2.0 Nature of the Ozone Air Quality Problem in the Northeast and Connecticut

Despite much progress over the last three decades, ground-level ozone remains a pervasive regional problem in the northeastern United States, with frequent exceedances of the 8-hour ozone NAAQS occurring during hot summer days. In this section, a conceptual overview of the ozone problem is provided from both a regional and local perspective. The regional perspective is extracted directly from a report[1] developed by NESCAUM for the OTC states. The full NESCAUM report is provided as Appendix 2A.

2.1 Regional Conceptual Description of the Ozone Problem

The Ozone Transport Region (OTR) of the eastern United States covers a large area that is home to over 62 million people living in Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and northern Virginia. Each summer, the people who live within the OTR are subject to episodes of poor air quality resulting from ground-level ozone pollution that affects much of the region (see Figure 2.1.1). During severe ozone events, the scale of the problem can extend beyond the OTR's borders and include over 200,000 square miles across the eastern United States. Contributing to the problem are local sources of air pollution as well as air pollution transported hundreds of miles from distant sources outside the OTR.

To address the ozone problem, the Clean Air Act Amendments require states to develop State Implementation Plans (SIPs) detailing their approaches for reducing ozone pollution. As part of this process, states are urged by the U.S. Environmental Protection Agency (USEPA) to include in their SIPs a conceptual description of the pollution problem in their nonattainment areas. This document provides the conceptual description of the ozone problem in the OTR states, consistent with the USEPA's guidance.

Since the late 1970s, a wealth of information has been collected concerning the regional nature of the OTR's ground-level ozone air quality problem. Scientific studies have uncovered a rich complexity in the interaction of meteorology and topography with ozone formation and transport. The evolution of severe ozone episodes in the eastern U.S. often begins with the passage of a large high pressure area from the Midwest to the middle or southern Atlantic states, where it assimilates into and becomes an extension of the Atlantic (Bermuda) high pressure system (see Figure 2.1.2). During its passage east, the air mass accumulates air pollutants emitted by large coal-fired power plants and other sources located outside the OTR. Later, sources within the OTR make their own contributions to the air pollution burden. These expansive weather systems favor the formation of ozone by creating a vast area of clear skies and high temperatures. These two prerequisites for abundant ozone formation are further compounded by a circulation pattern favorable for pollution transport over large distances. In

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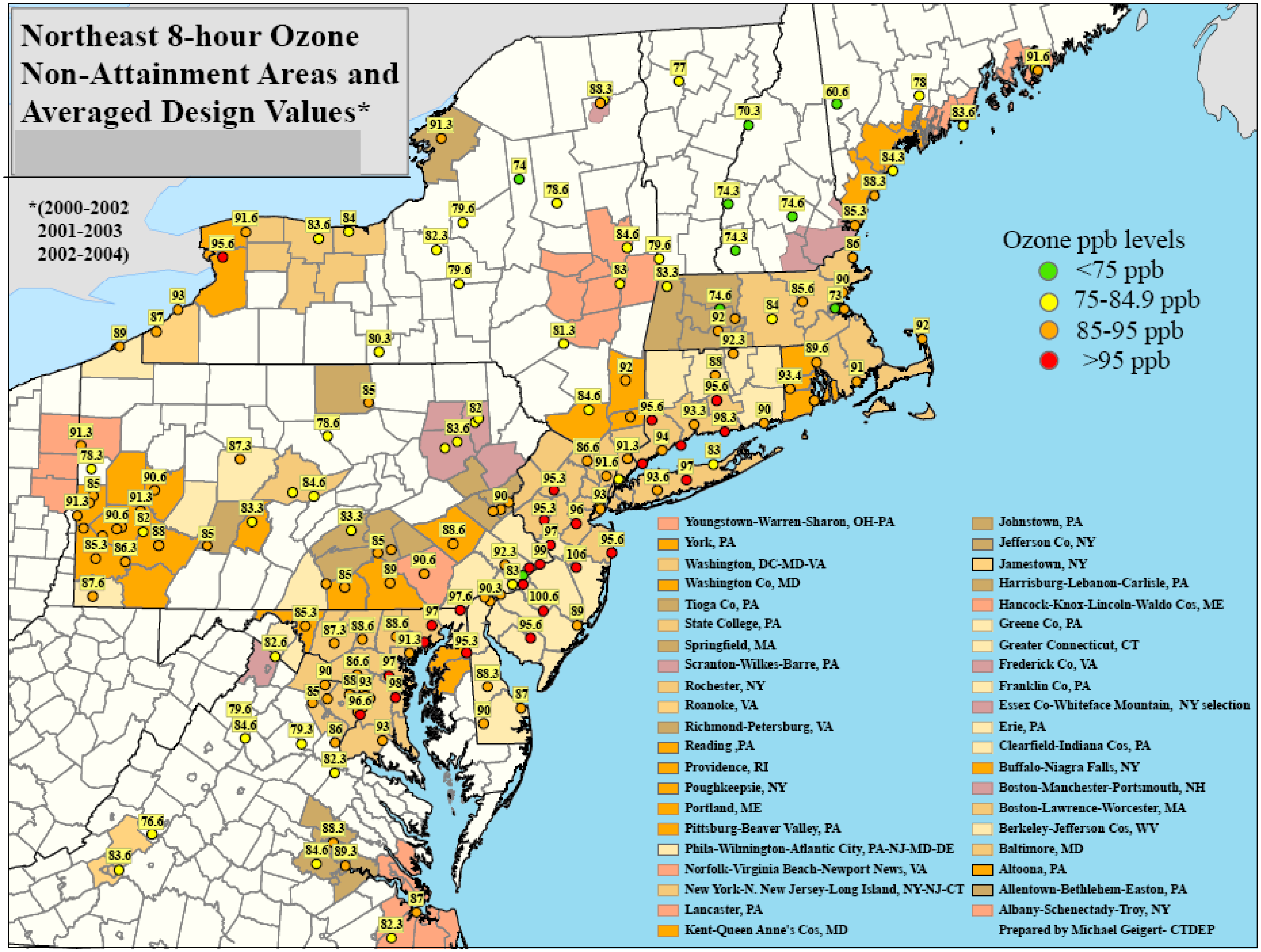
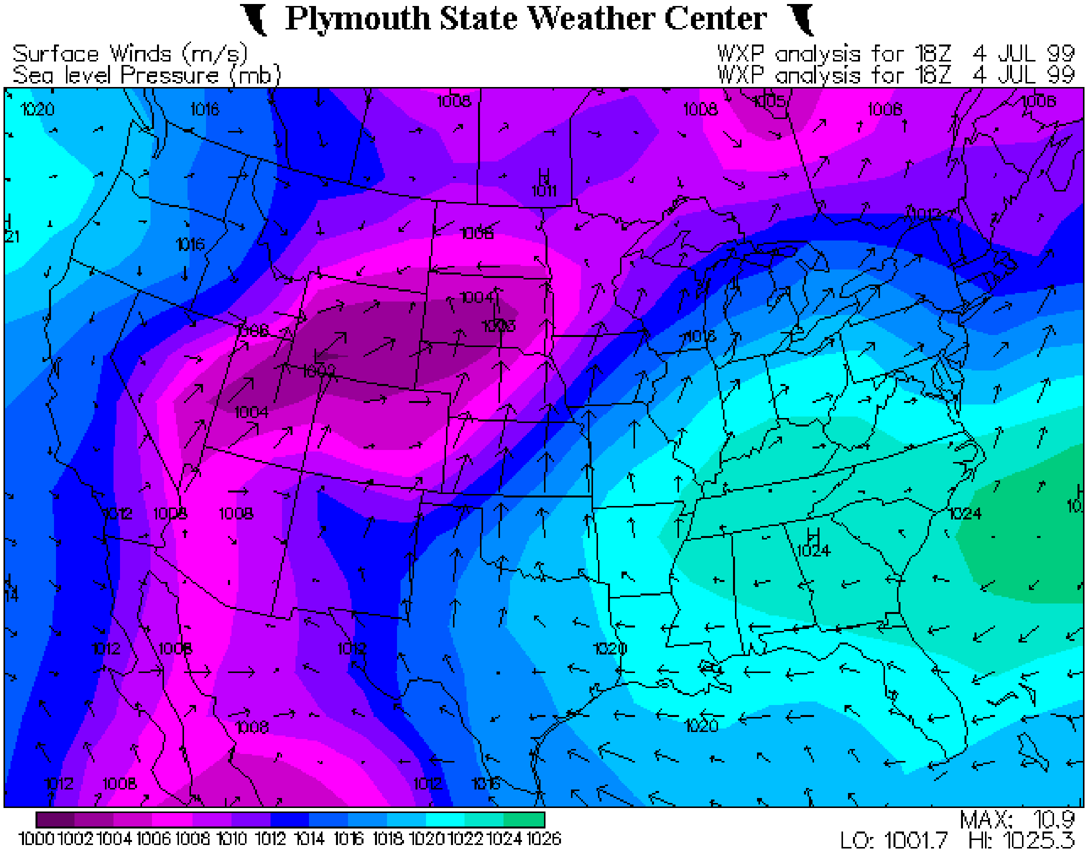
[1] The narrative in Section 2.1 was extracted, verbatim, from the Executive Summary of "The Nature of the Ozone Air Quality Problem in the Ozone Transport Region: A Conceptual Description," NESCAUM, October 2006. Supplemental figures (as noted in the text) are reproduced from the body of that report. Notes accompanying the figures have been augmented for clarity by paraphrased material from the text. The complete NESCAUM document is provided in Appendix 2A and is available at: http://bronze.nescaum.org/committees/attainment/conceptual/2006-1013b--O3%20conceptual%20model%20draft%20final%20--%20ALL.pdf.

Figure 2.1.1



Note: Values shown are the average of the three design values (3-year averages of the 4th maximum 8-hour ozone level) for the set of years 2000-2002, 2001-2003, and 2002-2004. The figure shows the regional nature of ozone levels in the OTR, with a number of closely adjacent nonattainment areas (average design values ≥ 85 ppb) along with a broader region of elevated regional ozone (e.g., average design values ≥ 75 ppb).

Figure 2.1.2 Typical weather pattern associated with severe ozone episodes in the OTR



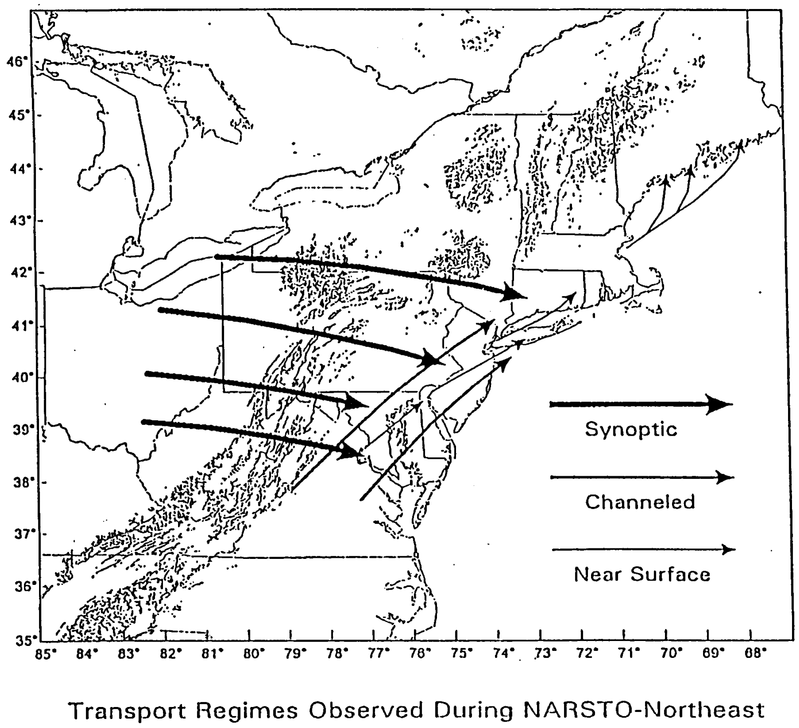
This figure shows the classic synoptic weather pattern at the Earth's surface associated with severe ozone episodes within the OTR. A quasi-stationary high pressure system (the Bermuda high) extends from the Atlantic Ocean westward into interior southeastern U.S., where a second weaker high is located. Surface winds, circulating clockwise around the high, are especially light in the vicinity of the secondary high. Farther north, a southwesterly flow strengthens toward New York and southern New England. This situation illustrates two circulation regimes often existing in OTR ozone episodes: more stagnant conditions in southern areas and a moderate transport flow in the OTR from southwest to northeast. In addition, high pressure systems exhibit subsidence, which results in temperature inversions aloft, and cloud free skies.

the worst cases, the high pressure systems stall over the eastern United States for days, creating ozone episodes of strong intensity and long duration.

One transport mechanism that has fairly recently come to light and can play a key role in moving pollution long distances is the nocturnal low level jet. The jet is a regional scale phenomenon of higher wind speeds that often forms during ozone events a few hundred meters above the ground just above the stable nocturnal boundary layer. It can convey air pollution several hundreds of miles overnight from the southwest to the northeast, directly in line with the major population centers of the Northeast Corridor stretching from Washington, DC to Boston, Massachusetts. The nocturnal low level jet can extend the entire length of the corridor from Virginia to Maine, and has been observed as far south as Georgia. It can thus be a transport mechanism for bringing ozone and other air pollutants into the OTR from outside the region, as well as move locally formed air pollution from one part of the OTR to another.

Other transport mechanisms occur over smaller scales. These include land, sea, mountain, and valley breezes that can selectively affect relatively local areas. They play a vital role in drawing ozone-laden air into some areas, such as coastal Maine, that are far removed from major source regions (see Figure 2.1.3).

Figure 2.1.3 Conceptual picture of different transport regimes contributing to ozone episodes in the OTR



Long-range (synoptic scale) transport occurs from west to east across the Appalachian Mountains. Regional scale transport in channeled flows also occurs from west to east through gaps in the Appalachian Mountains and in nocturnal low level jets from southwest to northeast over the Northeast Corridor. Daytime sea breezes can affect local coastal areas by bringing in air pollution originally transported near the surface across water parallel to the coast (e.g., along the Maine coastline)[2].

With the knowledge of the different transport scales into and within the OTR, a conceptual picture of bad ozone days emerges. After sunset, the ground cools faster than the air above it, creating a nocturnal temperature inversion. This stable boundary layer extends from the ground to only a few hundred meters in altitude. Above this layer, a nocturnal low level jet can form with higher velocity winds relative to the surrounding air. It forms from the fairly abrupt removal of frictional forces induced by the ground that would otherwise slow the wind. Absent this friction, winds at this height are free to accelerate, forming the nocturnal low level jet. Ozone above the stable nocturnal inversion layer is likewise cut off from the ground, and thus it is not subject to removal on surfaces or chemical destruction from low level emissions (see Figure 2.1.4). Ozone in high concentrations can be entrained in the nocturnal low level jet and transported several hundred kilometers downwind overnight. The next morning as the sun heats

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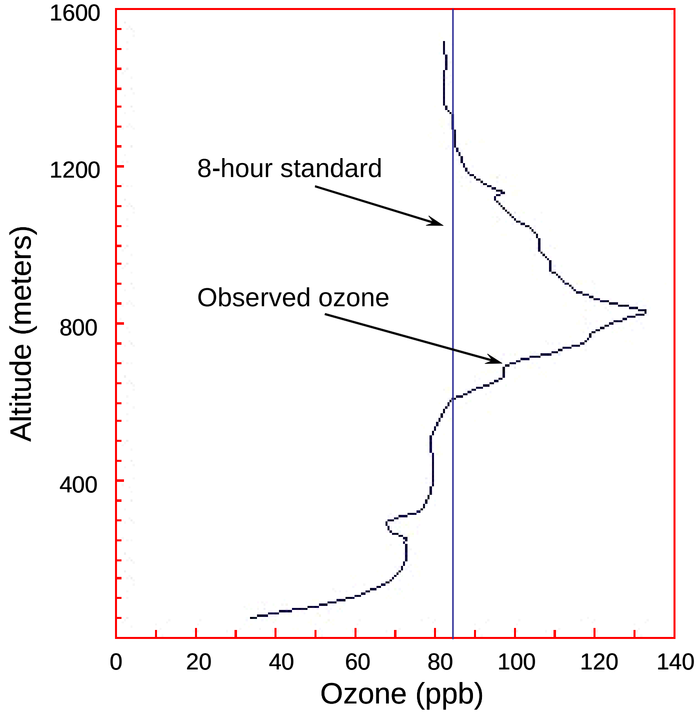
[2] NARSTO. *An Assessment of Tropospheric Ozone Pollution*. NARSTO, July 2000.

Figure 2.1.4 Observed vertical ozone profile measured above Poughkeepsie, NY at about 4 a.m. EST on July 14, 1995



Note: The figure includes a vertical line at 85 ppb for comparing aloft measurements with the 8-hour ozone NAAQS[3]. Elevated ozone levels aloft can be entrained in the nocturnal low level jet and transported several hundred kilometers downwind overnight. The next morning as the sun heats the Earth's surface, the nocturnal boundary layer begins to break up, and the ozone transported overnight mixes down to the surface where concentrations rise rapidly through the afternoon, partly from mixing and partly from ozone generated locally.

the Earth's surface, the nocturnal boundary layer begins to break up, and the ozone transported overnight mixes down to the surface where concentrations rise rapidly, partly from mixing and partly from ozone generated locally. By the afternoon, abundant sunshine combined with warm temperatures promotes additional photochemical production of ozone from local emissions. As a result, ozone concentrations reach their maximum levels through the combined effects of local and transported pollution.

Ozone moving over water is, like ozone aloft, isolated from destructive forces. When ozone gets transported into coastal regions by bay, lake, and sea breezes arising from afternoon temperature contrasts between the land and water, it can arrive highly concentrated.

During severe ozone episodes associated with high pressure systems, these multiple transport features are embedded within a large ozone reservoir arriving from source regions to the south and west of the OTR. Thus a severe ozone episode can contain elements of long range air pollution transport from outside the OTR, regional scale transport within the OTR from channeled flows in nocturnal low level jets, and local transport along coastal shores due to bay, lake, and sea breezes.

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[3] Observed ozone data from Zhang J. and S.T. Rao. "The role of vertical mixing in the temporal evolution of ground-level ozone concentrations." *J. Applied Meteor.* **38**, 1674-1691, 1999.

From this conceptual description of ozone formation and transport into and within the OTR, air quality planners need to develop an understanding of what it will take to clean the air in the OTR. Weather is always changing, so every ozone episode is unique in its specific details. The relative influences of the transport pathways and local emissions vary by hour and day during the course of an ozone episode and between episodes. The smaller scale weather patterns that affect pollution accumulation and its transport underscore the importance of local (in-state) controls for emissions of nitrogen oxides (NO_X) and volatile organic compounds (VOCs), the main precursors of ozone formation in the atmosphere. Larger synoptic scale weather patterns, and pollution patterns associated with them, support the need for NO_X controls across the broader eastern United States. Studies and characterizations of nocturnal low level jets also support the need for local and regional controls on NO_X and VOC sources as locally generated and transported pollution can both be entrained in nocturnal low level jets formed during nighttime hours. The presence of land, sea, mountain, and valley breezes indicate that there are unique aspects of pollution accumulation and transport that are area-specific and will warrant policy responses at the local and regional levels beyond a one-size-fits-all approach.

The mix of emission controls is also important. Regional ozone formation is primarily due to NO_X, but VOCs are also important because they influence how efficiently ozone is produced by NO_X, particularly within urban centers (see Figures 2.1.5 and 2.1.6). While reductions in anthropogenic VOCs will typically have less of an impact on the long-range transport of ozone, they can be effective in reducing ozone in urban areas where ozone production may be limited by the availability of VOCs. Therefore, a combination of localized VOC reductions in urban centers with additional NO_X reductions across a larger region will help to reduce ozone and precursors in nonattainment areas as well as downwind transport across the entire region.

Figure 2.1.5 2002 MANE-VU state VOC inventories in the OTR

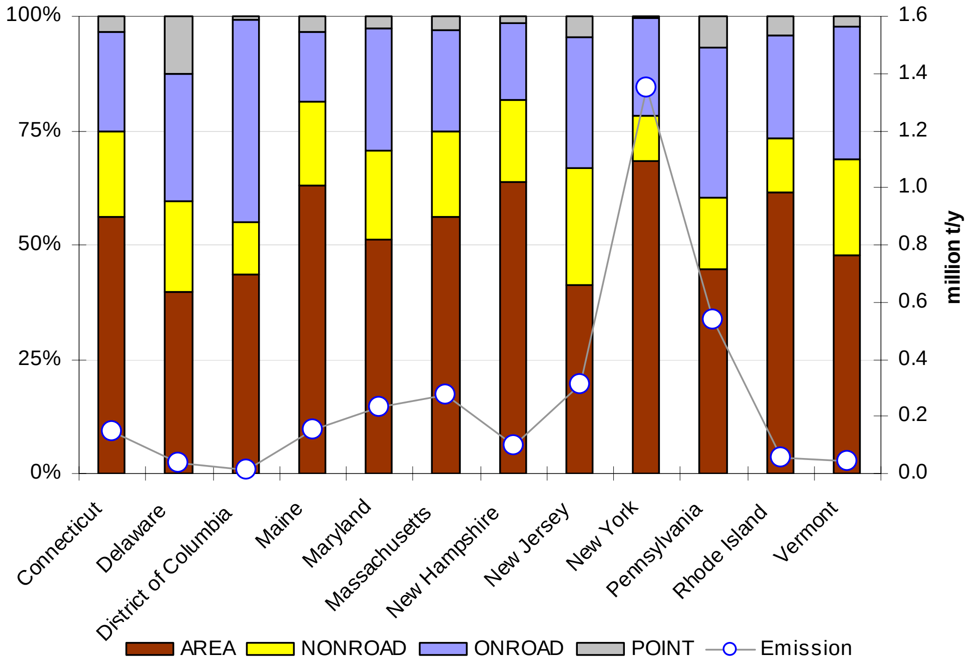

Figure key: Bars = Percentage fractions of four source categories; Circles = Annual emissions amount in 10^6 tons per year. The Virginia portion of the Washington, DC metropolitan area is not shown in the figure.

Figure 2.1.6 2002 MANE-VU state NO_X inventories in the OTR

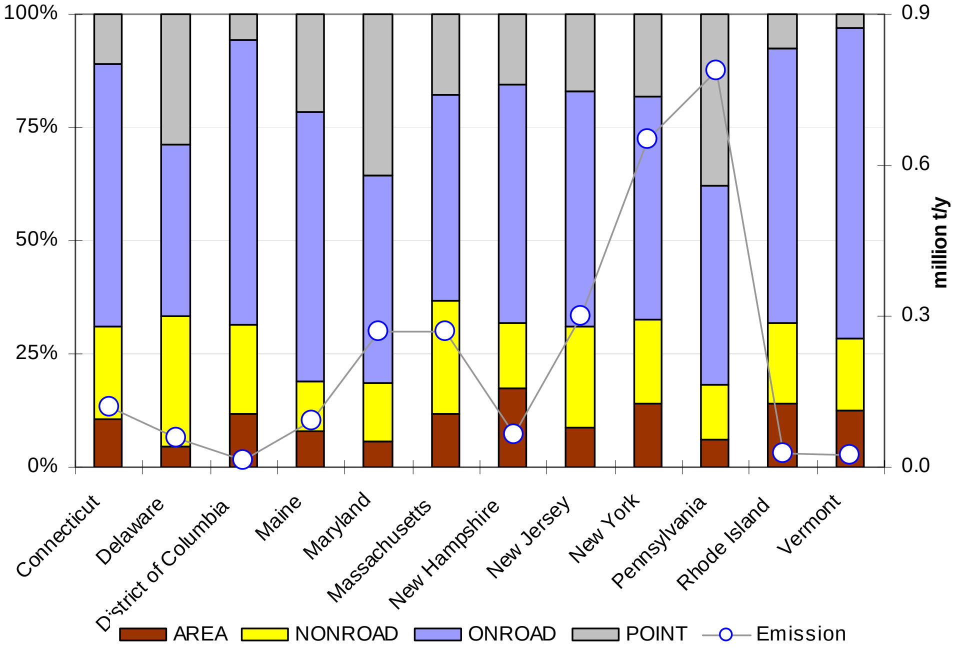

Figure key: Bars = Percentage fractions of four source categories; Circles = Annual emissions amount in 10^6 tons per year. The Virginia portion of the Washington, DC metropolitan area is not shown in the figure.

The recognition that ground-level ozone in the eastern United States is a regional problem requiring a regional solution marks one of the greatest advances in air quality management in the United States. During the 1990s, air quality planners began developing and implementing coordinated regional and local control strategies for NO_X and VOC emissions that went beyond the previous emphasis on urban-only measures. These measures have resulted in significant improvements in air quality across the OTR. Measured NO_X emissions and ambient concentrations have dropped between 1997 and 2005, and the frequency and magnitude of ozone exceedances have declined within the OTR. To maintain the current momentum for improving air quality so that the OTR states can meet their attainment deadlines, there continues to be a need for more regional NO_X reductions coupled with appropriate local NO_X and VOC controls.

2.2 A Connecticut Perspective on the Regional Ozone Problem

Although all of the states in the OTR are affected to some degree by ozone transport, Connecticut's location in relation to upwind emissions sources and ozone-favorable meteorological regimes makes the state particularly vulnerable to levels of transport that at times exceed the 8-hour ozone NAAQS. In addition to NESCAUM's regional conceptual description summarized above (and NESCAUM's full report in Appendix 2A), Appendix 2B provides a more focused examination of the role that transport plays in Connecticut's 8-hour ozone problem. Highlights of that analysis are presented below.

2.2.1 Meteorological Regimes Producing High Ozone in Connecticut

Ozone exceedances in Connecticut can generally be classified into four categories based on spatial patterns of measured ozone and the contributing meteorological conditions. Typically, most exceedances occur on sunny summer days with inland maximum surface temperatures approaching or above 90°F, surface winds from the south and west (favorable for transport of pollutants from the Northeast Megalopolis) and aloft winds from the west-southwest to west-northwest (favorable for transport of pollutants from Midwest power plants). Figures 2.1.2 and 2.1.3 above illustrate some of the meteorological conditions and wind patterns associated with the unique characteristics for each of the four common transport regimes discussed below.

- **Inland-only Exceedances:** Ozone is transported aloft from the west and mixed down to the surface as daytime heating occurs. At times, transport from the southwest can also occur overnight at lower levels aloft due the formation of a nocturnal jet. Strong southerly surface winds during the day bring in clean maritime air from the Atlantic Ocean, resulting in relatively low ozone levels along the coast. The maritime front may not penetrate very far inland, allowing transported and local pollutants to contribute to inland exceedances.
- **Coastal-only Exceedances:** Strong westerly surface winds transport dirty air down Long Island Sound from source regions to the west (e.g., New York and New Jersey). The relatively cool waters of Long Island Sound confine the pollutants in the shallow and stable marine boundary layer. Afternoon heating over coastal land creates a sea breeze with a southerly component, resulting in ozone exceedances along the coast. Inland winds from the west prevent sea breeze penetration and can sometimes contribute to the formation of convergence zone that can further concentrate ozone along the coast.
- **Western Boundary-only Exceedances:** Southerly maritime surface flow invades the eastern two-thirds of Connecticut, keeping ozone levels in that portion of the state clean. The south-southwest urban winds out of New York City result in exceedances along Connecticut's western boundary. Winds aloft are often weak for this scenario.
- **Statewide Exceedances:** This is the classical worst-case pattern, with flow at the surface in the Northeast up the Interstate-95 corridor, transport at mid-levels also from the southwest via the low level jet and flow at upper levels from the west. All of these flows are from emission-rich upwind areas, serving to transport ozone precursors and previously formed ozone into Connecticut.

2.2.2 Modeling Evidence of Ozone Transport

Modeling conducted by the New Hampshire Department of Environmental Services (NHDES) for the OTR states and by EPA in support of the Clean Air Interstate Rule (CAIR) illustrates the overwhelming level of ozone transport affecting Connecticut.

- **NHDES CALGRID Modeling:** NHDES provided California Photochemical Grid Model (CALGRID) simulations to investigate the effects emissions from each state have on ozone levels in downwind states (i.e., "zero-our" runs). Although CALGRID is not considered to be a SIP-quality modeling tool and has a tendency to predict higher ozone levels than the SIP-quality CMAQ modeling system, CALGRID simulations are less resource-intensive than CMAQ analyses and can provide useful information on the relative contributions of source areas and the relative effectiveness of control strategies.

CALGRID zero-out runs indicate that upwind states have a much greater influence on ozone levels in Connecticut than in-state emissions. When anthropogenic emissions from New York, New Jersey and Pennsylvania are "zeroed-out", CALGRID modeled ozone levels in Connecticut improve by as much as 35 ppb, compared to an estimated maximum impact from Connecticut's in-state emissions of less than 15 ppb. Given how close Connecticut is to full attainment in 2009 according to the SIP-quality CMAQ modeling (see Section 8.4), additional regional emission reduction measures in upwind states, such as the high electric demand day (HEDD) initiative (see Section 8.5.5), would provide greater confidence regarding projected attainment.

- **EPA CAIR Modeling:** EPA's CAIR program is intended to reduce interstate transport of ozone using market-based incentives targeted at electric generating units (EGUs). As more fully described in Connecticut's recent SIP revision satisfying Section 110(a)(2)(D) requirements,[4] EPA's modeling analysis[5] for CAIR identified eight upwind states as contributing significantly to 8-hour ozone NAAQS nonattainment in Connecticut (i.e., NY, PA, NJ, OH, VA, MD/DC, WV, MA). The analysis showed that Connecticut is the only state subject to transport exceeding 90% of projected 2010 ozone levels, illustrating the unique and overwhelming influence upwind emissions have on Connecticut's prospects for achieving timely attainment. EPA's CAIR modeling estimates that almost two-thirds of the transport affecting Connecticut results from emissions from the three states of New York, Pennsylvania and New Jersey.

  Despite EPA's stated goals for the CAIR program, the modeling predicts that improvements due to CAIR will be inconsequential in Connecticut when compared to the overwhelming levels of transport from upwind areas that cannot be addressed by in-state controls. EPA's modeling predicts that emission reductions from CAIR in 2010 will reduce transported ozone to Connecticut's by well less than one percent of the total transport affecting the state. These results suggest that the levels of transport after CAIR implementation will remain large enough that the prospects for 2009 attainment may be in jeopardy without additional upwind emission reductions from such programs as the HEDD initiative being pursued by several Northeast states. Results also indicate that upwind states will continue to contribute significantly to any residual nonattainment in Connecticut in 2009, highlighting the need for EPA to ensure that the remaining significant contributions are properly addressed in the ozone attainment demonstrations submitted by states upwind of Connecticut.

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[4] "Revision to Connecticut's State Implementation Plan: Meeting the Interstate Air Pollution Transport Requirements of Clean Air Act Section 110(a)(2)(D)(i)"; Submitted to EPA on March 13, 2007; See: http://www.ct.gov/dep/lib/dep/air/regulations/proposed_and_reports/revsipsec110appendix.pdf.

[5] "Technical Support Document for the Final Clean Air Interstate Rule: Air Quality Modeling"; US EPA OAQPS; March 2005; See: http://www.epa.gov/cleanairinterstaterule/pdfs/finaltech02.pdf.