An Automatic Detector for Observing Bay Breezes in the Atmosphere Baltimore, Maryland via Doppler LiDAR Remote Sensing

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Introduction

- Bay breezes, also referred to as “sea breezes”, were studied in Baltimore, Maryland, a phenomenon that occurs when there is a difference in the pressure of the atmosphere above an ocean and land caused by a temperature difference. This thermal contrast generates a pressure gradient force (PGF) from the water to the land near the surface (Stull 1988).
- They have many different effects, impacting temperature, humidity, air quality, and the circulation of pollutants.
- The goal of this research is to detect bay breezes in LiDAR wind data and investigate the effect of a bay breeze passage.

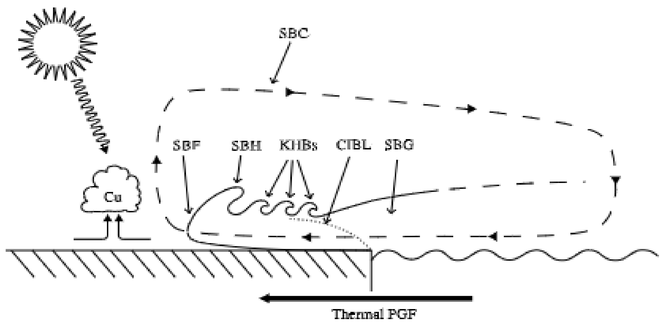


Fig. 1: Taken from Miller et al. 2003. Conceptual illustration of a sea breeze system (SBS). (Acronyms from left to right, Cu= Cumuliform Clouds, SBF: Sea Breeze Front, SBC: Sea Breeze Circulation, KHB: Kelvin Helmholtz Billows, CIBL: Connective Internal Boundary Layer, SBG: Sea Breeze Gravity Current.

Data and Instrumentation

- We utilized data from a Doppler LiDAR deployed in Baltimore, Maryland (Prince et al., 2024). LiDARs emit light which is scattered back by aerosols and use the Doppler effect to determine the wind speed and direction.
- The station recorded this atmospheric data continuously every 15 min from November 2023 to May 2024.

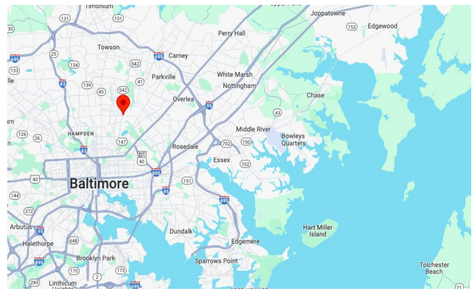


Fig. 2(a): Map of Baltimore and the Doppler LiDAR Station located at 39.3468861° N and -76.5850306° E. Photo taken from Google Maps.



Fig. 2(b): Photo of Doppler Lidar Station

Bay Breeze Detection Criteria

Using Doppler LiDAR, aerosol backscatter, wind direction, and wind speed are recorded. This data was then used to classify bay breeze days and non-bay breeze days.

Definitions:

- Offshore Wind Directions: 240° to 30°
- Onshore Wind Directions: 30° to 150°
- Hourly Wind Shift: $\Delta\theta = \theta_{i+1} - \theta_i$

Criteria:

1) The day must exhibit both an onshore and offshore wind direction.
2) There must be a wind shift ($\Delta\theta$) of at least 45° within a 1-hour period and θ_{i+1} come from the onshore direction.
3) The wind shift must occur in the late afternoon (14:00-18:00 EST).

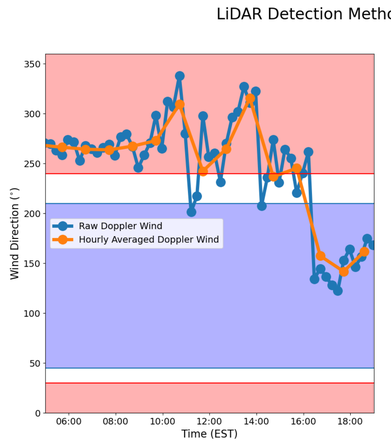


Fig. 3(a): Temporal series of wind direction time series on 03 Jan 2024. The red-shaded areas represent the range of offshore wind directions, whereas the blue-shaded areas represent the onshore wind directions.

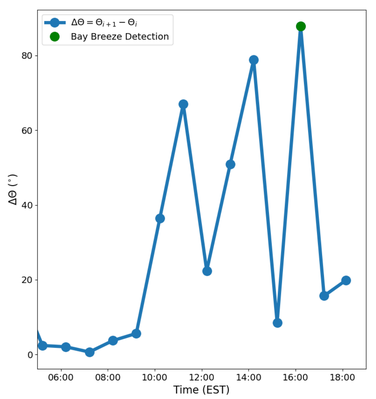


Fig. 3(b): Change in wind direction over time, (i.e. $\Delta\theta$,). The green marker indicates the time at which the bay breeze criteria was met on this day. Note that the change in wind direction must be greater than 45° to be considered a bay breeze.

Averaged Results of Bay Breeze Days

The results show the bay breeze detector had identified 11 different days that were classified as bay breezes between November 2023 and May 2024 in the Baltimore area.

- There were 161 total days that were studied, out of which 11 had a bay breeze according to this criteria. This accounts for 6.83% of the days.
- The average time of day that a bay breeze had occurred was 15:26 EST.
- The average $\Delta\theta$ was 94.4°.

	Average Wind Direction	Average Wind Speed	Average Attenuated Backscatter	Average Vertical Velocity	Vertical Velocity Variance
Before Bay Breeze	297.76°	2.28 m/s	~1.021E-5$m^{-1}sr^{-1}$	~ -0.02 m/s	0.013 m^2/s^2
After Bay Breeze	128.09°	2.34 m/s	~1.602E-5$m^{-1}sr^{-1}$	~ -0.32 m/s	0.002 m^2/s^2

Table 1: The averaged data from November 2023 to May 2024.

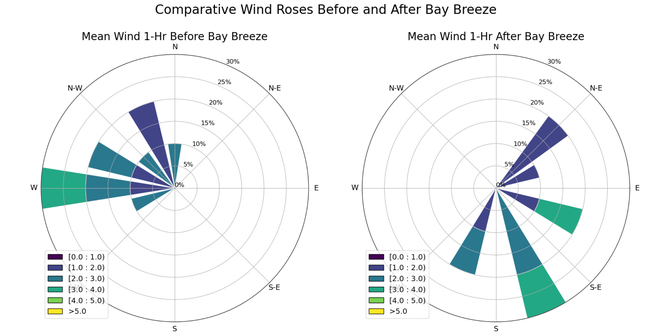


Fig. 4: Wind rose diagram of the average wind, both speed and direction, 1 hour before (left) and after (right) the time of bay breeze passage. The length of bar indicates the frequency of wind from that direction while color denotes frequency of the corresponding wind speed.

Concluding Remarks and Future Work

- It is important to understand when bay breezes occur since they have an impact on air quality, temperature, and precipitation. People living in these areas are impacted by these changes.
- Overall, the proposed bay breeze criteria methodology using Doppler Lidar was 93.79% accurate; however, 9 bay breeze days were identified as non-bay breeze days, indicating the need for more robust criteria specifications.
- Notably, the passage of a bay breeze in Baltimore leads to an increase in attenuated aerosol backscatter after the passage, indicating either greater aerosol concentrations or larger aerosols.
- Based on these results, additional research is needed to develop an automatic Doppler LiDAR bay breeze detector. The analysis can also be extended to investigate the impact of a bay breeze passage on nearby Maryland-operated ozone monitors and cloud formation.

References and Acknowledgements

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