Sea, bay, or lake breeze circulations can contribute to poor air quality near coastal urban areas. At many worldwide coastal locations, sea breeze circulations are often present when surface ozone (O₃) levels are elevated. In Houston, TX, for example, high surface O₃ episodes typically begin when the synoptic-scale winds transport pollutants offshore prior to the onset of a bay breeze. As the bay breeze begins to develop, stagnant conditions ensue over the water as the winds begin to reverse direction. As the bay breeze intensifies, O₃ and O₃ precursors that built up...
over the water are transported onshore (see Figure 1). In Maryland, the Chesapeake Bay breeze is the culprit for intensifying air pollution episodes.

The Chesapeake Bay breeze is responsible for elevated surface \( O_3 \) concentrations along the coastline of the bay. A Chesapeake Bay breeze case scenario for a poor air quality day found that: (1) prior to the development of the bay breeze, westerly winds allowed for pollutants from the Washington, DC, and Baltimore, MD, urban areas to be transported out over the surface waters of the Chesapeake Bay; (2) as the bay breeze began to form, stagnation developed over the bay, allowing pollutants to accumulate as the winds began to change to a southerly direction; and (3) once the bay breeze formed, southerly winds over the bay transported the high concentrations of surface pollutants that accumulated over the bay northward across the coastline.5

The bay breeze particularly enhances air pollution events at Edgewood, MD, which is on the northern coastline of the Chesapeake Bay, making it the most \( O_3 \)-polluted site in Maryland and one of the monitoring stations with highest \( O_3 \) on the East Coast. In addition, it was found that once the Chesapeake Bay breeze circulation forms, surface pollutants are transported to the bay breeze convergence zone where they are lofted and then transported downwind, impacting surface air quality far from the emissions sources.5

Studies of the bay or sea breeze in other locations of the Mid-Atlantic States have found a growing influence of these circulations on local air quality.6,7 Stauffer and Thompson,7 examining 25 years of data, noted that a bay breeze is observed between 10–15% of days from May to September at Hampton, VA, and Baltimore, MD, making this a relatively frequent phenomenon that exacerbates air quality problems in the Mid-Atlantic. The difference between midday \( O_3 \) concentrations during bay breeze and non-bay breeze days was also found to be increasing from the mid-1980s to present. This suggests that as regional \( O_3 \) precursor emissions are continually reduced through environmental regulations, the bay or sea breeze will be a mechanism through which localized pollution events are magnified compared to the regional background air quality.

Observations and Modeling Results from DISCOVER-AQ

Modeling and observations from the 2011 DISCOVER-AQ field campaign (ground- and aircraft-based measurements) and the concurrent GeoCAPE-CBODAQ8 field campaign (ship-based measurements) were utilized to build on our understanding of how bay breezes impact surface air quality and boundary layer venting. A comparison of ship observations and upwind monitoring sites noted that surface \( O_3 \) concentrations are usually higher over the water than upwind areas due to: (1) lower deposition rates over water; (2) ship emissions that mix with pollutants transported from over land becoming trapped in the shallow marine boundary layer; (3) higher photolysis rates due to the stable marine boundary layer inhibiting cloud development; and (4) a decrease in boundary layer venting due to the stable atmosphere over the water.9

Figure 1. A conceptual model of conditions prior to and during a bay or sea breeze circulation. Ozone precursor emissions drift over the body of water, via large-scale synoptic winds, where \( O_3 \) is then produced by sunlight and photochemical reactions. Solar heating raises the temperature of the land above that of the water, and the bay or sea breeze is initiated, advecting high \( O_3 \) to coastal locations.
When a bay breeze begins to form, stagnation develops as the winds begin to change direction causing pollutants to accumulate, further amplifying \( O_3 \) and \( O_3 \) precursor concentrations over the bay. The accumulation is greatest when the synoptic-scale winds are westerly, transporting emissions from the Washington, DC, and Baltimore, MD, metropolitan areas over the bay. A large pool of \( O_3 \) and \( O_3 \) precursors over the water and an environment favorable for net \( O_3 \) production allows for high surface \( O_3 \) concentrations to develop as southerly winds associated with the bay breeze transport this plume onshore (see Figures 2 and 3).

It was also found that \( O_3 \) concentrations observed at Edgewood, MD, peak in the evening hours on bay breeze days (Figure 3), about 3 hours later than non-bay breeze days. Slower \( O_3 \) loss rates over water due to less deposition result in a later peak in \( O_3 \) concentrations over water than upwind areas. This later peak is evident at Edgewood on bay breeze days when it is under the influence of transport from the bay. In the case documented in Figure 3, the bay breeze frontal passage occurred at approximately 11:30 EST (vertical dashed line) as the wind direction veered to a southerly direction. Relatively cool, moist air from over the bay entered Edgewood with the dew point increasing by \( \sim 4 ^\circ C \) and the temperature plateauing at \( 34 ^\circ C \) after the bay breeze front passed. A pool of high \( O_3 \) concentrations that formed over the surface waters continued to move northward over Edgewood into the early evening (18:30 EST), leading to a maximum 8-hr average \( O_3 \) of 94 parts per billion by volume (ppbv), exceeding the air quality standard of 75 ppbv.

DISCOVER-AQ also provided insight into the role of bay breeze circulations on exporting pollution plumes out of the planetary boundary layer and into the free troposphere (see Figure 4). When a bay breeze is present, air pollution converges at the bay breeze front (located near Padonia, MD, in the case shown in Figure 4), where it is lofted upward (depicted by the vertical arrows) and transported downwind aloft. The elevated pollution plume aloft was horizontally transported (depicted by horizontal arrow) by west-southwest winds over Edgewood, Aldino, and Fair Hill (areas with lower planetary boundary layer heights), resulting in the plume entering the free troposphere. Pollutants that are transported from the planetary boundary layer to the free troposphere gain longer lifetimes and are susceptible to long-range transport. These pollutants can then subside back into the planetary boundary layer impacting surface air quality far away from their emissions sources.
Much like other locations susceptible to sea, bay, or lake breeze circulations, the Chesapeake Bay breeze plays an important role in local air pollution events in Maryland. The transport of emissions from the Baltimore–Washington metropolitan area, favorable O3 production conditions over the bay waters, and subsequent transport of high O3 via the bay breeze lead coastal locations, such as Edgewood, MD, to observe some of the worst air pollution in the region. The Chesapeake Bay breeze also lofts pollutants from the surface into the free troposphere at the convergence zone, allowing pollution to be transported farther downwind from source locations.

The bay breeze was shown to increase surface O3 pollution in Maryland well above the regional background levels. Figure 3. Impact of bay breeze as observed at Edgewood, MD, on July 23, 2011, on wind direction with height (a, colors); surface O3 (a, black line); wind speed with height (b, colors); surface temperature (b, black dots); and dew point temperature (b, gray dots). Figure from Stauffer et al. (2012)11 published and used under permission of Creative Commons license 2.0 CC-BY.

Summary

Much like other locations susceptible to sea, bay, or lake breeze circulations, the Chesapeake Bay breeze plays an important role in local air pollution events in Maryland. The transport of emissions from the Baltimore–Washington metropolitan area, favorable O3 production conditions over the bay waters, and subsequent transport of high O3 via the bay breeze lead coastal locations, such as Edgewood, MD, to observe some of the worst air pollution in the region. The Chesapeake Bay breeze also lofts pollutants from the surface into the free troposphere at the convergence zone, allowing pollution to be transported farther downwind from source locations.
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1. For example, see: Evtyugina, M.G.; Nunes, T.; Pio, C.; Costa, C.S. Photochemical pollution under sea breeze conditions, during summer, at the Portuguese West Coast; Atmos. Environ. 2006, 40, 6277-6293, doi:10.1016/j.atmosenv.2006.03.046


