulting from shear layers capping the mixing layer around 1.5 km on May 20th.

Conclusions

This study underscores the interplay between chemistry and atmospheric dynamics in shaping air quality, particularly regarding boundary layer ozone. Atmospheric dynamics significantly influence ozone levels through horizontal and vertical mixing of surface-emitted precursors or by transporting ozone and its precursors from aloft. In the Mid-Atlantic U.S., summer months see the highest frequency of air quality (AQ) events, driven by increased emissions from combustion, dynamic atmospheric phenomena, and long-range biomass burning transport.

- Examined a confluence of these factors, culminating in a high surface ozone event with multiple exceedances of the NAAQS MDA8 standard.
- *Applied supervised machine learning to isolate NLLJ presence in Radar Wind Profiler (RWP) data.*
- Analyzed **90 NLLJ events revealing characteristic patterns**: core height near 500 m AGL; wind speeds predominantly between 10–15 m s^{-1}; and bi-modal core timing
- A *composite morphology illustrated the typical NLLJ structure,* highlighting nocturnal **wind speed intensification and oscillatory wind direction patterns.**
- These *findings align with known reports from Zhang et al. (2005) and Ryan (2004)* but suggest regional baroclinicity influences beyond classical predictions (i.e., Blackadar Theory).

While the ML model effectively captured southwesterly NLLJs, it showed limitations in fully resolving structural details, highlighting the need for enhanced training datasets. **Future studies should integrate additional instruments—such as lidars, sondes, and surface monitors—to create a synergized dataset that would improve temporal and spatial coverage.** Continued research into these low-level wind phenomena is essential for improving weather predictions and air quality management, particularly in understanding pollutant transport and dispersion in the Mid-Atlantic region. This study lays the groundwork for future investigations into the complex dynamics of low-level mesoscale phenomena and their broader climatic and environmental implications. **Accurately identifying and characterizing NLLJs is crucial for refining regional climate models and enhancing predictive capabilities for future climate scenarios.** This work contributes significantly to boundary layer studies, providing valuable insights into NLLJ phenomena and advancing our understanding of atmospheric dynamics.

Acknowledgments

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