The Changing Nature of Visibility Impairment

in the Mid-Atlantic/Northeast Visibility Union (MANE-VU) Region

MANE-VU Class 1 Areas (clockwise from top left): Moosehorn Wilderness Area (ME), Roosevelt Campobello International Park (New Brunswick, Canada), Lye Brook Wilderness Area (VT), Brigantine Wilderness Area (NJ), Presidential Range–Dry River Wilderness Area (NH), and in the center, Acadia National Park (ME).

by Sharon Davis, David Healy, and Alexandra Karambelas

Assessing the progress made in improving visibility at federally protected Class I areas located in MANE-VU states, the changing nature of regional haze in the Northeast, and the steps needed to continue progress in visibility improvement across the MANE-VU region.

Under the U.S. Clean Air Act, Class I designation was given to 156 national parks, wilderness areas, memorial parks, and international parks across the United States. The U.S. Environmental Protection Agency (EPA) promulgated the 1999 Regional Haze Rule (RHR) that set goals for states to achieve natural visibility conditions (i.e., no human-caused visibility impairment, in Class I areas by 2064). Per the RHR, all states—even those without Class I areas—are required to develop a State Implementation Plan (SIP) to outline how they intend to contribute to progress toward natural visibility conditions by 2064. States with Class I areas are further required to establish reasonable progress goals for Class I areas within their borders. States must submit a regional haze SIP revision every 10 years, along with corresponding five-year progress reports, to document reasonable progress towards the 2064 goal of natural visibility conditions.

The first round of SIPs, due in 2008, assessed the milestone year of 2018. For states in the Mid-Atlantic/Northeast Visibility Union (MANE-VU) region (see Figure 1), these SIPs identified sulfur dioxide (SO_2) as the predominant precursor to visibility impairment. Thus, the reductions implemented for the first 10-year planning period focused on reducing SO_2 emissions from sources such as power plants and large industrial boilers.

MANE-VU states recently completed the second phase of RH planning, which covers the period 2018–2028. As part of this phase, the MANE-VU states evaluated emissions inventory trends and regional haze metric trends from the baseline period of 2000–2004 to the most current period. Measurements confirmed that large SO_2 emissions reductions were achieved, and that other pollutants, mainly nitrates, are now more important contributors, changing the nature of haze in the region.

Figure 1. Map of MANE-VU region. Class I areas indicated with black stars. Nearby Class I areas outside of MANE-VU indicated with blue circles.

Emissions Trends

Visibility impairment is primarily caused by light scattering and absorption from aerosols. Aerosols may be emitted by anthropogenic sources such as combustion processes or by natural sources such as lightning-caused wildfires, or they may be formed through secondary reactions in the atmosphere. Secondary aerosols in MANE-VU often result from emissions of SO_2 and oxides of nitrogen (NO_x) reacting with ammonia to form ammonium sulfate and ammonium nitrate, respectively. MANE-VU uses data from emissions inventories and in situ observations to assess progress toward natural visibility in Class I areas.

Figure 2a shows the trend in annual MANE-VU state total SO_2 emissions for 2002–2017 from EPA's National Emissions Inventory (NEI) and from sources such as power plants and large industrial facilities that report directly to EPA's Air Markets Program Database (AMPD) (hatched bars). There is a clear downward trend in total SO_2 emissions that is largely driven by a decline in SO_2 emissions from AMPD sources, which are an overwhelming contributor to total SO_2 emissions. Because large point source emission reductions were a

The Mid-Atlantic/Northeast Visibility Union (MANE-VU)

MANE-VU includes 11 states—Maine, Vermont, New Hampshire, Rhode Island, Massachusetts, Connecticut, New York, New Jersey, Pennsylvania, Delaware, and Maryland—as well as the District of Columbia, the Penobscot Nation (ME), and the St. Regis Mohawk Tribe (NY). The MANE-VU Regional Planning Organization was formed to coordinate actions necessary to improve visibility at national parks and wilderness areas in the Northeast and Mid-Atlantic region. MANE-VU provides support to its member agencies by facilitating technical assessments, evaluations of regional air pollution, forums for discussion, and coordination with other regions. A Technical Support Committee assesses the nature of regional haze, the sources that contribute to regional haze, and the technical tools that states can use to develop their programs.

focus of the first regional haze planning phase, federal and state regulations to reduce these emissions contributed to a decline in coal use. This, in turn, led to reductions in SO_2 emissions at AMPD sources. Further, the economics of natural gas availability have likely contributed to recent reductions in SO_2 emissions, and state interest in renewable energy initiatives may be contributing to the decline in coal use and the associated reduction in SO_2.

Similarly, annual NO_X emission trends for state total and AMPD contributions (hatched bars) in the MANE-VU region show a clear downward trend between 2002 and 2017 (see Figure 2b), though declines are not quite as steep as for SO_2. This is, in part, because the first regional haze planning effort was focused on reducing SO_2 emissions and AMPD sources are a moderate contributor to NO_X. Further, former and current stationary source NO_X emission control programs, such as the NO_X SIP Call, the Clean Air Interstate Rule, and the Revised Cross State Air Pollution Rule Update, are mainly focused on reducing ozone pollution; therefore, most of the associated NO_X reductions occur during the summer ozone season. To address regional haze, MANE-VU has found that year-round NO_X controls are needed.

The impact of the reduced SO_2 and NO_X emissions can be seen in the sulfate and nitrate measurements from the Interagency Monitoring of Protected Visual Environments

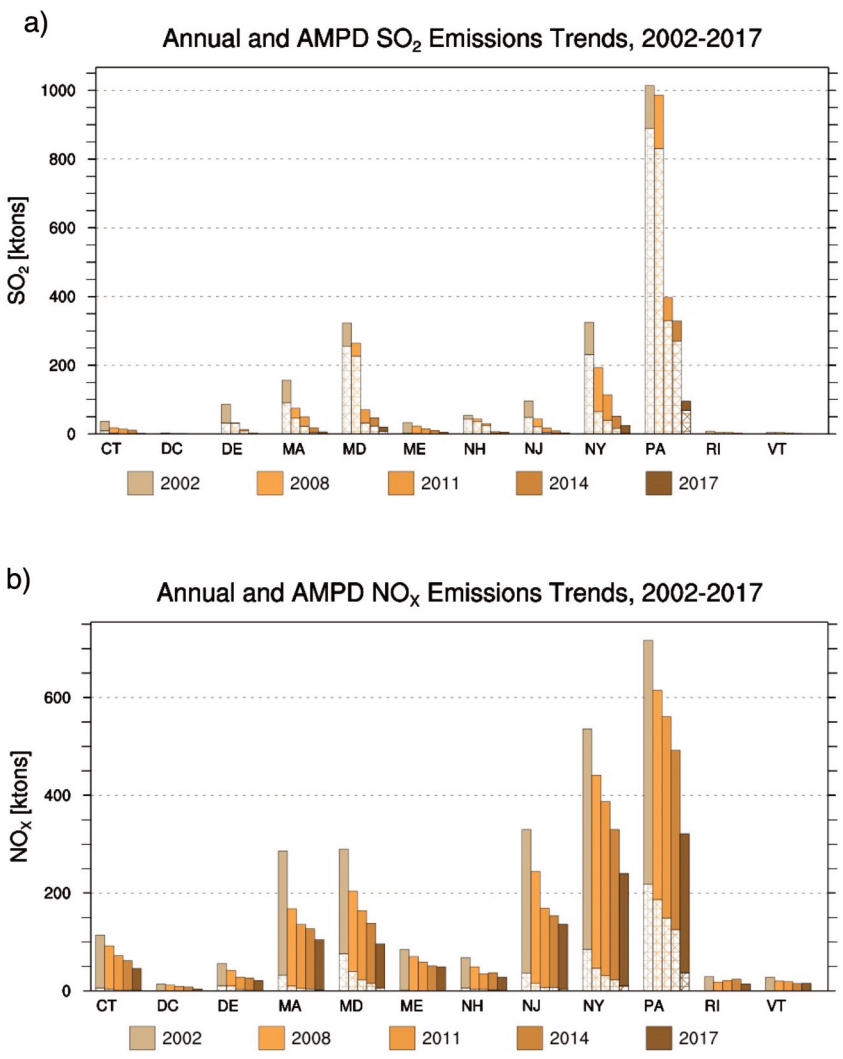

Figure 2. (a) Statewide total SO_2 emissions (height of bar) and SO_2 emissions from EPA Air Markets Program Data (AMPD) sources (hatched area) in the MANE-VU states (2000–2017). (b) Statewide total NO_X emissions (height of bar) and NO_X emissions from AMPD sources (hatched area) in the MANE-VU states (2002–2017).

(IMPROVE) visibility monitoring network. Sulfate concentrations ($\mu g/m^3$) decline considerably from 2000 to 2020 for all MANE-VU Class I areas (see Figure 3a). Nitrate concentrations trended downward to a trough around 2010 and then generally leveled off until 2020 at all Class I areas except Brigantine Wilderness Area, which did not reach a low point and level off until 2017 (see Figure 3b). In general, sulfate peaks in summer (see Figure 3c) while nitrate peaks in winter (see Figure 3d). In the winter, nitrogen dioxide (NO_2), a component of NO_X, exhibits a longer lifetime due to colder temperatures and increases the potential for conversion to nitrate rather than being removed from the atmosphere. Nitrate is also more stable under cooler conditions, leading to higher concentrations.

Regional Haze Metric Trends

Progress toward natural visibility conditions is evaluated using data collected from the IMPROVE visibility monitoring network. EPA guidance requires regional haze SIPs to focus on improving visibility on the 20% most impaired days—that is, the 20% worst visibility days accounting only for anthropogenic sources of visibility impairment.[1] Since 2000, there has been a seasonal shift in the 20% most impaired days. From

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Figure 3. Annual average (a) sulfate and (b) nitrate concentrations (µg/m³) at MANE-VU Class I areas (2000–2020). Monthly average (c) sulfate and (d) nitrate concentrations (µg/m³) at MANE-VU Class I areas (January 2018–December 2020). In all panels, observations at Acadia are shown in dark blue, Brigantine are in orange, Great Gulf Wilderness are in gray, Lye Brook are in yellow, and Moosehorn are in light blue. In (b), some of the Class I area 2019 nitrate concentrations may be artificially low due to missing January data.

2000 through 2012 for most MANE-VU Class I areas, most of the 20% most impaired days occurred during the summer months (see Figure 4, red bars), when sulfates tend to dominate the aerosol fraction. However, since 2013, most have occurred during winter months (see Figure 4, blue bars), when the nitrate fraction contribution increases. Spring and fall contributions to 20% most impaired days fluctuate year to year and don't exhibit a notable trend.

Annual and five-year rolling average haze indices, measured in deciviews, at MANE-VU Class I areas are compared to Uniform Rate of Progress (URP, red dashed line) and Reasonable Progress Goal (RPG, black crosshatch at 2028 and red-dotted glide path) projections in Figure 5. URP and RPGs are calculated metrics used in regional haze SIPs to evaluate progress toward the goal of natural visibility conditions. Annual haze indices (black line with circles) at representative MANE-VU Class I areas are below the URP, meaning that current haze indices for the 20% most impaired days are already below the level of the glide path from baseline 2000–2004 visibility levels to the 2064 natural visibility conditions goal. However, current five-year average haze indices for the 20% most impaired days are not at or below the level of the 2028 RPGs. Therefore, further progress is needed to achieve 2028 RPGs at all MANE-VU Class I areas. While not all MANE-VU states' RH SIPs have been finalized, MANE-VU used photochemical modeling to establish RPGs for 2028.[2]

Conclusions

MANE-VU Class I areas are realizing visibility improvements, but states in the region are no longer able to prioritize emission reductions for one pollutant alone. Haze indices on the 20% most impaired days have decreased considerably since 2000, primarily due to decreases in sulfate concentrations. However, nitrate contributions are collectively becoming a larger factor in visibility impairment, reflecting a seasonal shift such that a majority of 20% most impaired days in the MANE-VU region occur during winter months.

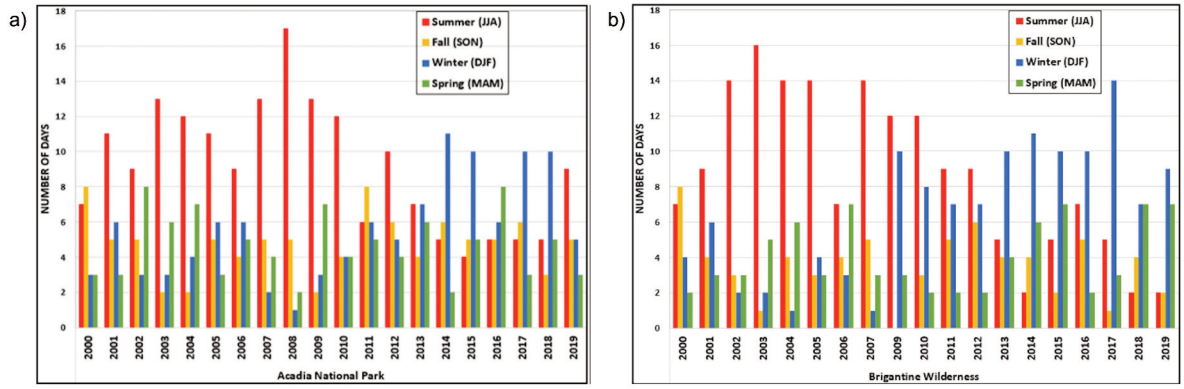

Figure 4. Seasonal contributions to 20% most impaired days 2000–2019 at two MANE-VU Class I areas: (a) Acadia National Park and (b) Brigantine Wilderness Area.

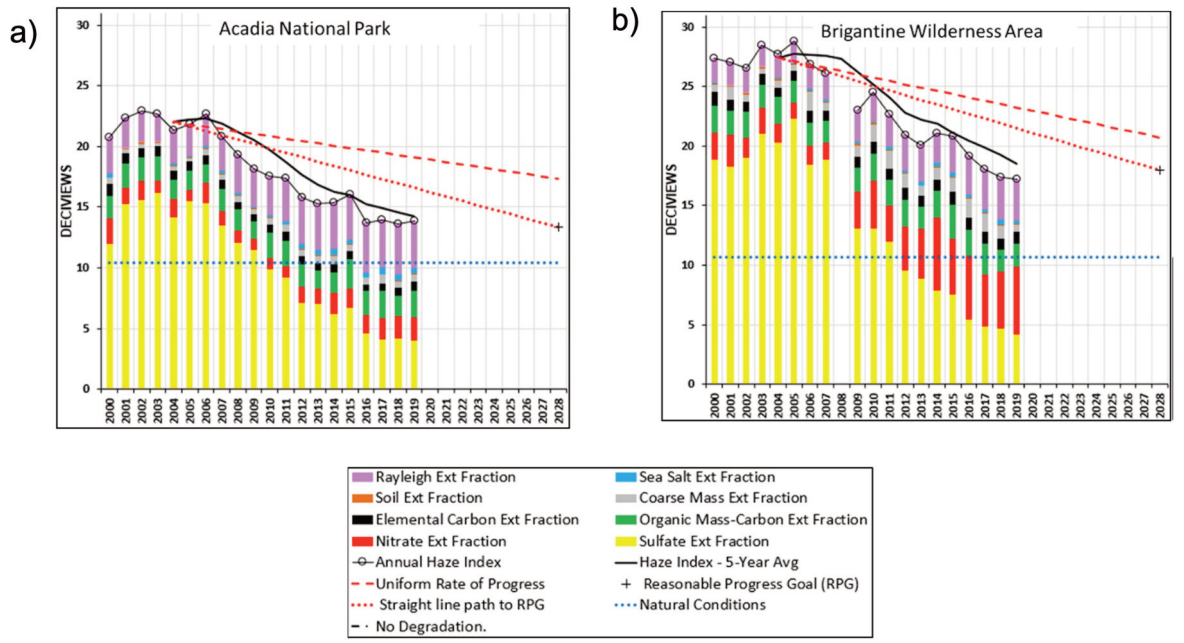

Figure 5. Visibility metric trends for 20% most impaired days 2000–2019 for two MANE-VU Class I areas: (a) Acadia National Park and (b) Brigantine Wilderness Area. Glide-paths for the URP are shown in red dashed lines, and RPGs are shown in red dotted lines. The black line is the five-year average Haze Index.

Reductions in sulfate and nitrate concentrations over time, although significant, are not as steep as the downward trends in their precursor SO_2 and NO_X emissions across sites in MANE-VU Class I areas. Recent research into the reduction of gaseous emissions in the eastern United States found that although SO_2, NO_2, and particulate sulfate have declined considerably, particulate nitrate concentrations in the winter-time have remained largely unchanged.[3,4] In one case, Shah et al.[4] found that if SO_2 emissions were to decrease while NO_X emissions remained at 2015 levels, projected nitrate concentrations may even increase in the future. Therefore, concurrent reductions of NO_X and SO_2 emission are needed during the winter to realize meaningful decreases in winter-time nitrate concentrations. It is important to move forward with a multi-pollutant, year-round focus to achieve the 2028 RPGs in Class I areas across the MANE-VU states to continue

making progress towards the 2064 goal of reaching natural visibility conditions. For these reasons, the MANE-VU states included as a measure in their second regional haze planning SIPs the year-round operation of existing NO_X controls for large sources such as coal-fired power plants.[5] MANE-VU called for implementation of this measure in its own states as well as upwind states that contribute to visibility impairment at MANE-VU Class I areas. MANE-VU will continue to support more year-round NO_X control measures, as well as measures that will reduce SO_2 emissions. **em**

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