2.0 Conceptual Model of the $PM_{2.5}$ Problem

The Northeast States for Coordinated Air Use Management (NESCAUM) is the regional association of air pollution control agencies representing Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. NESCAUM assists the states in developing technical support materials for regional planning efforts, such as for the particulate matter and regional haze state implementation plans. The regional planning organization coordinating regional haze programs in the Northeast is known as MANE-VU, the Mid-Atlantic and Northeast Visibility Union, which includes the NESCAUM states plus the states of Pennsylvania, Delaware and Maryland and the District of Columbia. In November 2006 NESCAUM prepared a report titled "The Nature of the Fine Particle and Regional Haze Air Quality Problems in the MANE-VU Region: A Conceptual Description." The executive summary of the NESCAUM report is reproduced below (with supplemental figures and text from the main body of the report) to provide the reader with an overview of the $PM_{2.5}$ problem in Connecticut and the Northeast. The full version of the NESCAUM report is provided in Appendix 2A.

2.1 Executive Summary from NESCAUM's Conceptual Description

A large body of scientific evidence has established a solid link between cardiac and respiratory health risks and transient exposure to ambient fine particle pollution. The same fine particles that are capable of penetrating deep into the lungs are also in the size range that is most efficient at absorbing and scattering visible light, thus impairing visibility. The emission sources, atmospheric chemistry, and meteorological phenomena that influence ambient concentrations of fine particle pollution can act on scales that range from hundreds to thousands of kilometers. Fine particles are not exclusively a secondary pollutant; primary fine particle pollution from local sources can have a significant effect on ambient concentrations in some locations. Fine particles are also not exclusively a summertime pollutant. There are important differences between the meteorological and chemical dynamics that are responsible for high fine particle levels during summer and winter.

In 1997, EPA issued national ambient air quality standards (NAAQS) for fine particles with an aerodynamic diameter of 2.5 micrometers or less. The annual NAAQS was set at 15 $\mu g/m^3$. To meet this standard, the 3-year average of a site's annual mean concentration (i.e., the design value) must not be greater than this level. The daily NAAQS was set at 65 $\mu g/m^3$ at the 98^{th} percentile level. To meet this standard, the 98^{th} percentile value (of daily measurements recorded at a site) must not be greater than this level, when averaged over three years. No counties in MANE-VU have been designated nonattainment for the daily standard, however, in 2006 EPA revised the NAAQS with respect to the 24-hr average concentrations and states will have to comply with the new standard (35 $\mu g/m^3$ at the 98^{th} percentile level) within five years of designations (expected in 2009). Fine particle data from EPA's Air Quality System (AQS) database for years 2002 through 2004 were used to determine the attainment status (with respect to the 1997 NAAQS) for monitoring sites in MANE-VU.

Table 2-1 shows a summary of areas found to exceed the annual standard (no areas exceed the 1997 24-hr standard) and the associated design values. As tabulated, 12 areas

in the Northeast fail to achieve the annual standard, with design values ranging from 15.1 to 20.4 μg/m^3. The nonattainment areas are concentrated in Pennsylvania and the coastal urban corridor. Sulfates and organic carbon represent the largest contributors to these high fine particle levels.

Table 2-1. 2004 $PM_{2.5}$ Design Values (μg/m^3) for Nonattainment Areas in MANE-VU

State(s)	Nonattainment Area	2004 Annual Design Value
MD	Baltimore	16.3
PA	Harrisburg-Lebanon-Carlisle	15.4
PA	Johnstown	15.3
PA	Lancaster	16.8
PA	Liberty-Clairton	20.4
MD	Martinsburg, WV-Hagerstown	16.1
NY-NJ-CT	New York-New Jersey-Connecticut	16.8
PA-NJ-DE	Philadelphia-Wilmington	15.4
PA	Pittsburgh-Beaver Valley	16.5
PA	Reading	16.1
DC-MD-VA	Washington, DC	15.1
PA	York	16.9

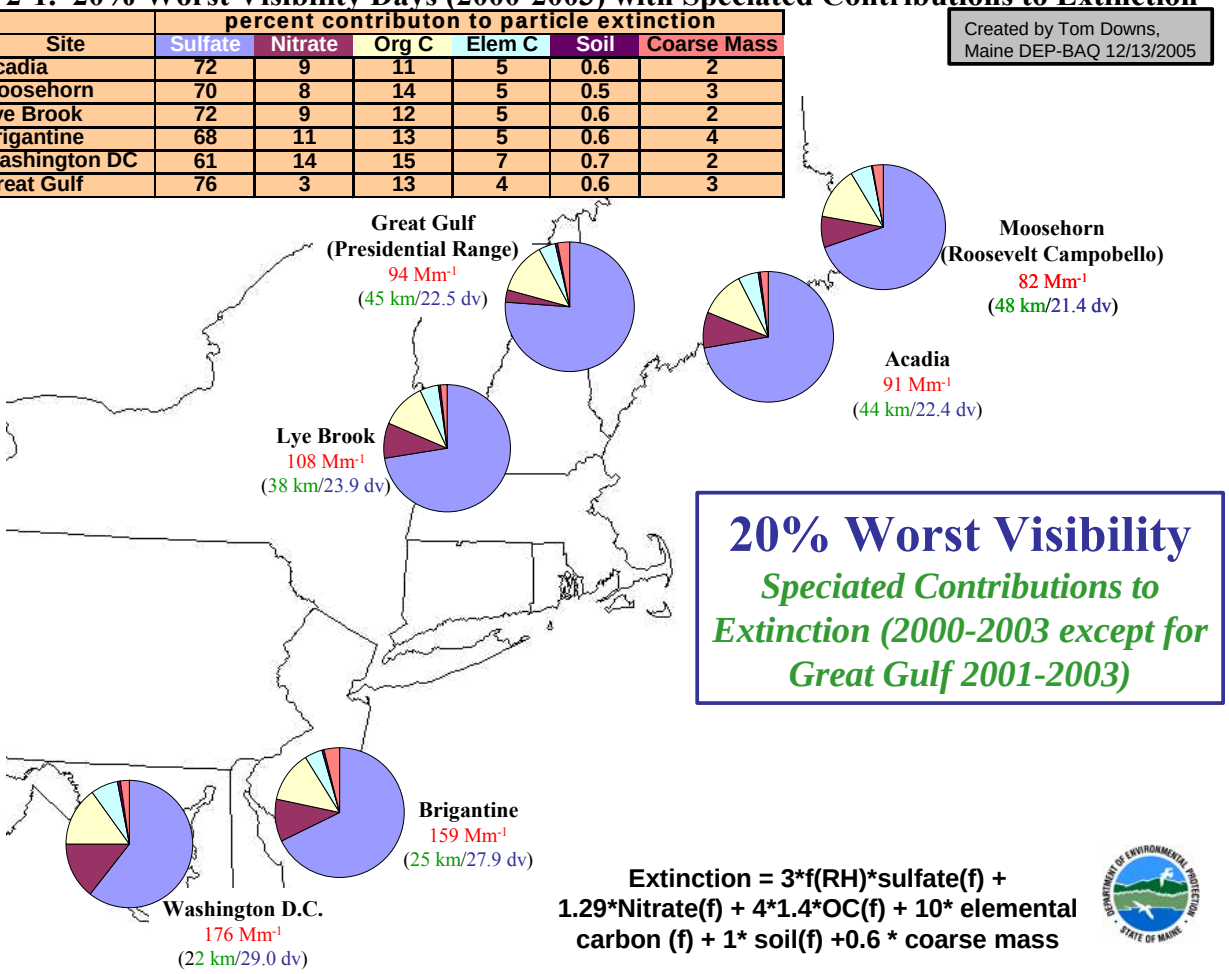
In 1999, EPA followed up with the Regional Haze Rule that enforces a national visibility goal laid out in the CAA. This will ultimately restore natural visibility to 156 national parks and wilderness areas across the country (called "Class I" areas). To address these CAA requirements, states will have to develop State Implementation Plans (SIPs) detailing their approaches for reducing fine particle pollution to meet the health-based fine particle NAAQS. They also must develop plans that address the degradation of visibility that exists in Class I areas of the MANE-VU region. As part of this process, EPA urges states to include in their SIPs a conceptual description of the pollution problem in their nonattainment and Class I areas. The full NESCAUM document, as presented in Appendix 2A, provides the conceptual description of the fine particle and regional haze problems in the MANE-VU states, consistent with EPA's guidance.

Scientific studies of the regional fine particle problem have uncovered a rich complexity in the interaction of meteorology and topography with fine particle formation and transport. Large scale high pressure systems covering hundreds of thousands of square miles are the source of classic severe fine particle episodes in the eastern United States, particularly in summer. These large, synoptic scale systems create particularly favorable conditions for the oxidation of sulfur dioxide (SO_2) emissions to various forms of sulfate which, in turn, serve to form – or are incorporated into – fine particles that are subsequently transported over large distances. These synoptic scale systems move from west to east across the United States, bringing air pollution emitted by large coal-fired

power plants and other sources located outside MANE-VU into the region. This then adds to the pollution burden within MANE-VU on days when MANE-VU's own air pollution sources are themselves contributing to poor air quality. The worst regional haze events typically occur under these conditions as well (see Figure 2-1). At times, the high-pressure systems may stall over the East for days, creating particularly intense fine particle episodes.

Figure 2-1. 20% Worst Visibility Days (2000-2003) with Speciated Contributions to Extinction

Site	percent contributon to particle extinction					
	Sulfate	Nitrate	Org C	Elem C	Soil	Coarse Mass
Acadia	72	9	11	5	0.6	2
Moosehorn	70	8	14	5	0.5	3
Lye Brook	72	9	12	5	0.6	2
Brigantine	68	11	13	5	0.6	4
Washington DC	61	14	15	7	0.7	2
Great Gulf	76	3	13	4	0.6	3



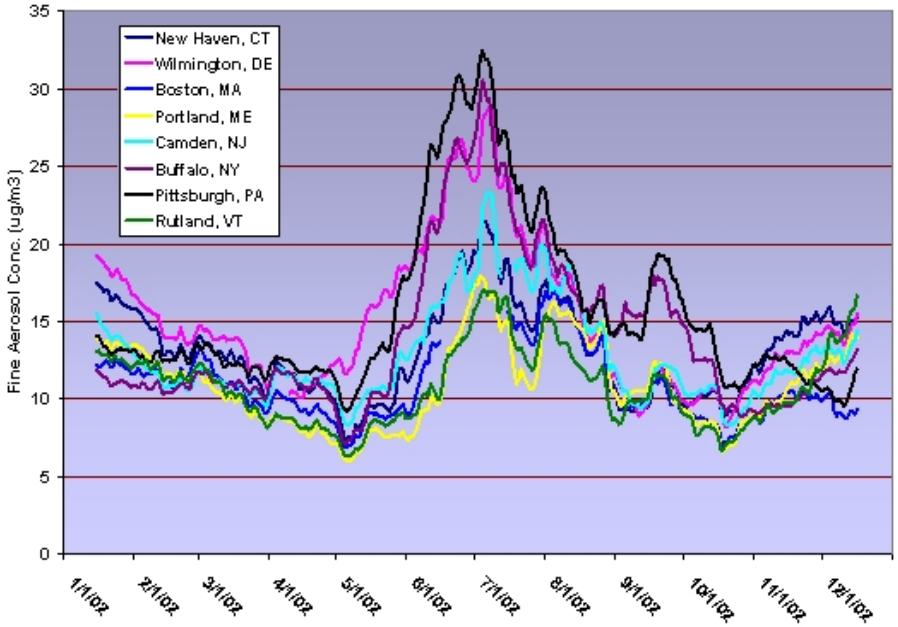
In the winter, temperature inversions occur that are effective at concentrating local primary particle emissions at the surface overnight and during early morning hours. This pollution can then be mixed into regionally transported particle pollution (aloft) later in the morning when convection is restored. Additionally, the lower temperature in the winter can shift the chemical equilibrium in the atmosphere slightly toward the production of nitrate particle pollution relative to sulfate formation. As a result, nitrate can become a significant fraction of measured fine particle mass in parts of the eastern U.S. during winter months.

Primary and secondary emissions of carbon-containing compounds (e.g., diesel exhaust, biogenic organic carbon emissions, and anthropogenic volatile organic compound

emissions) all contribute to a significant presence of carbonaceous aerosol across the MANE-VU region, which can vary from urban to rural locations and on a seasonal basis. In addition, short range pollution transport exists, with primary and precursor particle pollutants pushed by land, sea, mountain, and valley breezes that can selectively affect relatively local areas. With the knowledge of the different emission sources, transport scales, and seasonal meteorology in various locations adjacent to and within MANE-VU, a conceptual picture of fine particle pollution and its impacts emerges. The seasonal variations in $PM_{2.5}$ levels across the MANE-VU region are shown in Figure 2-2.

The conceptual description that explains elevated regional $PM_{2.5}$ peak concentrations in the summer differs significantly from that which explains the largely urban peaks

Figure 2-2.
The 30-day Average $PM_{2.5}$ Concentrations from 8 Northeastern Cities During 2002



observed during winter. On average, summertime concentrations of sulfate in the northeastern United States are more than twice that of the next most important fine particle constituent, organic carbon (OC), and more than four times the combined concentration of nitrate and black carbon (BC) constituents. Episodes of high summertime sulfate concentrations are consistent with stagnant meteorological flow conditions upwind of the MANE-VU region and the accumulation of airborne sulfate (via atmospheric oxidation of SO_2) followed by long-range transport of sulfur emissions from industrialized areas within and outside the region.

National assessments have shown that in the winter, sulfate levels in urban areas are higher than background sulfate levels across the eastern U.S., suggesting that the local urban contribution to wintertime sulfate levels is significant relative to the regional sulfate contribution from long-range transport. A network analysis for the winter of 2002 suggests that the local enhancement of sulfate in urban areas of the MANE-VU region ranges from 25 to 40% and that the long-range transport component of $PM_{2.5}$ sulfate is still the dominant contributor in most eastern cities.

In the winter, urban OC and sulfate each account for about a third of the overall $PM_{2.5}$ mass concentration observed in Philadelphia and New York City (see Figures 2-3, 2-4 and 2-5). Nitrate also makes a significant contribution to urban $PM_{2.5}$ levels observed in the northeastern United States during the winter months. Wintertime concentrations of OC and nitrate in urban areas can be twice the average regional concentrations of these pollutants, indicating the importance of local source contributions. This is likely because winter conditions are more conducive to the formation of local inversion layers, which prevent vertical mixing. Under these conditions, emissions from tailpipe, industrial and other local sources become concentrated near the Earth's surface, adding to background pollution levels associated with regionally transported emissions.

From this conceptual description of fine particle pollution formation and transport into and within MANE-VU, air quality planners need to develop an understanding of what it will take to clean the air in the MANE-VU region. Every air pollution episode is unique in its specific details. The relative influences of the transport pathways and local emissions vary by hour, day, and season. The smaller scale weather patterns that affect pollution accumulation and its transport underscore the importance of local (in-state) controls for SO_2, nitrogen oxides (NO_X) and volatile organic compound (VOC) emissions. Larger synoptic scale weather patterns, and pollution patterns associated with them, support the need for SO_2 and 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 SO_2 and NO_X sources as locally generated and transported pollution can both be entrained in 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 fine particle formation is primarily due to SO_2, but NO_X is also important because of its influence on the chemical equilibrium between sulfate and nitrate pollution during winter. While the effect of reductions in anthropogenic VOCs is less well characterized at this time, secondary organic aerosol (SOA) is a major component of fine particles in the region and reductions in anthropogenic sources of OC may have a significant effect on fine particle levels in urban nonattainment areas. Therefore, a combination of localized NO_X and VOC reductions in urban centers with additional SO_2 and NO_X reductions from across a larger region will help to reduce $PM_{2.5}$ and precursor pollutants in nonattainment areas as well improve visibility across the entire MANE-VU region.

Figure 2-3. 2002 Seasonal Average SO_4 Based on IMPROVE and STN Data

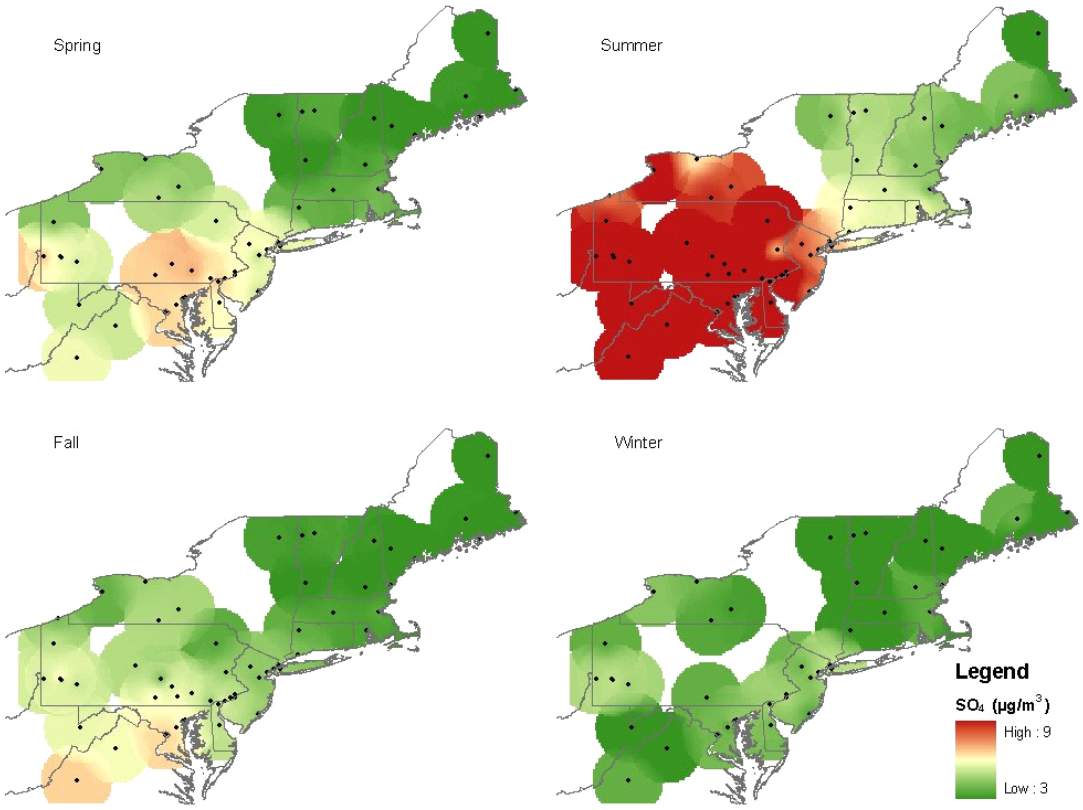


Figure 2-4. 2002 Annual Average $PM_{2.5}$, Sulfate, Nitrate and Total Carbon for MANE-VU Based on IMPROVE (I) and STN (S) Data. $PM_{2.5}$ Mass Data are Supplemented by Measurements from the FRM Network (•).

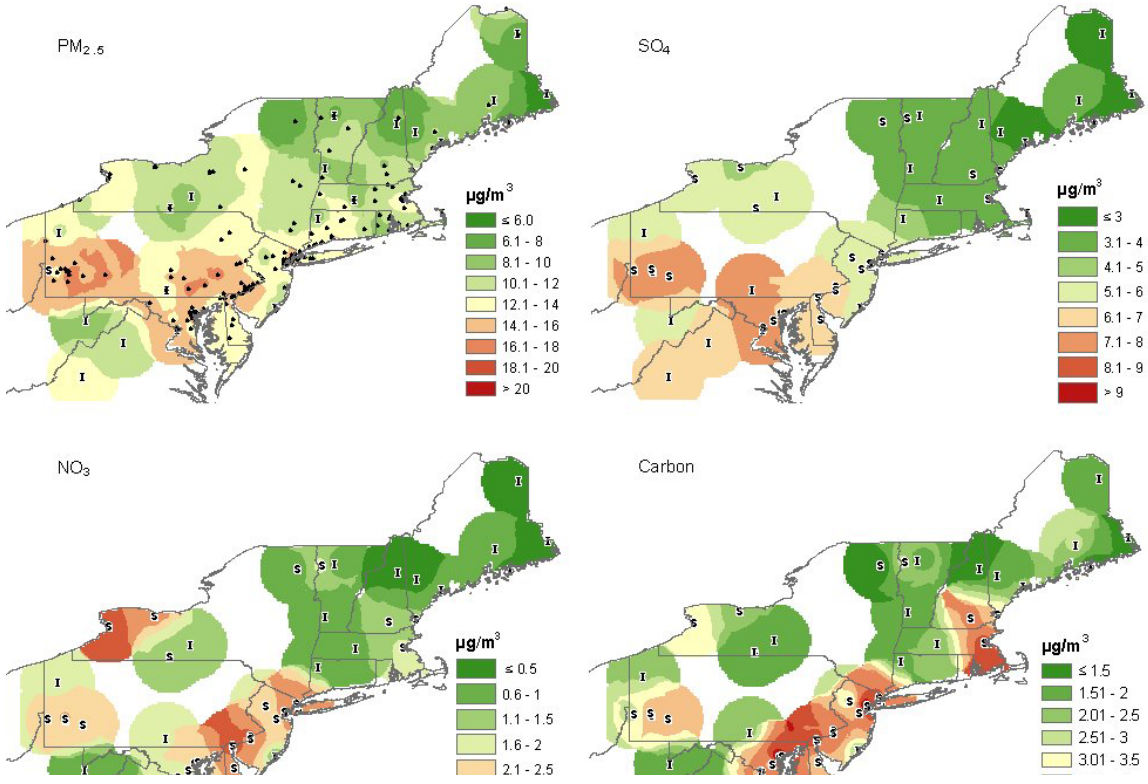
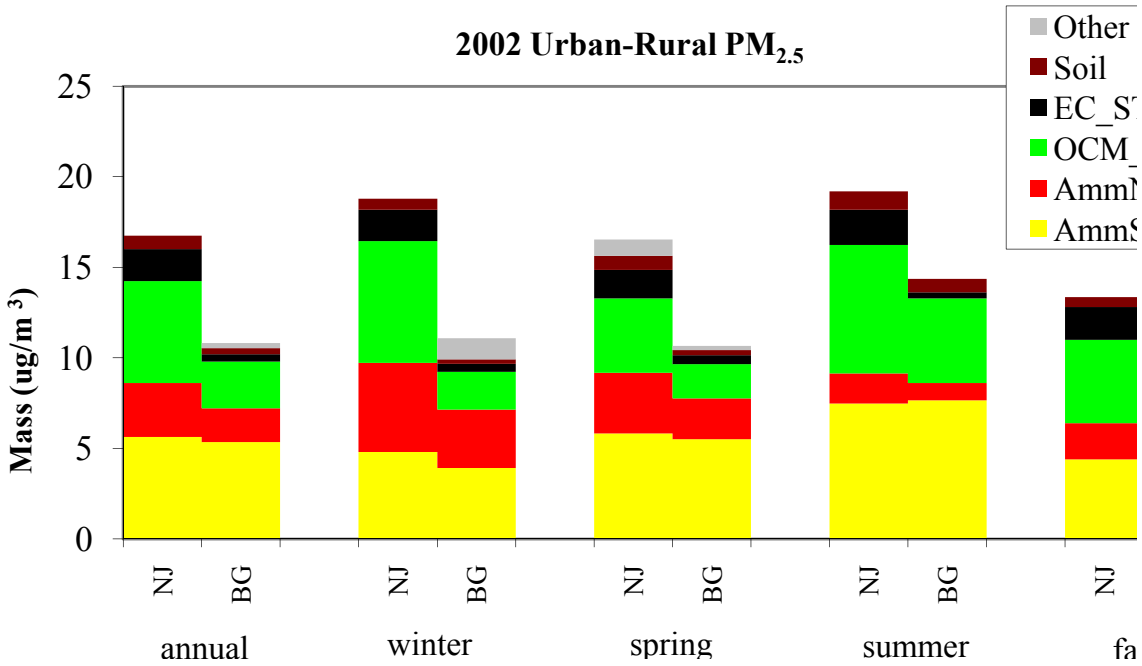


Figure 2-5. $PM_{2.5}$ Species Contribution in the Urban New York Nonattainment Area, NJ (Elizabeth, NJ), Compared to an Upwind Background Site, BG (Chester, NJ).



2.2 Conceptual Model for Elevated $PM_{2.5}$ in Connecticut

Elevated $PM_{2.5}$ levels in Connecticut can occur in either winter or summer and follow similar patterns to those described above for the MANE-VU region. Appendix 2B contains CTDEP's analysis of speciated $PM_{2.5}$ data, meteorological data, and receptor modeling to characterize both winter and summer events. Conclusions from that analysis are summarized below.

2.2.1 Summary of the Seasonal Characteristics of Elevated $PM_{2.5}$

$PM_{2.5}$ events in Connecticut can be categorized as winter or summer time events.

Winter events can be characterized as having:

1. 98^{th} percentile 24-hour value > 32 µg/m^3;
2. Low mixing heights (250m) and E/F Pasquill stability class (shallow, little mixing) for an extended period of time;
3. Warm fronts or overrunning warm air forcing low mixing heights with non-stagnant wind conditions;
4. Low level winds from the southwest (following the urban northeast corridor);
5. Extended periods of high values, not just short duration diurnal rush hour peaks;
6. The primary PM source is motor vehicle (MV) (fresh and aged) and secondary aerosol (volatile species). Lesser contributions come from oil combustion aerosol and wood smoke;
7. Constituent aerosol is primarily carbon (organic and elemental) and;
8. Wintertime sulfate aerosol is less than summertime sulfate aerosol. This can be attributed to cold temperature affinity of ammonium to nitrate over sulfate, the shallow mixing prohibiting deep mixing of Midwest aerosol downward, and reduced EGU emissions during the cold months (no air conditioning).

Summertime events can be characterized as having:

1. 98th percentile 24-hour value > 40 μg/m^3;
2. High mixing heights 600-1200m coast, >1500m inland;
3. Bermuda high weather conditions lasting over several days;
4. Low-level winds from the SSW-SW (NYC CMSA), midlevel winds from the SW and WSW enhanced by the nocturnal low-level jet (LLJ) (following urban NE corridor;)
5. Extended periods of high values, not just short duration diurnal rush hour peaks;
6. The primary $PM_{2.5}$ source is coal burning EGUs, followed by carbon from mobile sources;
7. Constituent aerosol is primarily ammonium sulfate, followed by organic carbon and;
8. Summertime sulfate aerosol is greater than wintertime sulfate aerosol. This can be attributed to warm temperature affinity of ammonium to sulfate over nitrate, the deep mixing of western aerosol downward, and increased EGU emissions during the warm months (air conditioning).

2.2.2 Seasonal Speciation of $PM_{2.5}$

Figures 2-6 and 2-7 illustrate the difference between summer and winter $PM_{2.5}$ composition during typical high events. Motor vehicle (MV) and other fossil fuel combustion sources dominate in the winter at the New Haven site, as depicted by the levels of ammonium nitrate (ammnit) and organic carbon (oc). Ammonium sulfate (ammsul) contributions are somewhat smaller during the winter, but still important. During a typical summer high $PM_{2.5}$ event at the Cornwall site, over 75% of the speciation occurs as ammonium sulfate. This is indicative of long-range transport from the west and southwest.

Figures 2-8 and 2-9 show typical meteorological patterns during high $PM_{2.5}$ events in the winter and summer, respectively. Wintertime events are often associated with the passage of warm fronts and may or may not be long in duration, and high pressure stagnation events. Summertime patterns events are often associated with broad Bermuda high type air masses that may persist for several days.

The implications of this analysis to national air quality regulation are two-fold:

- Control measures on electric generating units to the west of Connecticut are necessary to reduce sulfate sufficiently during the summer;
- Control measures on motor vehicles are needed to reduce nitrate in winter and carbon in both summer and winter.

Figure 2-6. Typical High $PM_{2.5}$ Winter Speciation at New Haven, CT (Criscuolo)

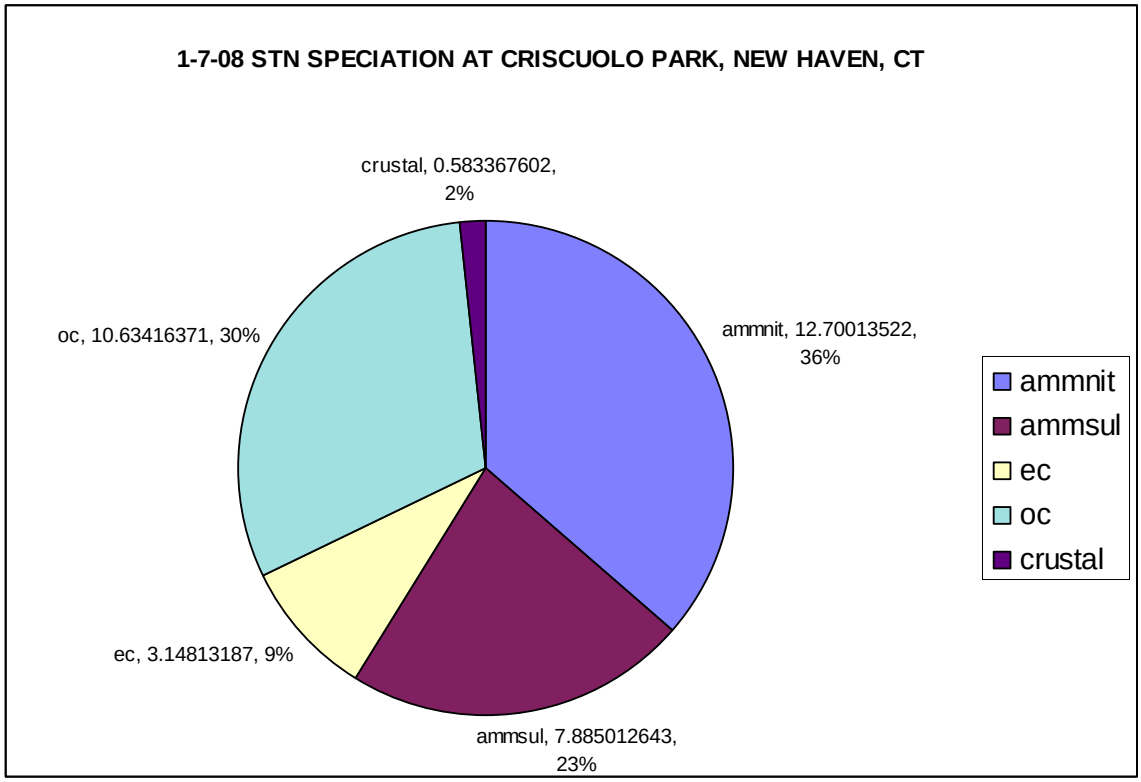


Figure 2-7. Typical High $PM_{2.5}$ Summer Speciation at Cornwall, CT (Mohawk)

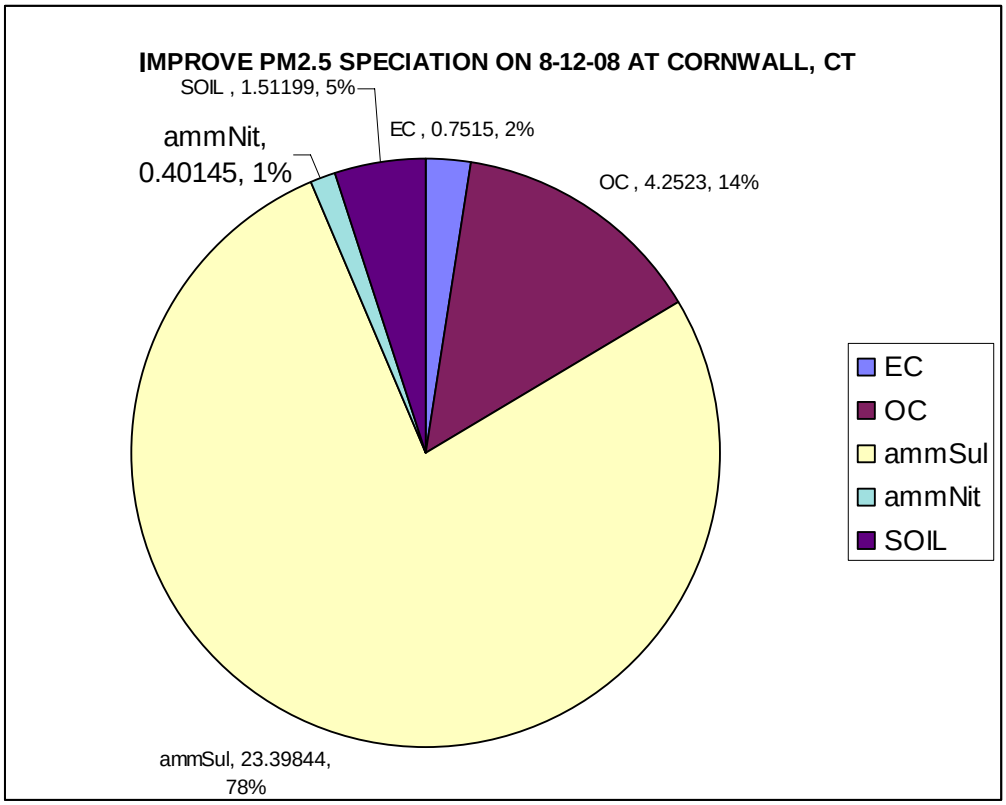


Figure 2-8. Surface Analysis for 3/14/07 12Z (Winter)

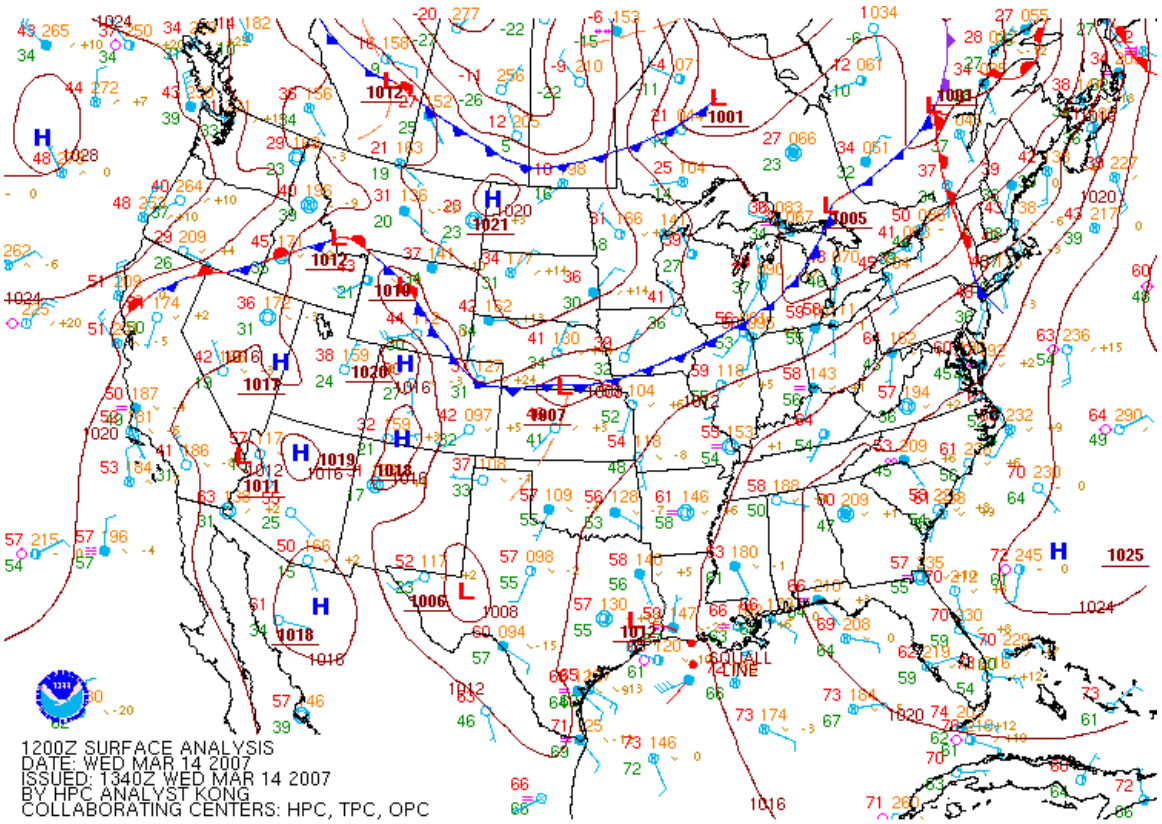


Figure 2-9. Surface Analysis for 8/12/02, 18Z (Summer)