Appendix G-11: The Role of Land-Sea Interactions on Ozone Concentrations at the Edgewood, Maryland Monitoring Site

This study is applicable as well to the near-shore Collier's Mill, NJ Site.

The Role of Land-Sea Interactions on Ozone Concentrations at the Edgewood, Maryland Monitoring Site

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Charles Piety

Department of Atmospheric and Oceanic Sciences
University of Maryland
College Park, MD

1. **Why is this analysis important?**
   This analysis is important because the Edgewood ozone monitor is currently the monitor with the highest 8-hour ozone design value in the Baltimore non-attainment area and therefore it is the determining monitor for the current non-attainment status of the region.

2. **What questions are answered by this analysis?**
   Do any situational circumstances such as microscale meteorology or topography play a role in making Edgewood, Maryland the air monitoring site with the highest 8-hour ozone design value in the Baltimore Non-Attainment Area? More specifically, could the presence of a sea breeze in the vicinity of the Edgewood adversely impact measured ozone values at this location relative to other monitoring location in the Baltimore Non-Attainment Area.

3. **What are the key take-away messages of this analysis?**
   From this analysis, sea breeze circulation is introduced. A literature review shows several instances when sea breeze circulation was coincident with enhanced ozone concentrations. The incidences of high ozone and sea breeze circulation were present several places across the United States and around the world. Because of the fine temporal and spatial scale of the sea breeze, it has yet to be clearly identified at the Edgewood ozone monitor. However, inspection of the location relative the Chesapeake Bay strongly suggests that the sea breeze is a factor in high ozone concentrations at the Edgewood ozone monitor. Given the geography of the Edgewood site, it likely encounters a sea breeze circulation, which may exacerbate peak 8-hour ozone concentrations.

4. **What conclusions are reached in this analysis with respect to Maryland's attainment demonstration?**
   The Edgewood ozone monitoring location may be situated so that it is less responsive to emission reduction strategies than other ozone monitoring locations in the Baltimore Non-Attainment Area, which do not encounter sea breeze circulations.

Abstract

Where land and sea meet, the atmosphere above is often characterized by temperature gradients that influence microscale circulations resulting in the formation of a sea breeze. Field studies and numerical modeling efforts around the country and internationally have shown that a sea breeze circulation can influence local ozone concentrations. A sea breeze may exacerbate air pollution levels by constricting local ventilation and instead recirculating air that would otherwise move off shore. On other occasions, a sea breeze may move relatively clean air onshore that will rapidly lower ozone concentrations. Understanding ozone formation and transport occurring at the Edgewood, Maryland ozone monitor is important because ozone levels at this location are likely enhanced by a "bay-breeze" because of the proximity of the site to the Chesapeake Bay. The Edgewood ozone monitor is currently the monitor with the highest average 8-hour ozone design value in the Baltimore non-attainment area, and therefore is the determining monitor for Baltimore's current non-attainment status. The ozone monitor is located on the west coast of the Chesapeake Bay approximately 1.5 miles northeast of the Bush River and approximately 1.5 miles southwest of the Gunpowder River. Because of the subtle spatial and temporal scale of the bay breeze, numerical models (i.e. MM5) are challenged to resolve this feature even at small-scale (4 km) resolutions. Based on recent studies of pollution transport associated with the sea breeze it is reasonable to assert that at times ozone levels at Edgewood may be influenced by bay breeze circulations.

Introduction

The large heat capacity of lakes, oceans, bays, or any large body of water results in a near zero change in water-surface temperature on a diurnal cycle (Stull, 1999). Land surface, by contrast, warms and cools more dramatically because of a smaller heat capacity and the relatively inefficient energy transfer process (within the land) of conduction. As a result, the land is warmer than water during the day and cooler at night. These temperature differences produce ideal conditions for sea breeze formation (see Figure 1). The precise timing of a particular sea breeze is a function of the local conditions (i.e. water temperature, land temperature, season of the year, and synoptic-scale weather patterns). In general, 15:00-16:00 EST is a standard time for sea breeze formation (Stull, 1999). The timing of a sea breeze is important for ozone at the Edgewood monitor because the hourly peak ozone values are often observed there shortly after a bay breeze is believed to have formed. The Edgewood ozone monitoring location currently has the highest average 8-hour ozone design value in the Baltimore non-attainment area, and therefore is the determining monitor for Baltimore's current non-attainment status. Given the importance of ozone levels at Edgewood, Maryland, a literature review of land-sea interactions and ozone along with an inspection of the geography surrounding the Edgewood, Maryland ozone monitoring location was performed in an effort to better understand the local and unique nature of this monitoring site.

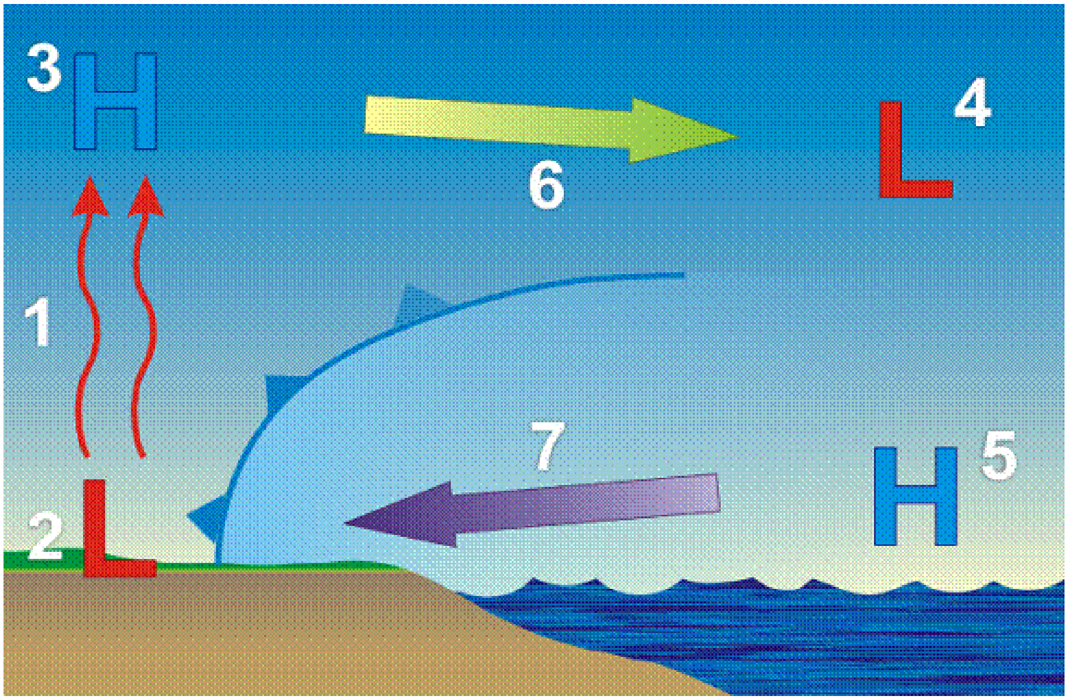

Figure 1. Sea breeze circulation at the surface. The sun heats both the ground and ocean at the same rate. However, since the heat in the ground is not absorbed well, it returns heat to warm the air. The warmed air, with its decreased density, begins to rise (1). The rising air creates a weak low-pressure area (called a thermal low) due to a decrease in air mass at the surface (2). Typically, from 3,000 to 5,000 feet (1,000 to 1,500 meters) above this low pressure, as the air cools, it begins to collect, resulting in an increase in pressure, creating a "high" (3). These differences in pressures over land, both at the surface and aloft are greater than the differences in pressures over water at the same elevations (4 and 5). Therefore, as the atmosphere seeks to reestablish the equal pressure both onshore and offshore, two high pressure to low pressure airflows develop: the offshore flow aloft (6) and surface flow onshore, called the sea breeze (7). Source: (http://www.srh.weather.gov/srh/jetstream/ocean/seabreezes.htm)

Methodology

Numerous studies in the United States and internationally have shown that a sea breeze circulation can influence local ozone concentrations (Seaman and Michelson, 1998; McElroy et al., 1986; Bornstein et al., 1993; Cheng, 2002; Boucouvala and Bornstein, 2003; Martilli et al, 2003, Evtyugina et al., 2006). Because of the fine temporal and spatial scale of these processes, most of these studies required comprehensive field campaigns and/or numerical modeling efforts. In a report detailing the mesoscale structure of a high ozone episode as part of the NARSTO-Northeast study, Seaman (1998) noted:

"…sea breeze, valley breeze, deep convection, and shallow cloud processes probably caused modification to regional scale circulation and affected low ozone concentrations, as well. This combination of mesoscale influences provides a coherent explanation for the very high ozone levels…"

In another comprehensive study of land-sea interactions over the California South Coast Air Basin, Boucouvala and Bornstein (2003) showed that under certain synoptic conditions, such as weak synoptic forcing, peak ozone concentrations are associated with a sea breeze. They determined that the combination of weak easterly offshore winds in the evening preceded a high ozone day and westerly sea breeze winds on subsequent days often resulted in a convergence zone of elevated ozone. The extent of inland penetration of the convergence zone on the high ozone day was in the same location as peak ozone concentrations, and occurred shortly after sea breeze formation. Cheng (2002) looked at ozone values in Taiwan associated with sea breezes using a 3-year data set obtained from a network of air-pollution monitoring sites in conjunction with vertical data obtained from twice daily tethersonde launches. The tethersondes measured wind-speed, direction, temperature and humidity as well as a number of trace gases (e.g. ozone, carbon monoxide, sulfur dioxide). Cheng concluded that depending on the season, the sea breeze was either associated with low or high ozone. The difference in ozone concentrations was explained by different synoptic-scale winds occurring during different seasons. Evytugina et al., (2006) reported results from two detailed studies (June-July 2001 and July 2002) of the photochemical production of pollution under sea breeze conditions at the Portuguese west coast. In that study, vertical profiles of ozone and volatile organic compounds (VOCs) were collected throughout periods of sea breeze circulations and compared with vertical measurements of meteorological variables. The study concluded that marine breezes play an important role in the formation and transport of photochemical pollution. Specifically, the concentration of ozone in the diurnal boundary layer gradually increased with the strengthening presence of the sea breeze (i.e. ozone levels increased when air associated with the sea breeze was encountered).

Results and Discussion

Based upon the studies mentioned previously, it should be noted that the Edgewood, Maryland ozone monitoring location is ideal for land-sea interactions. The site is indicated with a green arrow in Figures 2-4 at 39.410 N, 76.297 W. Figure 2 shows Edgewood in relation to Baltimore, Maryland (~23 miles to the northeast) and Washington, D.C. (~68 miles to the southeast). Figure 2 also reveals that Edgewood resides on the western coast of the northern portion of the Chesapeake Bay. A closer perspective of Edgewood in Figure 3 shows the close proximity (~5 miles) of Edgewood to Interstate 95 and Maryland State Highway 40. A finer inspection still of Edgewood in Figure 4 shows it is a relatively narrow stretch of land surrounded by water to the south and the north, by the Gunpowder and Bush rivers, respectively. Thus, Edgewood is perhaps a unique location in the Baltimore Non-Attainment Area in that it is downwind of two urban areas, and thus influenced by regional transport, and downwind of two major highways so that local pollution is also important. To make matters completely challenging for air quality, the sea breeze may be consistently preventing typical ventilation from the locale.

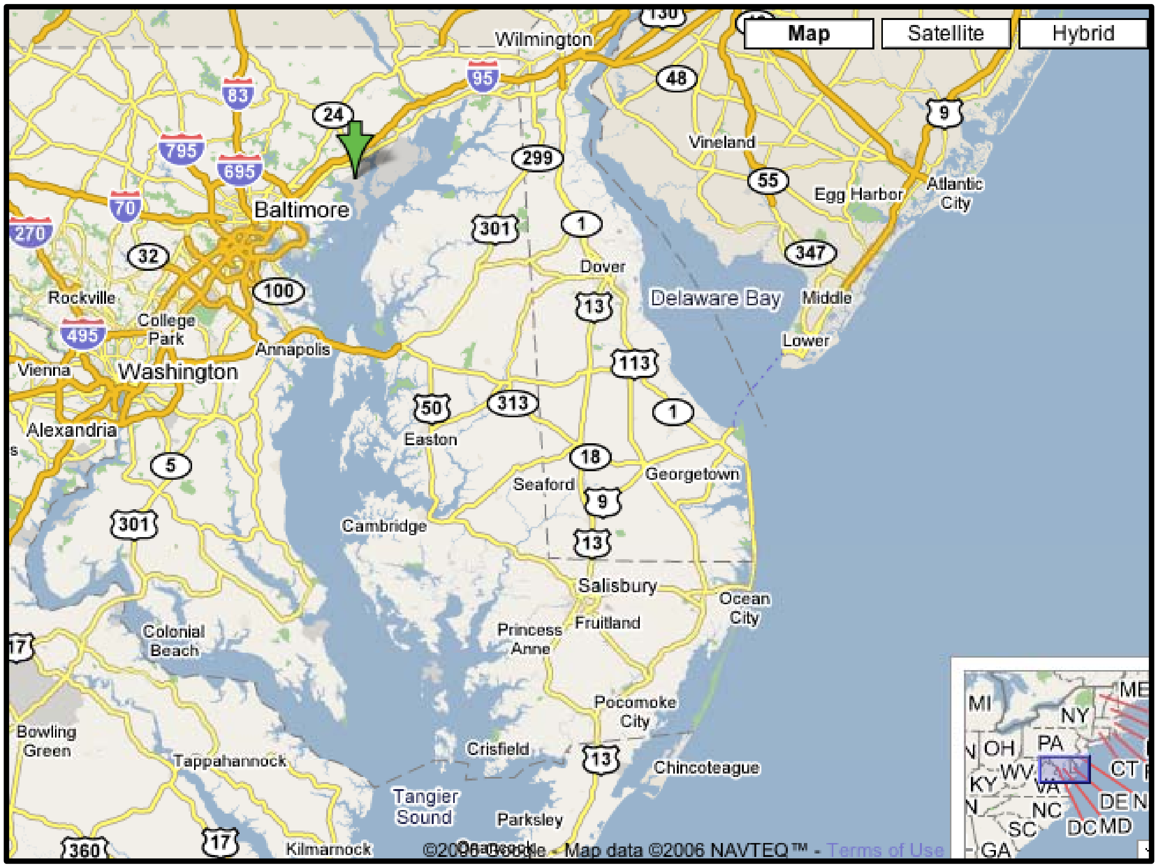

Figure 2. Edgewood Maryland (the green arrow) is often downwind from two urban areas (~23 miles northeast of Baltimore Maryland and ~68 miles northeast of Washington, D.C.) and on the west coast of the Chesapeake Bay.

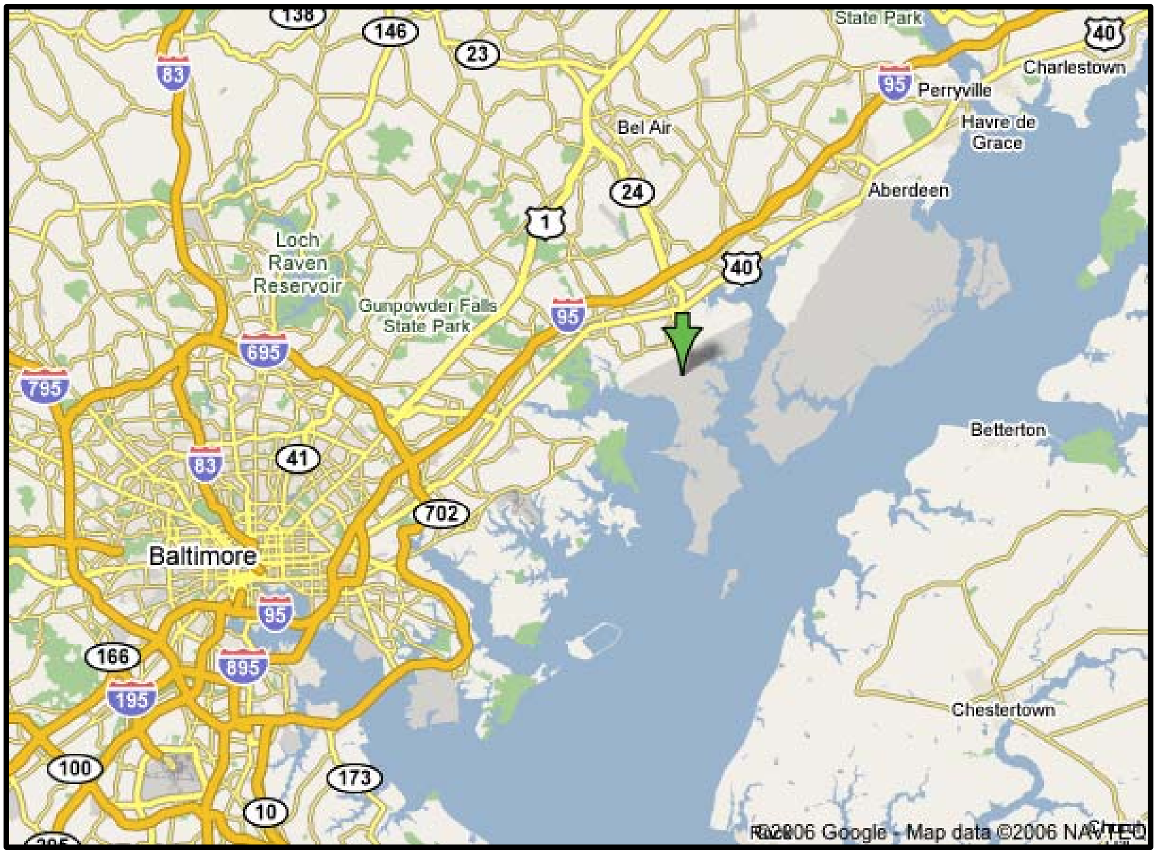

Figure 3. A closer inspection of Edgewood Maryland (the green arrow) shows it is often downwind from two major highways (Interstate I-95 and Maryland State Route 40).

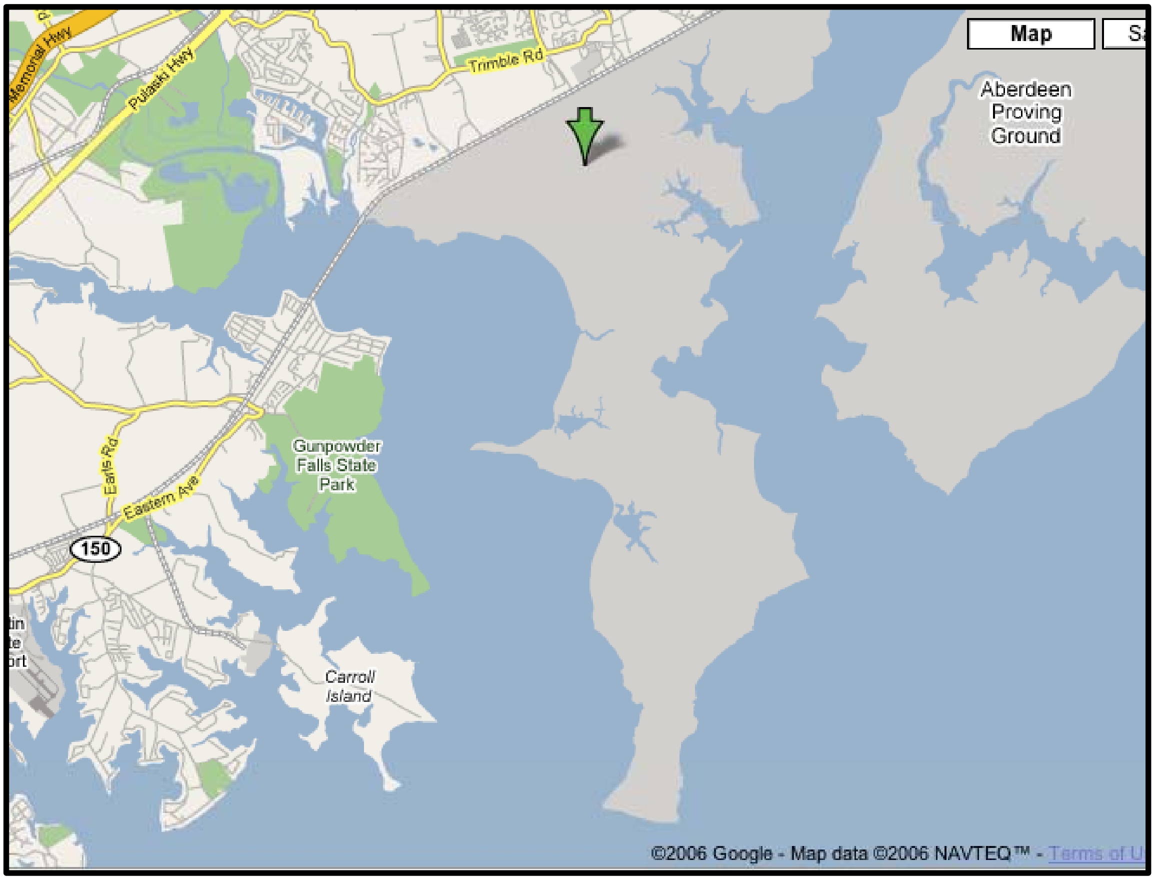

Figure 4. Not only is Edgewood downwind from two major highways (Interstate 95 and Maryland State Route 40), but the proximity of the Edgewood ozone monitor (see green arrow) to a large body of water creates ideal conditions for a land-sea breeze. As a whole, these factors make a situationally-challenging location that lends itself to accumulation of air pollutants that are ordinarily ventilated at locations that are not under the influence of microscale meteorological features.

Conclusions

The Edgewood air monitoring site's proximity to the Chesapeake Bay and two local rivers, suggests sea breeze recirculations may play an important role in contributing to ozone levels at the site. Specifically a local-scale, sea breeze circulation can exacerbate peak ozone concentrations not only during regional-scale high ozone episodes, but also during periods when local scale circulation is more significant than regional transport. Understanding the special topography of Edgewood may help explain the recalcitrant nature of peak ozone levels at Edgewood. In other words, Edgewood may be a hot spot for the buildup of ozone concentrations. The Bay Breeze experienced at Edgewood on a micro-to-meso scale is reminiscent of the larger scale meteorological challenges that face Maryland as a state (i.e. westerly transport and transport by the nocturnal low-level jet). The sea breeze is yet another example of how Maryland is a meteorologically challenged state, and Edgewood is a meteorologically challenged monitoring location, which helps to explain the high 8-hour ozone design values.

Future Work

The sea breeze is a challenging atmospheric phenomenon to characterize because of its relatively small temporal and spatial scale. Most of the comprehensive studies of sea breezes are either intensive field campaigns during high pollution events or longer term climatologically motivated studies. Future work to study the sea breeze at Edgewood would benefit from a permanent LIDAR instrument and radar wind profiler. These instruments would allow for better time-resolved studies of the boundary layer over Edgewood. Other useful work could include inspection of finer-scale ozone data (i.e. 5 minute average values) from the Edgewood monitor as well as analysis of other trace gases such as sulfur dioxide and carbon monoxide. The boundary layer meteorological data obtained from those techniques, in conjunction with periodic aircraft, tethersonde and other surface trace gas measurements would significantly improve the understanding of the importance of sea breeze interaction on local ozone levels observed at Edgewood.

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