Technical Support Document (TSD)
Revised Recommendations for Visibility Progress Tracking Metrics for the Regional Haze Program

U.S. Environmental Protection Agency

Office of Air Quality Planning and Standards

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LIST OF ACROYMNS (and abbreviations)

b_{ext}	Light extinction coefficient, called beta extinction, expressed in the units of inverse megameters (Mm^{-1}). It represents the amount of light extinction from scattering and absorption.
CM	Coarse Mass
CONUS	Continental United States
dv	deciview
e3	extreme episodic extinction
EC	Elemental Carbon[1]
EPA	Environmental Protection Agency
IMPROVE	Interagency Monitoring of Protected Visual Environments
HI	Haze index that is derived from calculated light extinction
NCII	Natural Conditions II, the 2006 update to the EPA's original natural conditions estimates
NCDC	National Climatic Data Center
OCM	Organic Carbon Mass[2]
RHR	Regional Haze Rule
SIP	State Implementation Plan
SOA	Secondary Organic Aerosol

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[1] Elemental carbon measurements produced by the IMPROVE monitoring method are also known as black carbon and light absorbing carbon. The latter is abbreviated LAC and is the term used in the EPA guidance. EC is the term used in this document.

[2] There are currently three terms used to denote this fraction of PM and contribution to extinction: OCM (organic carbon mass, an older term but still frequently used), OM (organic mass, a term most frequently used by modelers, and which has recently been adopted by EPA for describing mass in measured $PM_{2.5}$), and OMC (the abbreviation used by the IMPROVE program and in the various online databases for the Organic Mass among carbon parameters). While OCM is the term generally used in this document, some figure legends may use "OM."

1 Introduction

The purpose of this document is to provide and document technical details of the analyses to support the EPA guidance[3] on tracking progress on reducing regional haze with sufficient details to facilitate external review.[4] The document includes a description of a generalized framework for the new approach to tracking metrics, together with a draft step-by-step method for its implementation as well as the technical rationale and results that helped the EPA support its proposed revisions. Comparisons among alternative approaches to the first implementation period's approach are provided. Also included is the derivation of the aerosol extinction budgets for natural and anthropogenic fractions of total haze. These are a logical outgrowth of the methodology to establish the new tracking metric and may prove useful to help the states with their determination and review of reasonable progress towards natural visibility conditions. The document identifies potential issues and concerns regarding the recommended data handling steps, which states may also consider as they develop their state implementation plans.[5]

Section 169A (a)(4) and other subsections of the Clean Air Act call for reasonable progress "toward meeting the national goal" of eliminating anthropogenic (man-made) impairment of visibility. The EPA guidance for "Tracking Progress under the Regional Haze Rule" published in 2003 describes how representative monitoring data collected from the IMPROVE network should be used to establish baseline conditions (for the 2000-2004 period) for each Class I area and to track progress toward goals established in future State Implementation Plans(SIPs).[6,7]

The 2003 tracking guidance indicates that states are required to set progress goals to provide for an improvement in visibility for the most impaired days and ensure no degradation in visibility for the least impaired days. The 2003 document defines visibility conditions on the least and most impaired days as data representing a subset of the annual measurements that correspond to best and worst days of the year which are defined as the **clearest (least hazy)** and **dirtiest (most hazy).**[8] Accordingly, the 2003 guidance states that States "should track progress on the best days as well as the worst days in order to determine if emission reduction strategies lead to an improvement in the overall distribution of visibility conditions." The 2003 guidance also states

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[3] Draft Guidance on Progress Tracking Metrics, Long-term Strategies, Reasonable Progress Goals and Other Requirements for Regional Haze State Implementation Plans for the Second Implementation Period, EPA-457/P-16-001, July 2016.

[4] To facilitate comment and document finalization, this draft version of this technical support document is written as if the revisions to the Regional Haze Rule proposed in April 2016 have been finalized as proposed and as if the associated new guidance document has been finalized as drafted, except as specifically noted. If the final revisions to the Rule and/or the final new guidance document differ from this assumption, corresponding changes will be made in the final technical support document.

[5] These issues and concerns warrant continued discussions and analyses before specific recommendations are finalized. Some suggestions for resolution of the issues and development of new data are provided. Comments are solicited on all aspects of this document. Even after finalization of this document, states may use other approaches provided those approaches are not in conflict with the revised Regional Haze Rule.

[6] 40CFR51.308 (d) (2) (i). Also, as discussed in the preamble to the Regional Haze Rule (64FR 35728-9, July 1, 1999), representative monitoring data collected from this network will be used to establish baseline conditions (for the 2000-2004 period) for each Class I area and to track progress toward goals established in future SIPs.

[7] Guidance for Tracking Progress Under the Regional Haze Rule EPA-454/B-03-004 September 2003.

[8] Consistent with the new EPA guidance on tracking progress, this document recommends the use of the clearest days to mean the best days and instead of the haziest days, recommends the use of the most impaired days for the worst days.

that reasonable progress goals must provide for a rate of improvement sufficient to attain natural conditions by 2064, or justify a suitable alternative to this rate. In addition, the guidance states that the estimates of natural visibility conditions should represent long-term averages, analogous to the 5-year averages used to determine baseline conditions and current conditions. A separate 2003 guidance document provides a methodology for developing estimates of natural visibility conditions for each Class I area which builds upon estimates published by Trijonis.[9,10] These estimates were subsequently updated and called natural conditions II (NCII) with “p10” and “p90” values for the clearest and haziest 20% of the days, respectively.[11] Natural conditions are discussed in more detail in Section 3.2.

As stated at 40 CFR 51.308 (d)(1) and repeated in the 2003 guidance, baseline visibility conditions, progress goals and changes in visibility must be expressed in terms of deciview (dv) units. The deciview is a unit of measurement of haze, implemented in a haze index (HI) that is derived from calculated light extinction. It is designed so that uniform changes in haziness described by this index correspond approximately to uniform incremental changes in perception, across the entire range of conditions, from pristine to highly impaired. The HI is expressed in deciview (dv) units by the following formulas:

$$\mathbf{HI = 10}\boldsymbol{ln}\mathbf{(b_{ext}/10)} \qquad [1]$$

$$\mathbf{HI =} \boldsymbol{dv}\mathbf{(b_{ext})} \qquad [2]$$

where b_{ext} represents total light extinction expressed in inverse megameters (Mm^{-1}).[12] Figure 1 below graphically shows the relationship between deciviews, light extinction and visual range which is a third metric used to describe visibility conditions.

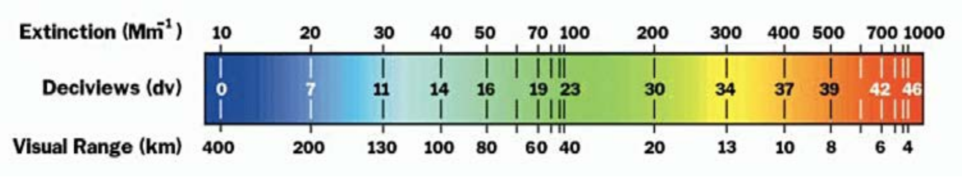

Figure 1. Comparison of the three visibility metrics (extinction, deciview and visual range)

The total light extinction (b_{ext}) is derived from IMPROVE monitoring data using the latest IMPROVE algorithm, which has been revised in 2007.[13] The original and revised formulae for calculating extinction from aerosol components combined with monthly climatologically

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[9] Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Program, EPA-454/B-03-005 September 2003.

[10] Trijonis, J. Visibility: Existing and Historical Conditions-Causes and Effects, Acidic Deposition: State of Science and Technology: Report 24. 1990.

[11] http://vista.cira.colostate.edu/improve/Publications/GrayLit/029_NaturalCondII/naturalhazelevelsIIreport.ppt

[12] Pitchford, M.L., Malm, W.C. Development and Application of a Standard Visual Index, Atmos. Environ., 28(5), 1049-1054, 1994.

[13] Pitchford, M.L, Malm, W. C, Schichtel, B., Kumar, N., Lowenthal, D., Hand, J. Revised Algorithm for Estimating Light Extinction from IMPROVE Particle Speciation Data, J. Air & Waste Manage, Assoc. 57, 1326 – 1336, 2007

averaged terms to reflect the scattering enhancement from relative humidity are provided elsewhere.[14,15] The analyses in this document are based on the revised algorithm.

1.1 First implementation period's tracking metric performance

The 2003 guidance states that the **best days** and **worst days** are those with the **20% lowest** and **20% highest** deciview values for the year, respectively, and that these annual estimates should be based on all valid measured aerosol concentrations during the calendar year and that for tracking purposes 5-year average annual values should be used. The exclusion of outliers was considered and the document states that by excluding measurements greater than 2 standard deviations from the mean of the 20% best and worst days, the change in the mean haze indices was less than 3%, based on an analysis of IMPROVE data collected during 1994-1998. Accordingly, the guidance noted that "the impact from a small number of days tends to average out when the visibility is examined on a deciview scale over a 5-year period", and that "it is important to include these extreme concentrations in the estimates for 5-year baseline and current visibility conditions because the impact from these events may be part of natural background and is thus reflected in the estimate for the target visibility levels." The 2003 tracking guidance describes a uniform rate of progress (URP) from baseline to estimated natural conditions in dv units to help States develop and then judge their progress goals. The uniform rate of progress line is also called the glidepath. Figure 2 illustrates the URP with the first implementation period's tracking metric. This general framework includes the tracking metric, baseline condition, glidepath, a modeled future year value and the natural condition endpoint.

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[14] Monthly average climatological f(RH) values for small and large sulfates/nitrates and sea salt, labeled fsrh, flrh and fssrh are available for each IMPROVE location at http://views.cira.colostate.edu/fed/DataWizard/Default.aspx, from the data set "IMPROVE Aerosol RHR (New Equation)."

[15] By design, the extinction estimated by the IMPROVE algorithm does not precisely characterize actual visibility conditions and instead is intended to represent an expected daily extinction associated with a suite of regionally representative measured aerosol concentrations. To account for the scattering enhancement effect of RH on hygroscopic aerosols, the algorithm does not use measured RH and instead uses monthly average climatological values. For tracking purposes, 5-year annual averages of daily deciviews of such extinction estimates are judged to better focus on the changes in emissions rather than changes in weather conditions.

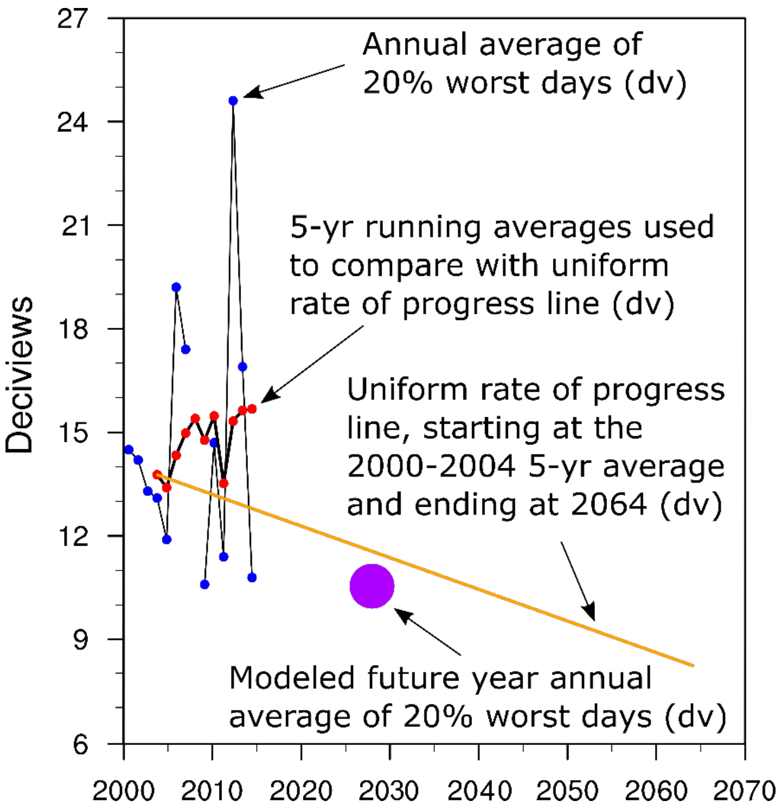

Figure 2. Diagram illustrating the elements of the first implementation period's tracking metric for the Sawtooth site

The 2003 guidance states that "given that progress is determined based upon long-term averaging, the EPA believes that it is unlikely that unusual events (e.g., large wildfires) will have a significant effect on observing progress in most cases," and that "the State should submit a technical demonstration if the State finds that unusual events (e.g., large wildfires), have affected visibility progress during the 5-year period.

1.2 Goals of an updated tracking metric

For many Class I areas, particularly in the Western U.S., the annual and five year averages of a haze index based on the **haziest days** of the year frequently result in a data series with very large year-to-year variability. Figure 3 illustrates the trend in these values for the haziest 20% of days for selected sites. It also includes a map showing the deviations of the current 5-year average from the glidepath with many locations displaying positive values (above the glidepath).

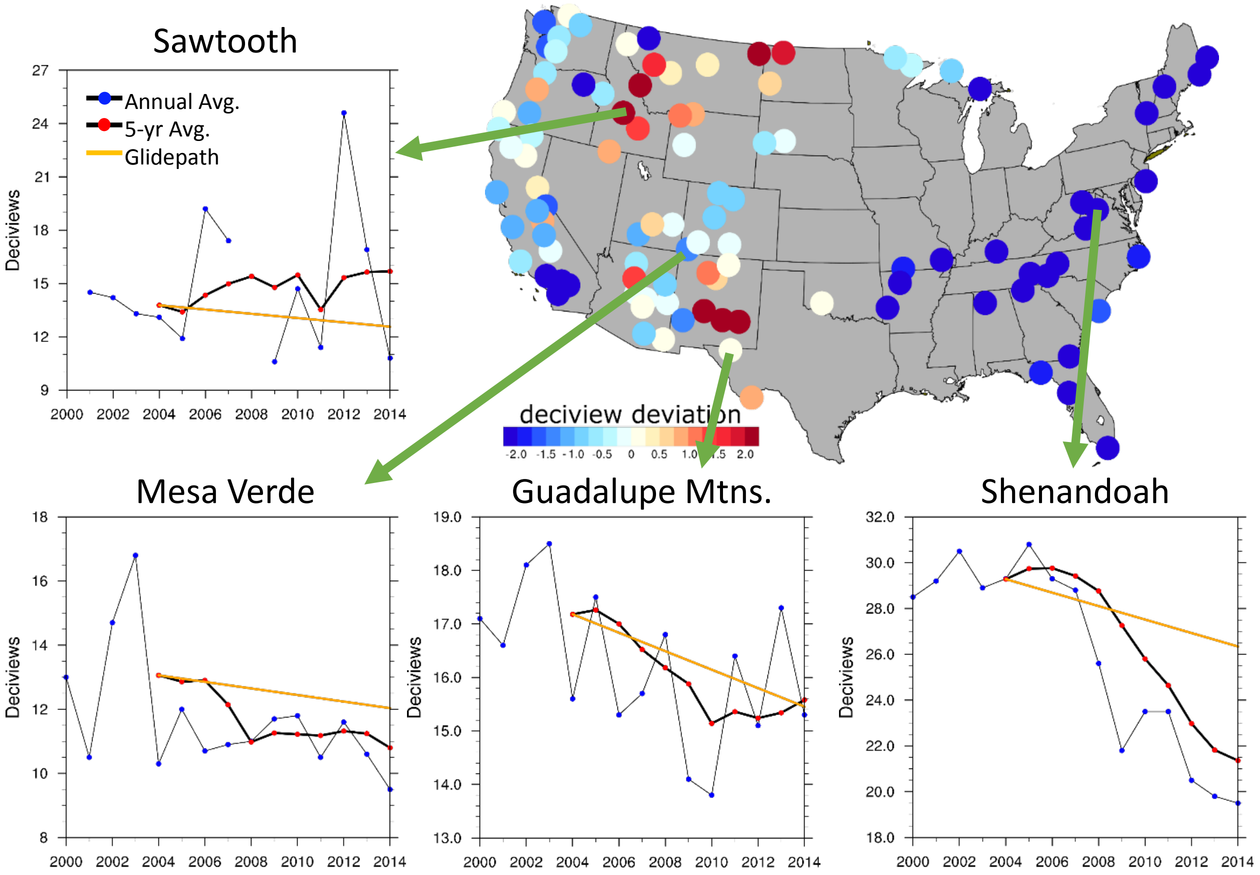

Figure 3. Glidepath deviation in deciviews for 20% haziest days from 2010-2014 and time series of glidepath and annual/5-year average deciview values for 20% haziest days from 2000-2014 at selected sites[16]

As described in Section 3, these days are often dominated by carbonaceous components (Organic Carbon Mass (OCM) and Elemental Carbon (EC)) or dust (fine soil and Coarse Mass (CM)) and thus appear to be due to uncontrollable wildfires or wind-blown dust events. These large and variable contributions from natural sources can frequently dominate the overall contributions to the haze index from all emission sources and make it difficult to discern improvements in anthropogenic impairment of visibility. Assessment of extinction budgets on the haziest days over the past 15 years also suggests that the impact of extreme events is larger and more pervasive than suggested by the aforementioned 1994-1998 analysis and that such contributions may not be adequately represented in the estimates of natural conditions currently used for the 2064 endpoint. The persistence and increasing inter-annual variability of extreme events was not anticipated in the original guidance.

Rather than focus on the haziest days per year, an updated approach to regional haze tracking metrics should better focus on days not affected by extreme episodic extinction (e3). Accordingly, the updated metric for the 20% "worst days" should not be significantly affected by

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[16] In this and most other national maps hereafter, only sites in the Continental U.S. are shown to maintain geographical continuity. Also, sites listed in Table 1 which do not meet the 3 year completeness criteria for 5-year averages remain on this and other national maps hereafter for reference. Graphics for all of the sites including those in Hawaii, Alaska, and the U.S. Virgin Islands can be found in Appendices G-J.

haze resulting from uncontrollable wildfires and dust events and therefore be more capable of tracking changes in controllable anthropogenic emission contributions.

Regional haze is described by light extinction calculated from ambient aerosol concentrations and climatological f(RH) plus a site-specific value for Rayleigh scattering. These temporally and spatially varying aerosols result from numerous anthropogenic and natural emission sources. The contributions to each chemical component of total light extinction can have different spatial patterns and can result from different emission sources. Thus, temporal patterns can vary among nearby monitoring sites.

The day-to-day and year-to-year variability in aerosol concentrations and associated light extinction can be very large, particularly for carbon and dust components.[17,18] These values which are often episodic tend to result from large wildfires and dust events whose emissions are very large – particularly in the Western U.S. - and whose influence can be far reaching. The contributions from such emissions account for a large amount of the daily variability and greatly complicate the tracking of regional haze resulting from anthropogenic emissions.

Analysis of extinction data in this document reveals that identification and removal (or adjustment) of the most extreme extinction from carbon and dust results in a time series with less interannual variability. Alternatively, focusing on the days without these influences provide similar results. Initial exploratory analyses demonstrated that this could be accomplished with screening levels derived from regional groupings of sites.[19] The revised analyses presented in this document are now performed on a site-specific basis which appears to provide more precise results and allows for spatial singularities in the general regional behavior.

For the analyses described in this document, various metrics have been considered to reduce the influence of e3. Those metrics which are directly based on the daily haze index are judged to be more desirable to those that present adjusted values of the site-specific haze index and became the focus of the analysis to update the first implementation period's tracking metric. The analyses in this document also explored alternative estimates of natural conditions and the document presents updates to the current estimates used by the EPA that may better conform to the revised tracking metric. The EPA guidance document related to this TSD indicates that these estimates may be used in SIP development. General suggestions for further analyses and modifications to these revised estimates of natural conditions are provided. The EPA may provide (or endorse) further revisions to the estimates of natural conditions in the future.

The remainder of this section describes the data, analyses, and rationale used to support the updated metrics approach to track progress in reducing regional haze. The presented results of these analyses might be best viewed as illustrative of a new generalized framework that is designed to focus on days with the highest anthropogenic impairment. This methodology can

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[17] Hand et al. Spatial and Seasonal Patterns and Temporal Variability of Haze and its Constituents in the United States: Report V June 2011.

[18] Jaffe, D, Hafner, W., Chang, D., Westerling, A., Spracklen, D. Interannual Variations in $PM_{2.5}$ due to Wildfires in the Western United States, Environ. Sci. Technol. 42, 2812–2818, 2008.

[19] Initial EPA analyses to illustrate and explore concepts used nine National Climatic Data Center (NCDC) regions for CONUS. Other potential groupings include 28 regions used in IMPROVE reports, and 15 zones described by Tombach (2008) which were established using 1999-2003 data with the original IMPROVE algorithm. http://www.wrapair.org/forums/aamrf/projects/NCS/Haze_Sensitivity_Report-Final.pdf.

continue to evolve as updates to the data and revised estimates of natural conditions become available.

The results are first presented using example illustrations for selected sites to contrast the updated progress metrics approach with the first implementation period's approach. The examples include locations with large and episodic influences from smoke, dust and those predominantly affected by anthropogenic emissions. Results for all sites in the Continental U.S. (CONUS) are portrayed on national maps to show spatial patterns and regional consistency. Graphs for all individual sites are included in Appendices G-J. Sensitivity analyses are also provided which contrast the alternative approaches used to identify episodic and routine natural contributions as well as alternative indicators of daily visibility used to establish the best and worst 20% of the days per year.

2 Elements of an updated metric to track regional haze

There are several elements of the approach to establish a metric for tracking regional haze, all of which start with the calculation of daily extinction from aerosol measurements and an associated daily haze index.[20] The next element is an indicator of daily conditions more reflective of impairment from anthropogenic contributions. The development of this updated daily visibility impairment indicator depends on an estimate of natural contribution and the resulting split between anthropogenic and natural; and a ranking approach by which days are selected to characterize the best and worst days per year. The following section describes the identified elements.

2.1 Split of total extinction into natural and anthropogenic fractions

Estimates of the daily contribution from natural sources are an important part of the new framework and are needed to better characterize anthropogenic impairment and its estimated portion of total extinction. In the analysis described in this document, natural contribution to total extinction and the daily HI have two components: an e3 event component and a routine natural component.

2.1.1 Extreme episodic extinction

To identify days with potential contribution from wildfire and dust events, statistically derived thresholds are established for each IMPROVE site by identifying the year from 2000-2014 with the lowest 95th percentile for carbon and lowest 95th percentile for dust. The years with the lowest 95th percentiles are used to characterize the "least extreme years" and are presumed to have the lowest impact from wildfire and dust events.[21] Daily extinction values for the entire 2000-2014 period with carbon and/or dust extinction above the 95th percentile values from these least extreme years are then assumed to be associated with an e3 event and added to the natural fraction of the extinction budget. Alternative methods to estimate e3 are discussed in Section 4.

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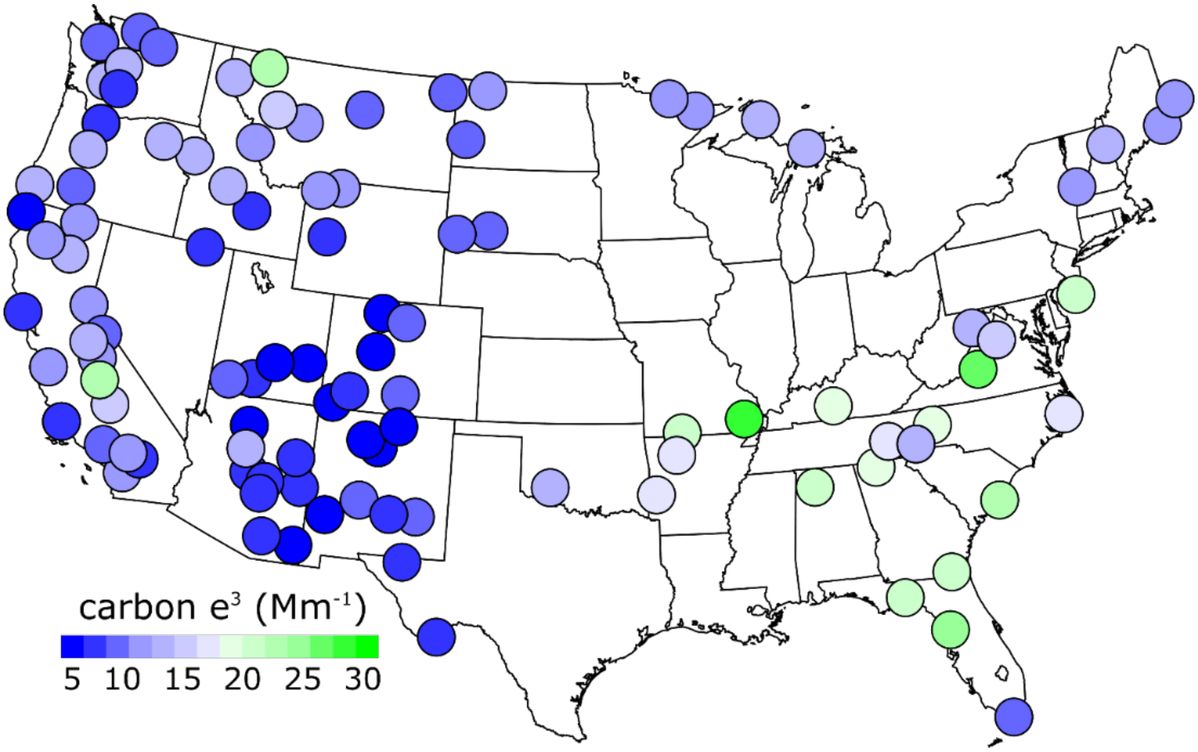
[20] Daily extinction from aerosol measurements may include substitutions for some missing components in accordance with established IMPROVE program data handing protocols.

[21] An alternative statistic not used in this analysis, but which might better characterize years with the least impact from wildfire or dust events, could be the average extinction above the 95th percentile. This would also consider the variability among the unusual annual extinction values.

For all of the presented analyses, an episodic contribution attributed to e3 is derived from the measurement derived extinction values in a nationally consistent manner.[22] Two estimates are established – one for contributions from wildfires, associated with unusually high extinction values for carbonaceous aerosols, and a second for contributions from dust events associated with atypical extinction values from fine soil and CM. The estimates of e3 are shown to often represent a dominant part of the daily extinction, particularly in the Western U.S.

The presented method to identify e3 is based on extinction associated with carbon (=OCM+EC) and dust (=fine soil+CM) instead of the 4 individual components (OCM, EC, fine soil and CM). For carbon, this approach is used to reduce the chance of misclassifying a day with high EC without high OCM as predominantly affected by natural contribution. For dust, the combined value is judged to be more robust than the individual components due to strong correlation between fine soil and CM.

The site-specific thresholds used to identify the most extreme contributions from carbon and dust are assumed to be associated with wildfire and dust events. The minimum annual 95th percentiles among 2000-2014 used to describe the clearest years with the least impact from wildfire and dust are shown in Figure 4 for carbon and Figure 5 for dust.[23] With these thresholds, at least 5% of the carbon and dust extinction values per year are labeled as e3.



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[22] An approach which examines the variability among measured aerosol components and makes judgements on the ambient concentrations (instead of the calculated extinctions) was not pursued at this time.

[23] Two alternate thresholds were also considered: one based on a regional 95th percentile and another based on the 15-year site-level median. These are discussed in Section 4.1 where they are compared to the use of the minimum site level 95th percentile.

Figure 4. Site-specific threshold for screening extinction values of carbon from extreme episodic fire events

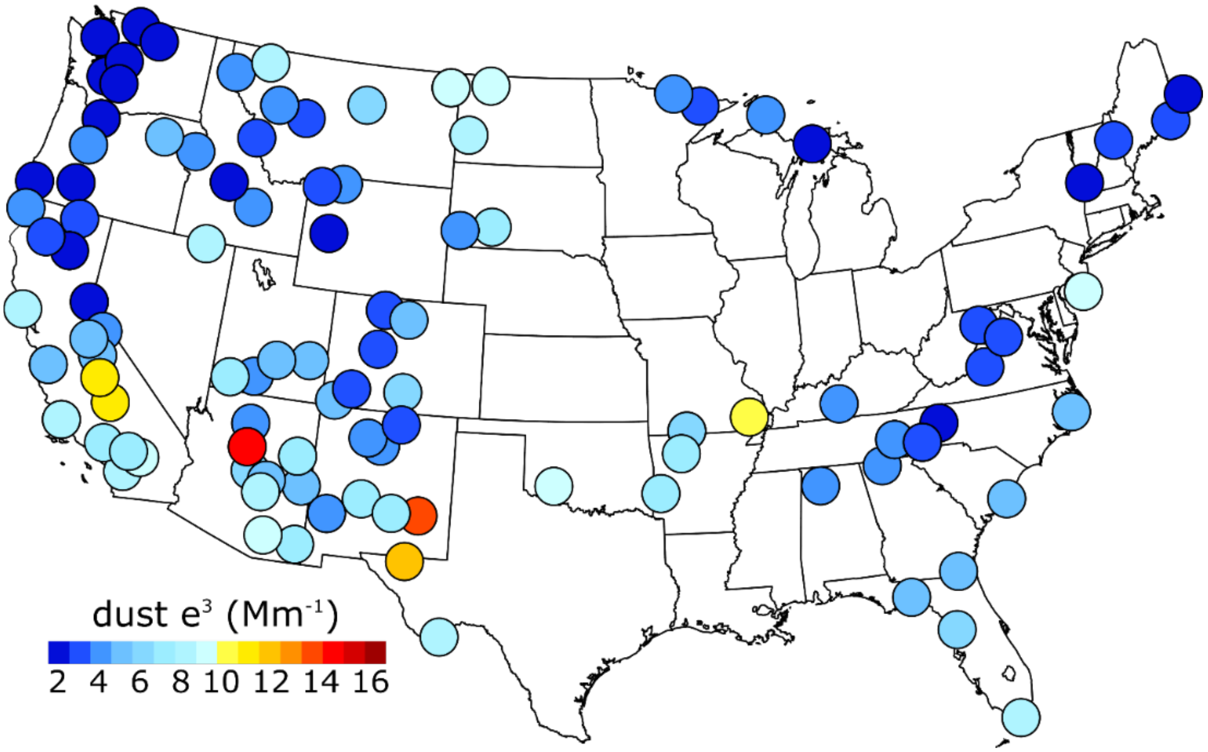

Figure 5. Site-specific threshold for screening extinction values of dust from extreme episodic events

2.1.2 Routine natural contribution

For the bulk of the analyses described in this document, the Trijonis-based NCII estimates of natural conditions for aerosol components are used as the starting point to produce the routine portion of the daily natural contribution.[24] Although it is recognized that the Trijonis estimates are quite uncertain, they are used in these analysis as the best currently available information to describe routine contributions. Rather than allow every day to have the same natural contribution as the annual average Trijonis based-value, however, daily estimates of the routine portion of the natural contribution by aerosol component are created. These are derived by the simple assumption that they vary in direct proportion to the non-episodic portion of their measurement based daily extinction.[25] The combination of estimated e3 and routine natural conditions are then used to establish daily values of total natural contribution. These also become the basis for revised natural condition values.

The routine natural contributions are derived as the sum of extinction from the following aerosol components:

1) All sea salt (as with the NCII work).

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[24] http://vista.cira.colostate.edu/improve/Publications/GrayLit/029_NaturalCondII/naturalhazelevelsIIreport.ppt.

[25] Alternative assumptions are considered in Sections 4 and 5.

2) Daily amounts of ammonium sulfate and ammonium nitrate which are proportional to their measurement-based extinction and whose annual averages equal the average NCII values.[26]

   No ammonium sulfate or ammonium nitrate is attributed to extreme fire or dust events, although it is known that fires can produce some SO_2 and NO_x emissions. This approach also assumes the same f(RH) effect on the disaggregated NCII average values.

3) Daily amounts of carbon and dust which are proportional to the non-e3 portions of their measurement-based extinction and whose annual averages equal the non-e3 portion of their average NCII values.

   For sulfate, nitrate, carbon and dust, the daily routine natural contribution extinction values $\mathbf{a}_{\mathrm{RNC}}$ are thus defined as:

$$\mathbf{a}_{\mathrm{RNC}} = \bar{\mathbf{a}}_{\mathrm{NCII}} \times \left(\frac{\mathbf{a}'}{\bar{\mathbf{a}}'}\right) \qquad [3]$$

   where $\bar{\mathbf{a}}_{\mathrm{NCII}}$ is the average NCII value, for sulfate and nitrate, $\mathbf{a}'$ and $\bar{\mathbf{a}}'$ are the daily and annual average aerosol extinction values and for carbon and dust, $\mathbf{a}'$ and $\bar{\mathbf{a}}'$ are the non-e3 portions, respectively.[27]

   For each of the four aerosol components, when $\bar{\mathbf{a}}_{\mathrm{NCII}}$ is greater than $\bar{\mathbf{a}}'$:

$$\mathbf{a}_{\mathrm{RNC}} = \mathbf{a}' \qquad [4]$$

   Daily routine natural contributions for the individual carbon and dust constituents (OCM, EC, fine soil and CM) are constructed from the derived routine contributions of the non-e3 portions of the carbon and dust values. These would be used for construction of extinction budgets, as described in section 3. Here, these are assumed to be proportional to their individual measurement-based extinction and whose annual averages similarly equal their average NCII extinction.

Together with the site-specific value for Rayleigh scattering, the sum of the routine and episodic components provides a “seasonalized” distribution of total daily natural contributions. From these, daily values in deciview units and annual average estimates for the worst 20% of days are produced and then long-term 15-average values are derived to estimate natural conditions.

The daily natural contributions and corresponding estimated natural conditions will be different for particular subsets of days per year. They may be the highest for the haziest days when those days result from large natural contributions, including e3 contributions. In contrast, the natural conditions may be lower for the most impaired days.

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[26] An alternative method to produce daily b_{ext} due to routine natural conditions assumes that the $PM_{2.5}$ component mass associated with natural contribution is proportional to the corresponding measured component mass. In this way, the routine natural contribution to extinction would be calculated from those mass values and thus would consider the difference in extinction and f(RH) as a function of concentration, in accordance with the new IMPROVE algorithm. This would allow natural contributions to be more efficient for scattering light on days when the natural contribution to $PM_{2.5}$ component concentrations are higher.

[27] Section 4 discusses an alternative approach in which these calculations are performed in step 3 using OCM, EC, fine soil and CM together with the implications of such an alternative. Section 5 presents a second alternative approach which makes use of source apportionment modeling.

2.1.3 Anthropogenic contribution

After the daily episodic and routine natural contributions have been identified, for the purposes of this document the remaining portion of the total light extinction estimated from the IMPROVE measurements of each PM component concentration is considered to be the anthropogenic contribution to that PM component.[28] Clearly, the accuracy of the split and the component specific extinction budgets is dependent on the availability of appropriate data and the assumptions associated with the data handling methodology. This issue will be discussed more in Section 4.

2.2 Indicators of daily visibility impairment

The next two steps in the construction of a tracking metric involve the identification of the daily visibility impairment indicator and its ranking among days. There are two primary indicators of daily visibility impairment which have been considered in this analysis: total extinction expressed as the HI and anthropogenic impairment as quantified by the perception-based haze index described in the EPA guidance. Anthropogenic impairment represents the incremental amount of total extinction relative to its natural contribution. This describes the impairment due to anthropogenic contributions. Two additional extinction-based indicators which specifically focused on the removal of e3 were also considered and are discussed as part of a sensitivity analysis in Section 4. Each of the indicators are described more precisely using mathematical notation below.

2.2.1 Anthropogenic impairment

The most straightforward way to focus on anthropogenic contribution is with an indicator which directly describes this impact. This indicator is calculated as the incremental amount of total impairment relative to natural contributions in deciview units. This varies from day-to-day and its perception to the human eye depends on the level of extinction and quantity of natural contribution. For example, the ability to perceive 10 Mm^{-1} relative to a background of 10 Mm^{-1} is greater than its comparison to a background of 100 Mm^{-1}. The identification of the daily natural contributions including e3 is necessary to estimate the anthropogenic impairment.

With any natural contribution, the incremental level of anthropogenic impairment is less than the deciviews of total extinction. The most impaired days will have less extinction than the haziest days, particularly when there is a large contribution from natural sources. For locations with smaller contributions from e3, however, the most impaired days will closely track the haziest days. Such is the generally case for the Eastern U.S. In the Western U.S., the most impaired days will typically not be influenced by e3 and will nicely track changes in extinction associated with anthropogenic sources.

Anthropogenic impairment, or more simply impairment **(I)** is defined as the perceptible portion of extinction from controllable emissions relative to natural conditions, and whose computation is equivalent to the difference between total and natural extinction, each expressed in deciviews.

When total extinction is estimated as $\mathbf{T_i}$, natural extinction estimated as $\mathbf{N_i}$, and anthropogenic extinction estimated as $\mathbf{A_i}$ then this visibility impairment indicator is defined as:

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[28] Anthropogenic contribution as derived in this document could include international contribution.

$$\mathbf{I_i = \mathit{dv}(T_i) - \mathit{dv}(N_i)} \qquad [5]$$

Mathematically, this is equivalent to:

$$\mathbf{I_i = 10 \times \mathit{ln}(T_i/N_i)} \qquad [6]$$

$$\mathbf{I_i = 10 \times \mathit{ln}(1 + [A_i/N_i])} \qquad [7]$$

Thus, ranking of $\mathbf{I_i}$ is the same as the rankings of $[T_i/N_i]$ or $[A_i/N_i]$.

2.2.2 Extinction-based indicators

The HI is an extinction based indicator that is expressed as a deciview value. The two alternative extinction-based indicators considered in this analysis are best expressed in Mm^{-1} units.

The alternative extinction-based indicators of daily visibility impairment are designed to describe an absolute amount of extinction associated with anthropogenic controllable emissions which is termed A_i. Like the impairment indicator, their numerical values may only be intended to describe days for which the daily HI are eligible to be considered as one of the worst (or best) visibility days for tracking purposes.

Starting with total extinction, $\mathbf{T_i}$, in Mm^{-1} units, an adjusted value is produced to better reflect the portion associated with $\mathbf{A_i}$. Two variations are considered: 1) only e3 has been considered. When converted to deciviews, only to facilitate comparison to the HI, this daily indicator $\mathbf{V_i}$ is calculated as:

$$\mathbf{V_i = \mathit{dv}(T_i - e3_i)} \qquad [8]$$

In this case, T_i - $e3_i$ does not account for the routine contributions from natural sources or Rayleigh scattering and thus would be greater than A_i.

Second, the adjusted extinction method includes a further removal of the routine natural contribution from **T**, and then this daily indicator is calculated as:

$$\mathbf{V_i' = \mathit{dv}(T_i - N_i)} \qquad [9]$$

where N_i is a site-specific value of total natural contribution that includes $e3_i$ and Rayleigh scattering.

This is equivalent to:

$$\mathbf{V_i' = \mathit{dv}(A_i)} \qquad [10]$$

A further variation to such an adjustment to total extinction might only consider the portion associated with certain aerosol components such as sulfate and nitrate to represent A_i. These have not been considered in this document.

Although the individual terms included in $\mathbf{V_i'}$ and $\mathbf{I_i}$ are the same, the order of the arithmetic is different and thus they result in different numerical values and may result in different rankings, i.e. the magnitude and relative distribution of their daily values can be different according to the varying amounts of e3 and routine natural contributions. This contrast between the impairment and anthropogenic sorts is discussed in more detail in Section 4.

2.3 Selection of the best and worst days and tracking metric computation

The next step in the approach to establish the best and worst days involves the ranking of daily impairment values from best to worst. Sorting each impairment indicator generally results in a different ranking of the days and thus different selections of the best and worst 20% of the days per year. Total extinction is used to sort and rank the days per year with the first implementation period's approach. This is used both for the purpose of selecting the best days and the worst days. In this case, the best visibility days represent the clearest days. The first implementation period's sort approach also results in the haziest days as the worst days.

With the approach recommended in the 2016 EPA guidance document, daily impairment is the indicator used to rank the days per year for the purpose of selecting the worst days.[29]

The IMPROVE approach to define percentiles for selecting the top and bottom 20% of days from ranked data has been used for this analysis. This also conforms to the EPA's approach to establish percentiles for national ambient air quality standards.

Thus, if the number of observations is **n**, and if we establish the following integer values defined as:

$$\mathbf{n20 = integer\ (0.2*n)} \quad [11]$$

$$\mathbf{n80 = integer\ (0.8*n) + 1} \quad [12]$$

and if the daily impairment values are ranked from low to high, then the "best" 20% of the days are those with ranks <= "n20" and the "worst" 20% of the days are those with ranks >= "n80." For example, if there are 114 available monitored days, the 20% "best" day set has 22 members and the 20% "worst" day set has 23 members.

2.3.1 Computation of the tracking metric

For each daily visibility indicator, the tracking metric for worst visibility days is derived by sorting the daily values, selecting the highest 20% per year and constructing an average value. Next, a 5-year average is produced. Thus the revised tracking metric depends on the estimate of daily natural contribution, the numerical values of the daily visibility indicator and their relative ranking for the year.

2.3.2 How to present the visibility indicator

As explained in the 2016 EPA guidance, the best or worst days should be presented as the average of their daily haze index for those selected days according to ranking of the daily visibility indicator. The indicator to best characterize worst days can be different than the daily indicator to characterize the best or clearest days. In this manner, the HI is retained without modification for data reporting and visibility characterization purposes.

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[29] If impairment were used to produce the best days, large natural contributions could be included and the resulting trends could reflect changes in wildfires and dust events rather than changes in anthropogenic contributions.

2.3.3 Appropriate units for the metric

As recommended by the EPA, deciviews are the units which will be used for tracking regional haze. This is the case both for the best and for the worst days. However for intermediate steps of the process to create the metric, different indicators and sometimes different associated units have been used.[30] Moreover, those alternative indicators and units are used for other purposes in understanding regional haze and addressing its causes. This is discussed elsewhere in this support document.

In particular, total extinction, natural conditions, and impairment can each be appropriately described in deciview units. Indicators that characterize part of total extinction should be presented in Mm^{-1}. These include the estimated anthropogenic portion, subsets such as sulfate + nitrate, as well as total extinction without e3, and would be best presented in an extinction budget framework. This is discussed further in Section 3.

Finally, it is suggested that the measurement-based calculations of the daily HI be rounded to one decimal place. Annual and 5-year averages of the 20% worst and best days can be presented to 2 decimal places. This is the way these values are presented in this analysis. See Appendix A for a summary of the databases and data handling conventions used for the analysis.

2.4 Recommended metrics

2.4.1 Tracking the "clearest" days

Consistent with the first implementation period's tracking metric, days within the lowest 20% annual values of the daily HI are used to represent the clearest days.[31] The current "p10" estimate of natural conditions can continue to be used as a reference value. Section 6 which presents these data includes a discussion of the clearest days.

2.4.2 Tracking the "worst" days

Anthropogenic impairment, **I**, defined as:

$$\mathbf{I} = \boldsymbol{dv}(\textbf{total extinction}) - \boldsymbol{dv}(\textbf{natural contribution}) \qquad [13]$$

is the suggested approach to identify the worst days in order to de-emphasize contributions from extreme natural events and to refocus on contributions from controllable emissions. Consistent with the first implementation period's tracking metric, however, the visibility values for the most impaired days are not presented in terms of the calculated values for **I**, but instead are presented in terms of their daily haze index, HI. This literally is "visibility on the most impaired days."

2.5 Glidepath construction

The glidepath is the line which describes a site-by-site URP between baseline visibility conditions for the worst 20% of the days and the corresponding estimate of natural conditions.

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[30] Total extinction or equivalently, its HI in deciviews, is used to sort/rank the days per year for the purpose of selecting the "best" and "worst" days.

[31] If impairment were used to produce the best days, large natural contributions could be included and the resulting trends could reflect changes in wildfires and dust events rather than changes in anthropogenic contributions.

According to the Regional Haze Rule (RHR), a glidepath is not needed for tracking of the best days.[32]

For both the old and updated metrics, the glidepath is used to help track a uniform rate of progress from current to natural conditions. In each case, the glidepath starts from a base period value (e.g. derived from the five-year average of the annual tracking metric values) and ends in 2064 at a value which represents visibility conditions without any contribution from controllable emissions.

2.5.1 Baseline conditions

For the analyses in this document, baseline conditions are derived from the 2000-2004 annual average value of the 20% best and worst day tracking metric. With the first implementation period's approach, baseline is derived from the 20% haziest days per year. With the updated approach, this is based on the most impaired days. As was described in the 2003 EPA guidance, a minimum of three complete years are required.[33] For the analyses presented in this document, sites lacking such a baseline are not included. Examples are provided in Section 3.

2.5.2 The 2064 endpoint

The 2064 endpoint represents estimated average natural visibility conditions for the worst 20% of the days represented by the tracking metric. For the haziest days, an estimate called the "p90" value is currently used by the EPA and by the IMPROVE program. This is a site-specific value derived by adjusting 2000-2004 aerosol concentrations to simulate the distribution of natural haze values with the annual mean for each species being equivalent to the Trijonis estimated natural concentration for that species.[34] Daily natural haze values matching the 20% worst days are used.[35]

To estimate natural conditions for the most impaired days, the approach described in Section 2.1 is used. The analysis described in this document shows that the variability of natural contributions, particularly the portion associated with e3, may have changed during the 2000-2014 period of analysis. Therefore, a 15-year average annual value of estimated natural contributions on the most impaired days is used in this document for the revised site-specific natural condition estimates. This estimate may also be sufficient to describe natural conditions in future years, but to the extent that natural contributions and in particular the e3 portion changes, the number of included years for these estimates may require adjustment.

2.6 Summary of draft steps to establish updated metric

- Estimate e3 using statistically derived site-specific thresholds
- Establish daily estimates of routine contribution using NCII (Trijonis-based) values

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[32] A baseline for judging degradation in the best days is needed even though a glidepath to natural conditions for the best days is not needed.

[33] Baselines for sites lacking 3 complete years are established in coordination with EPA and the IMPROVE program.

[34] Copeland et al. Regional Haze Rule Natural Level Estimates Using the Revised IMPROVE Aerosol Reconstructed Light Extinction Algorithm, 2008.

[35] Analogously, a "p10" natural condition value matching the 20% best days has also been produced, although it is not needed for a glidepath.

- Derive daily values of extinction and anthropogenic impairment
- For best and worst 20% of days per year, produce annual and 5-yr averages for clearest and most impaired days, including updated baseline values
- Develop revised estimate of average natural conditions to be used as the 2064 endpoint using revised daily natural conditions values that match the most impaired days
- Construct updated glidepath using new baselines and 2064 endpoints
- Prepare extinction budgets for the anthropogenic and natural portions to guide interpretation of contributing sources and to help identify potential issues associated with input data

3 Results of the updated tracking metric

There are three broad sets of results for the updated tracking metric. The first set includes the characterization of the split of total extinction into natural and anthropogenic fractions and the presentation of those results on a daily, seasonal and annual basis into an extinction budget for the individual aerosol components. Contrasts are provided between the haziest days and most impaired days identified by the updated tracking metric methodology. Second are new estimates for natural conditions which conform to the derivation of the updated tracking metric. Finally, presentation of the updated tracking metric expressed as 5-year average values are included, with comparisons to the updated glidepath. Contrasts to the behavior of the first implementation period's metric which focuses on the haziest days are similarly provided. The information in each sub-section are provided for example sites and using maps to provide a national overview. Appendix E provides a summary table of data shown in the national maps. Appendix G provides a selection of key graphs for all sites.

The results in Section 3 will show that for many sites in the Western U.S. affected by wildfire and dust events, deviations from the glidepath for the 2010-2014 average visibility conditions is closer to zero or negative with the updated tracking metric. At many other sites, the updated metric performed very similarly to the first implementation period's approach based on the haziest days. The latter sites include most of the Eastern U.S. and southern California which remain well below the glidepath, and sites in the Midwest U.S. which remain near or above the glidepath with both metrics. The updated metric also exhibits greater regional consistency in the glidepath deviations, particularly in the Western U.S. where adjacent sites show similar behavior and are consistently below the glidepath.

3.1 Extinction budgets

The set of aerosol-based extinction that comprise total haze is called the extinction budget. Because these aerosols result from particular emission sources, the budget is helpful to identify the suite of potential contributing sources (e.g. sulfate aerosol contribution is associated with SO_2 emissions). With the impairment framework and the split into anthropogenic and natural contribution, the extinction budget of total haze is likewise separated into an estimated anthropogenic and natural portion. Thus a more useful anthropogenic extinction budget for the most impaired days is provided which can both guide the identification of sources for control and help judge the results of anthropogenic emission changes.

The daily extinction budget characterizes the aerosol contributions to total haze. For these characterizations of total aerosol-based extinction, anthropogenic and natural contribution are not distinguished and Rayleigh scattering is not included. The intra-year variability of the daily budgets can identify seasonality in the total aerosol based extinction and its composition. The seasonality of the 20% haziest and the 20% most impaired days for calendar year 2012 is compared both on a national scale and at example sites. Next, average extinction budgets are presented with pie charts for all sites to contrast the haziest and most impaired days.

3.1.1 Seasonality of the worst days

The most impaired days can occur in different portions of the year than the haziest days. For those locations affected by e3 including Sawtooth (SAWT1), Mesa Verde (MEVE1) and Guadalupe Mountains (GUMO1), Figure 6 shows that the haziest days are often or even predominantly confined to the summer/fall (wildfire) or spring/summer (dust) seasons. In contrast, the most impaired days tend to be more widely distributed throughout the year. This is first illustrated for a few example sites during 2012 (Figure 6), followed by national maps (Figures 7 and 8) which characterize the fractions of days during the winter, spring, summer and fall climatological seasons.[36] In addition to the seasonal distribution of selected days, it is also worth noting that the total extinction on the most impaired days is much lower with a different mixture of aerosol components. When split further into anthropogenic and natural fractions (see Section 3.1.3), such budgets can help to better focus on the extinction associated with potential contributing emissions.

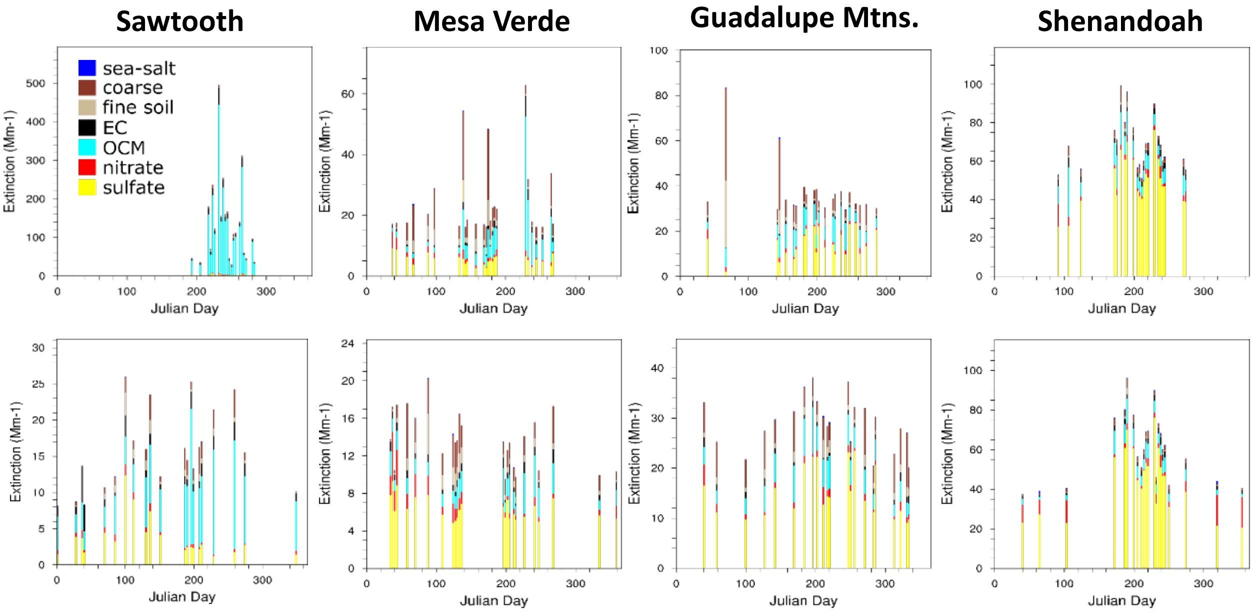

Figure 6. Annual extinction budget time series of days selected as 20% haziest (top row) and 20% most impaired (bottom row) in 2012 at selected sites

Figure 7 shows that the 20% haziest days in 2012 frequently occur during the summer (red) and fall (orange) which coincide with wildfire events in the intermountain west; and spring (green) in

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[36] Winter=December, January, February; spring=March, April, May; summer=June, July, August; Fall=September, October, November.

the southwest, while there is a relatively small fraction of the haziest days in the winter (blue) for most locations. Figure 8 shows the different distribution of days selected as the 20% most impaired, with a larger prevalence of winter or spring days for many locations.

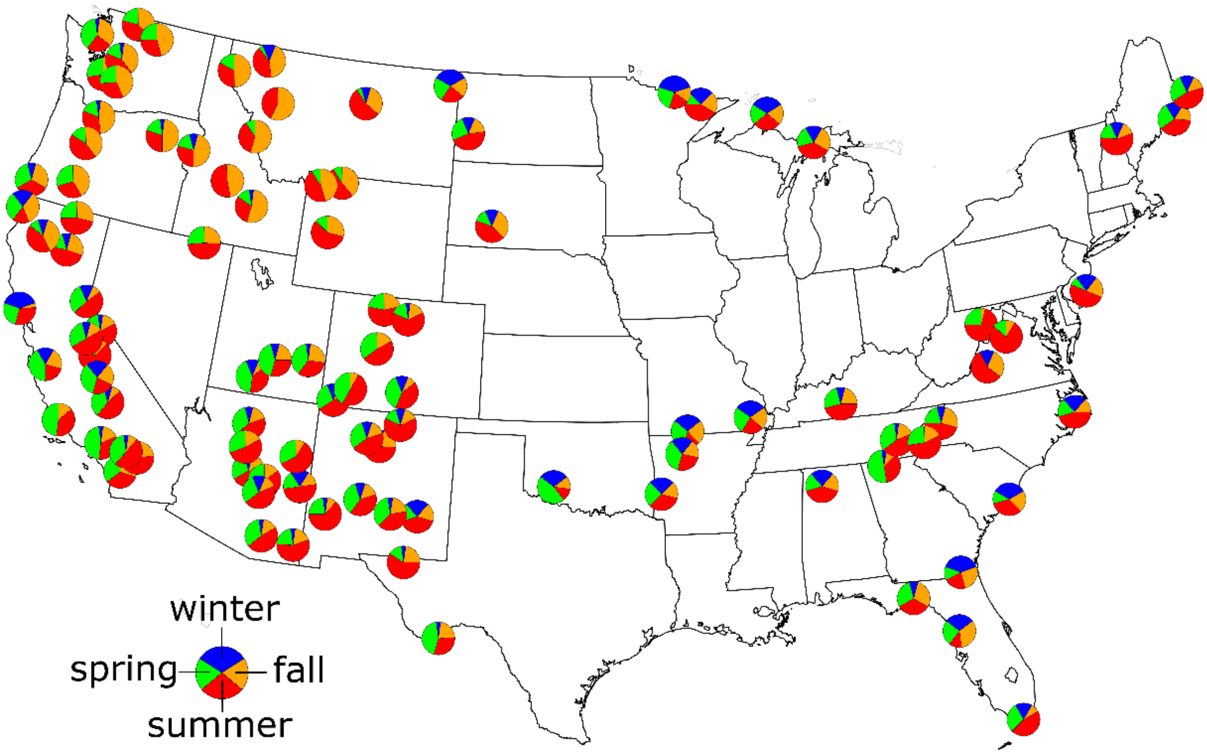

Figure 7. Seasonality of days in 2012 selected as the 20% haziest

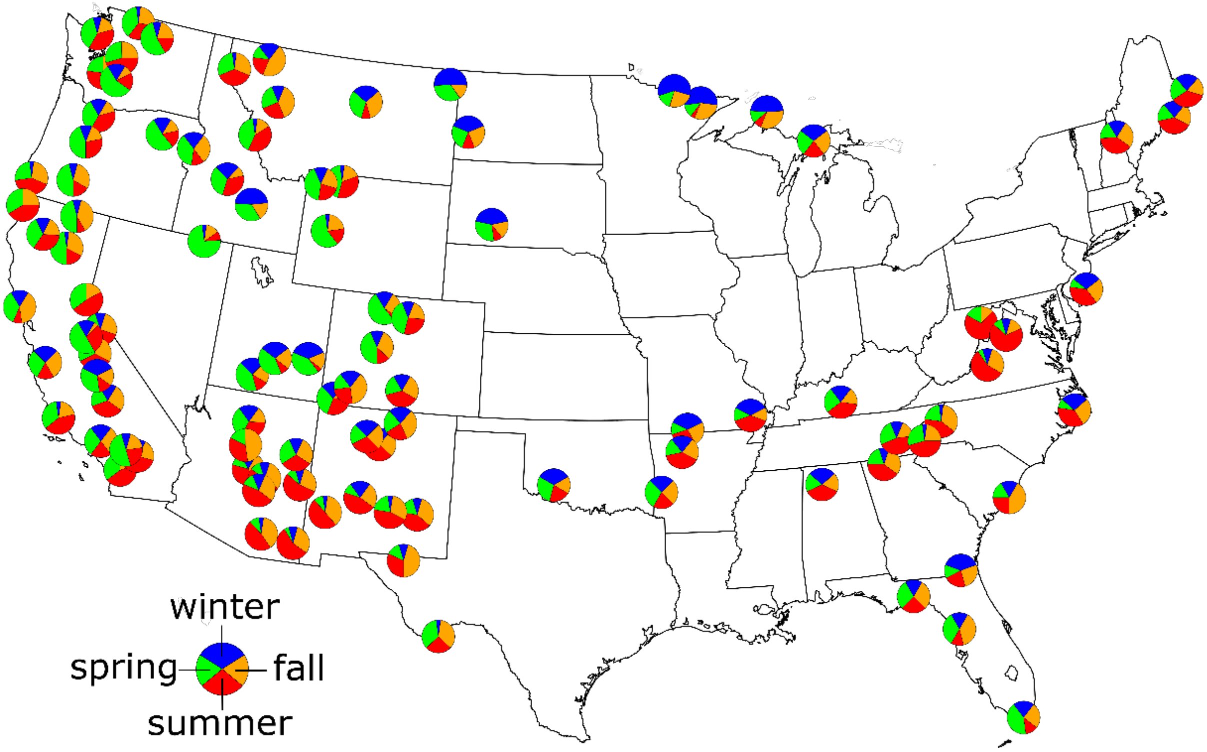

Figure 8. Seasonality of days in 2012 selected as the 20% most impaired

3.1.2 Comparison of extinction budgets for the 20% haziest and 20% most impaired days

Figures 9 and 10 show that the average extinction budgets for the 20% haziest and most impaired days in 2000-2004 can be substantially different. The same is true for 2010-2014 as shown in Figures 11 and 12. The pie chart format helps show the relative contribution among aerosol components and the spatial coherence in those proportions. The average extinction for the 20% haziest days in 2000-2004 is composed largely of sulfate and OCM in the Eastern U.S.; sulfate, nitrate, and OCM in the upper Midwest and Southern California; and a mixture of components (including sea salt) in the Western U.S. For the 20% most impaired days, the fractions of sulfate and nitrate are higher for all sites, mainly replacing OCM, fine soil/CM and sea salt (at coastal sites in the Western U.S.). The size of the pies are also smaller on the most impaired days, particularly in the Western U.S., indicating that the average baselines and glidepaths are also lower.

In 2010-2014, Figure 11 shows that carbon and or dust at many locations in the Western U.S. continue to represent large portions of the average budget on the haziest days. In contrast, Figure 12 shows that sulfate and nitrate become more important contributors at those locations on the most impaired days. Based on the size of the pies, Figure 12 also shows that the Eastern U.S. generally has the highest impairment. Sulfate and nitrate are generally considered more controllable than components such as fine soil/CM, and sea salt as well as OCM on the haziest days, all of which can be dominated by natural emissions. Thus, the updated metric more effectively identifies components affecting anthropogenic impairment. As shown in Figure 9 and 10, the size of the pies are also smaller on the most impaired days during 2010-2014 indicating that the average visibility is also better on the most impaired days compared to the haziest days.

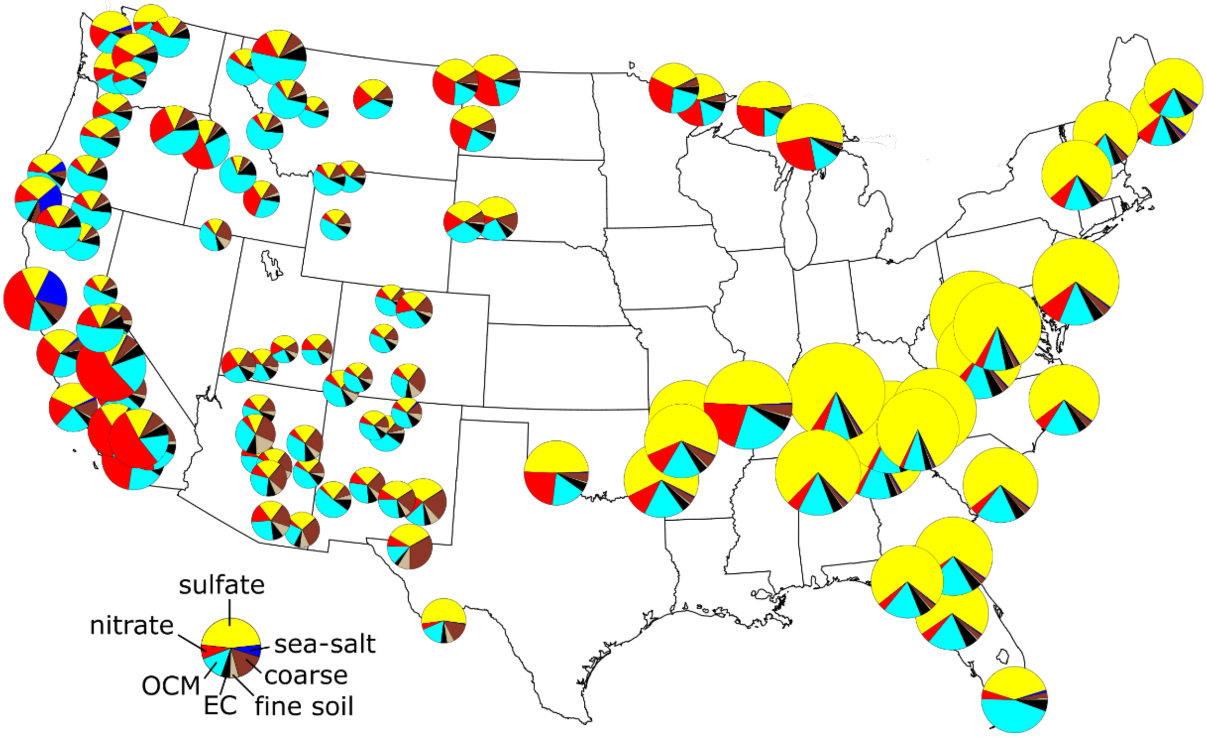

Figure 9. Average extinction budget on the 20% haziest days sized in proportion to the total extinction, 2000-2004

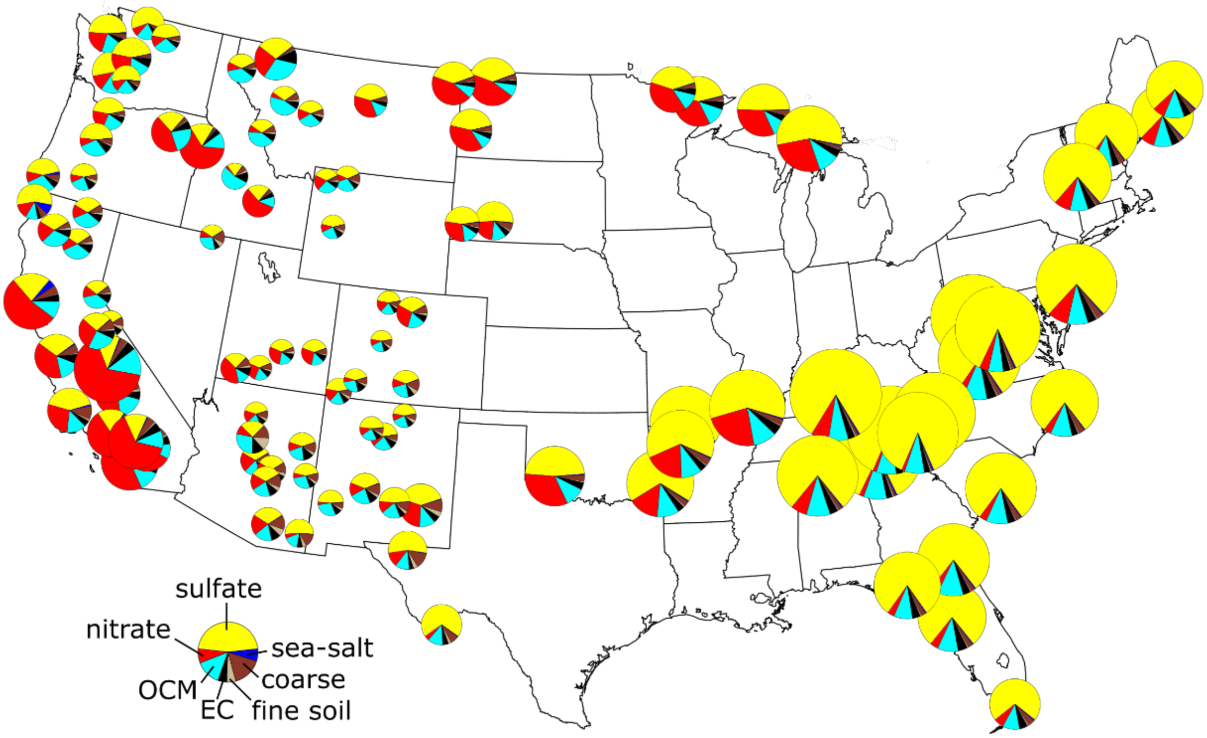

Figure 10. Average extinction budget on the 20% most impaired days sized in proportion to the total extinction, 2000-2004

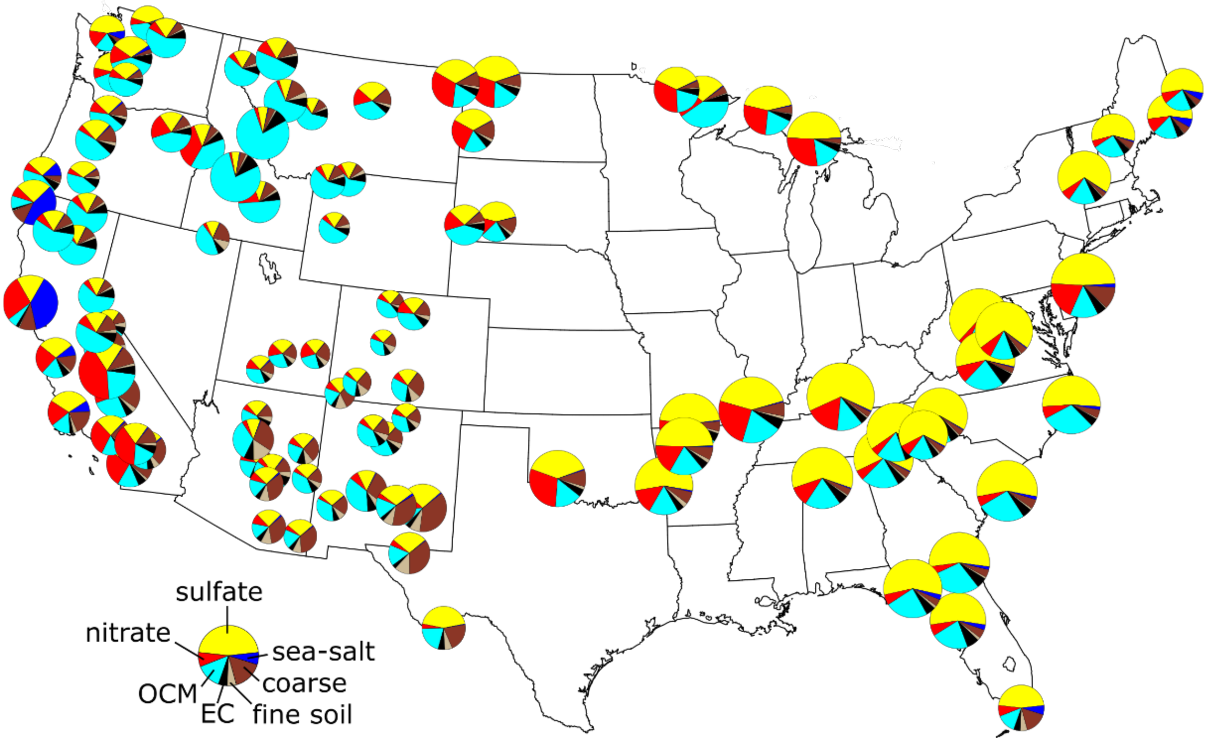

Figure 11. Average extinction budget on the 20% haziest days sized in proportion to the total extinction, 2010-2014

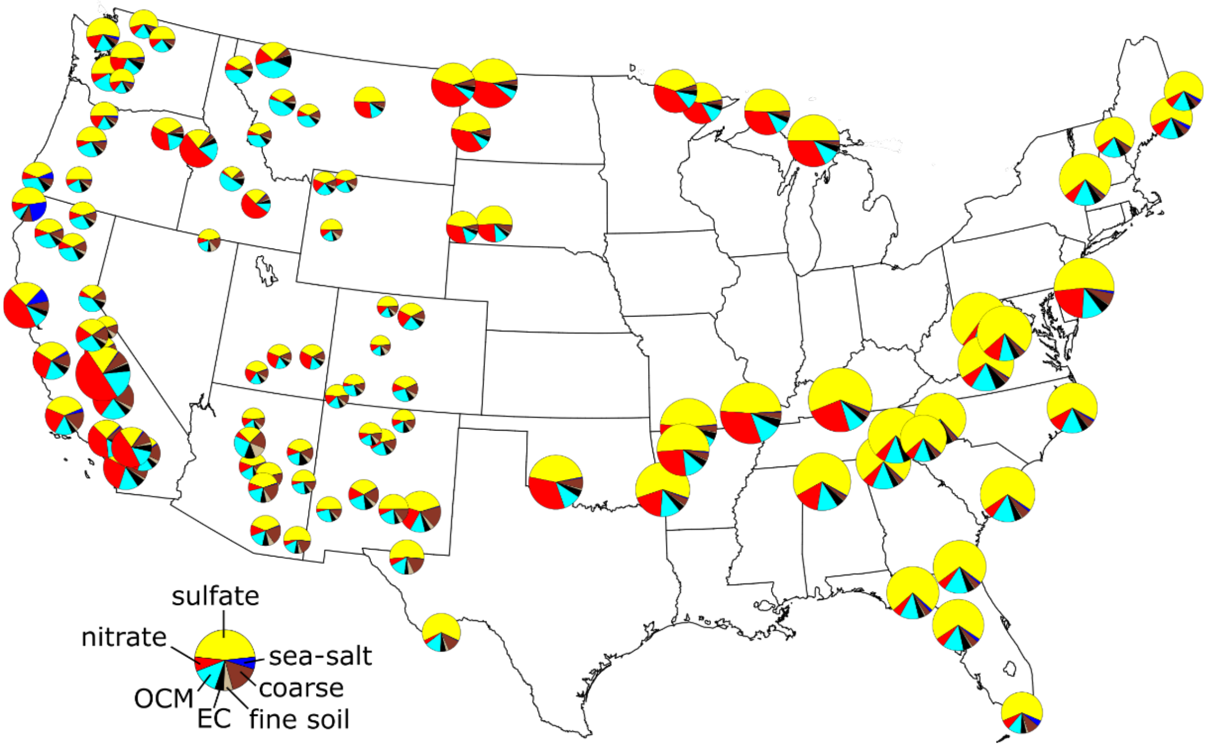

Figure 12. Average extinction budget on the 20% most impaired days sized in proportion to the total extinction, 2010-2014

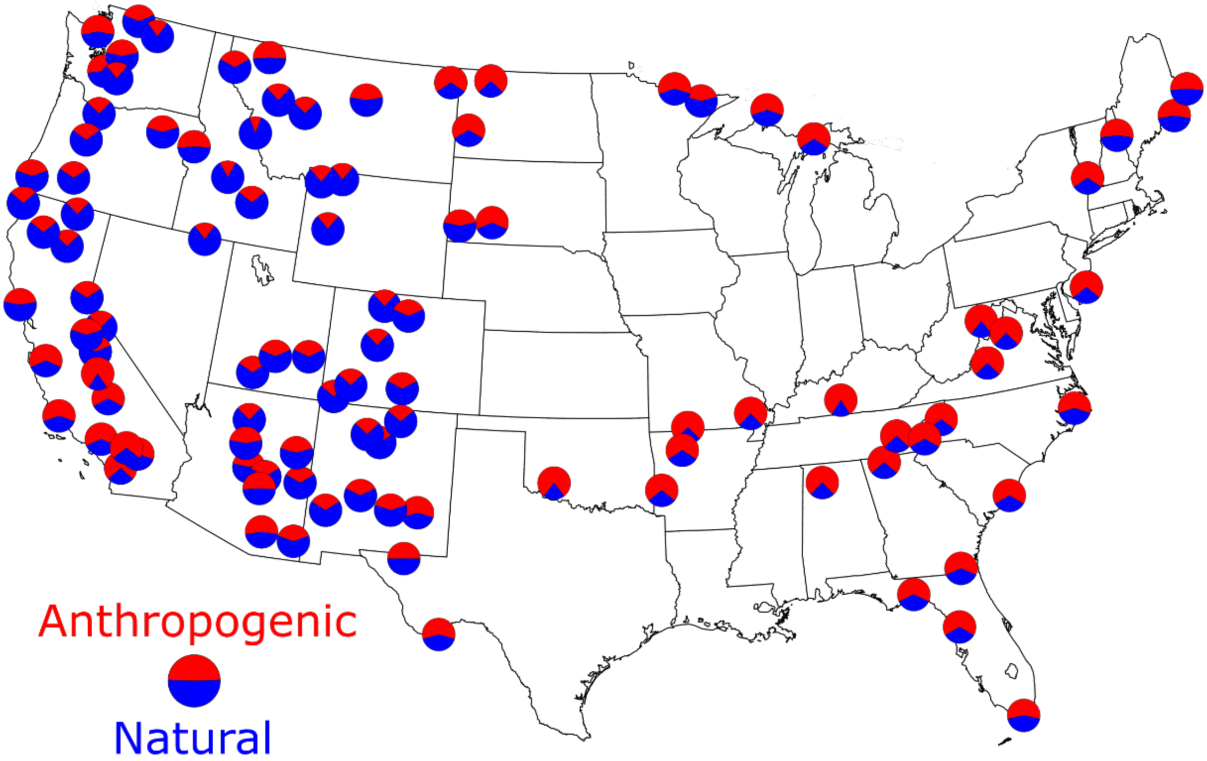

Figure 13. Average natural vs. anthropogenic extinction budget on 20% haziest days, 2010-2014

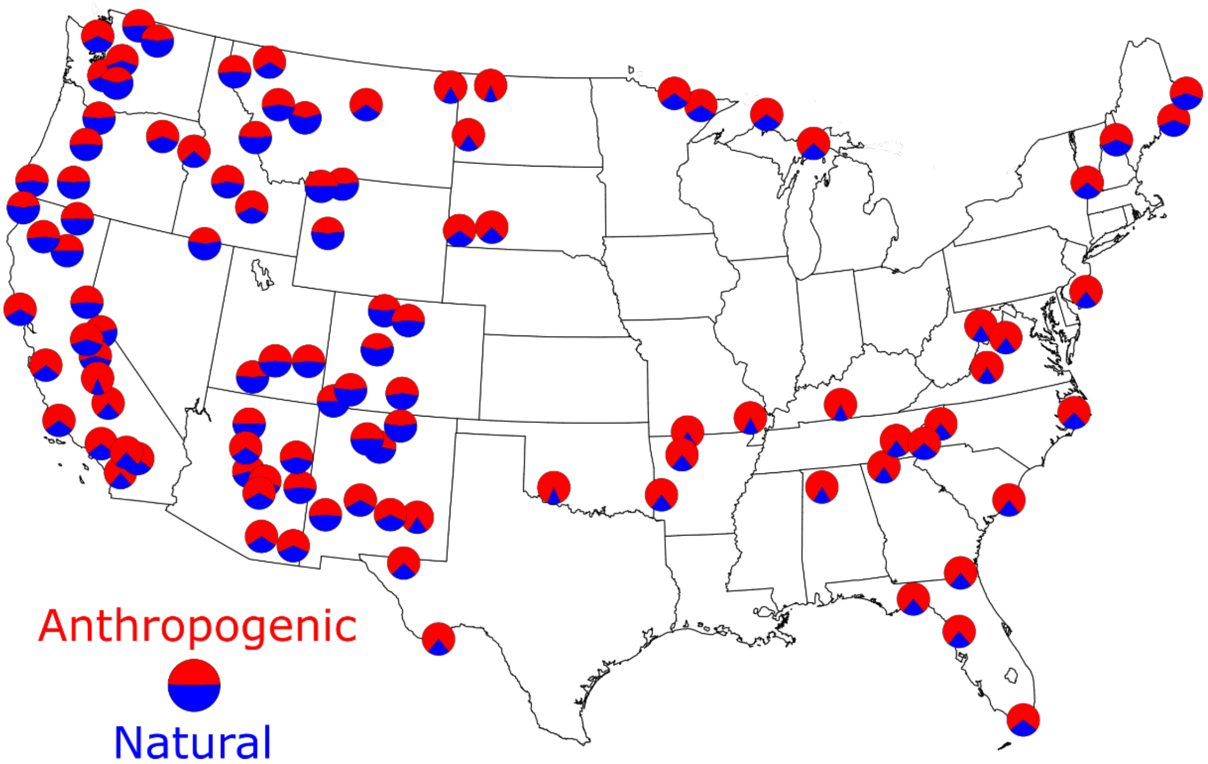

Figure 14. Average natural vs. anthropogenic extinction budget on 20% most impaired days, 2010-2014

The new data analysis framework of the updated approach allows total extinction to be presented in terms of the natural and anthropogenic portions, for both the haziest days and the most impaired days. Average contributions for 2010-2014 are portrayed in Figures 13 and 14. While the haziest days are typically dominated by natural contributions in the Western U.S., the most impaired days generally have larger estimated anthropogenic contributions. The role of estimated anthropogenic contribution is more consistent between the haziest and most impaired days in the Eastern U.S.

3.1.3 Trends in annual extinction budgets

After the daily total extinction are subdivided into anthropogenic and natural contributions, the annual average values for the 20% worst days per year can help reveal the trends in visibility attributable to controllable emissions. Figure 15 shows the budget for anthropogenic impairment (top row), natural contribution (middle row) and total extinction on the most impaired days (bottom row).

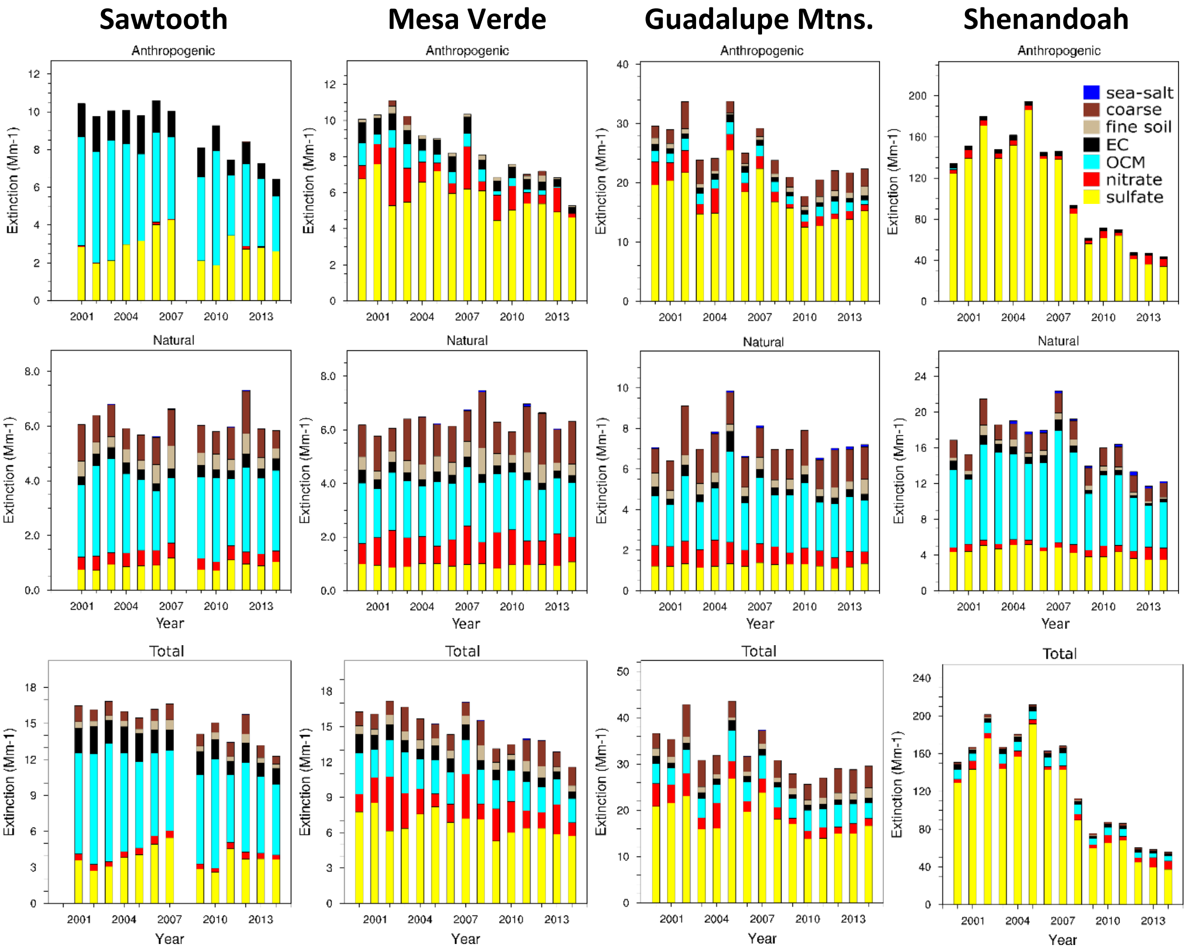

Figure 15. Annual average anthropogenic (top row), natural (middle row), and total (bottom row) extinction budget time series for days selected as 20% most impaired from 2000-2014 at selected sites

At these four sites which generally span from the least impaired at Sawtooth to the most impaired at Shenandoah, Figure 15 shows that the anthropogenic extinction is decreasing over time while the natural extinction is variable within the 15-year period and does not reveal any apparent or consistent trend in the total annual values. Figures 15 and 16 both show that sulfate is the dominant component of anthropogenic extinction at the more impaired sites, while natural extinction is comprised of a mixture of sulfate, nitrate, OCM, fine soil and CM. The lack of anthropogenic OCM extinction in Shenandoah is due to the low total OCM extinction during the 2000-2014 period with average values near or below that of the NCII estimates. The decrease in natural OCM extinction in Shenandoah is related to the decrease in total OCM extinction during the 2000-2014 period. It's possible that this decrease is partly due to the concurrent decrease in sulfate concentrations which can affect secondary organic aerosol (SOA) yields.[37]

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[37] Carlton, A.G., Pinder, R.W., Bhave, P.V., Pouliot, G.A. To What Extent Can Biogenic SOA be Controlled? Environ. Sci. Technol., 44(9), 3376-3380, 2010.

3.1.4 Anthropogenic extinction budget on the 20% most impaired days

In addition to better identifying controllable components in the average extinction budgets, the updated approach splits the daily extinction into natural and anthropogenic fractions to allow for an estimate of the anthropogenic extinction on the 20% most impaired days. The pie chart map in Figure 16 shows the relative contribution of each component to the average anthropogenic extinction from 2010-2014. Sulfate makes up the majority of the anthropogenic extinction at most sites, with nitrate making up a substantial fraction at sites in the Midwest and California. Other notable features of this figure include the large OCM fraction remaining at several sites in the northern Rockies, the moderate fine soil/CM fraction in the Southwest, and the lack of OCM in the anthropogenic fraction at many sites in the Northeast and upper Midwest. Interpretation of anthropogenic OCM in the context of estimated natural contribution is discussed further in Section 4.3.1 and Section 5.

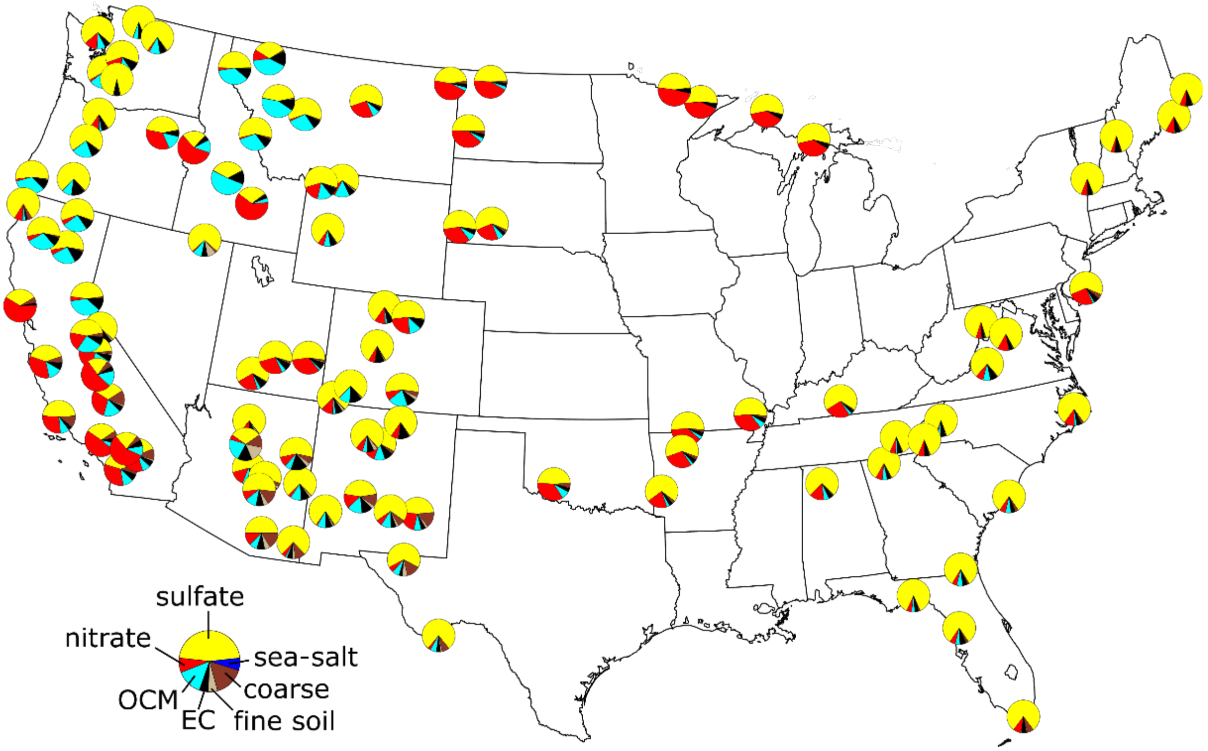

Figure 16. Average anthropogenic extinction budget on the 20% most impaired days, 2010-2014

Appendix G provides additional information about the anthropogenic portion of aerosol-based extinction on a site-by-site basis. Graphs are provided which show the 5-year average extinction budgets and the average number of included days, by season, for the most impaired days per year. This is contrasted with the budgets for total extinction for the haziest days which clearly shows significantly more carbon or dust for many regional groupings of sites in the Western U.S.

Refinement of routine site-specific contributions can also be informed by examination of spatial patterns in natural condition estimates and the derived anthropogenic portions among nearby IMPROVE sites in combination with facts about potentially influential anthropogenic emissions. Better quantifying transport of pollutants and effects of elevation and rough terrain could also be considered in this analysis, as well as source apportionment modeling using a chemical transport model.

The next series of maps separately present the individual aerosol contributions to the 2010-2014 average anthropogenic extinction budgets on the 20% most impaired days. In this format, the general regional patterns and spatial consistency among nearby sites can be more easily examined. In addition, the relative magnitudes of those aerosol-based extinctions and the potential broad categories of contributing emissions can be identified. The format also provides the opportunity to reveal issues which might be attributed to the way natural conditions are estimated in this document.[38]

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[38] The authors invite reviewers to examine the spatial patterns and singularities to help identify issues with the methodology or data.

Sulfate. Figure 17 indicates that there is strong spatial coherence in sulfate contribution to aerosol based extinction on the most impaired days. For example, the inter-mountain west shows consistently low values of sulfate among a large number of sites and most Eastern U.S. locations have similar and large contributions from this aerosol component. There is also a relatively sharp gradient to higher sulfate in and near the locations in the Dakotas.

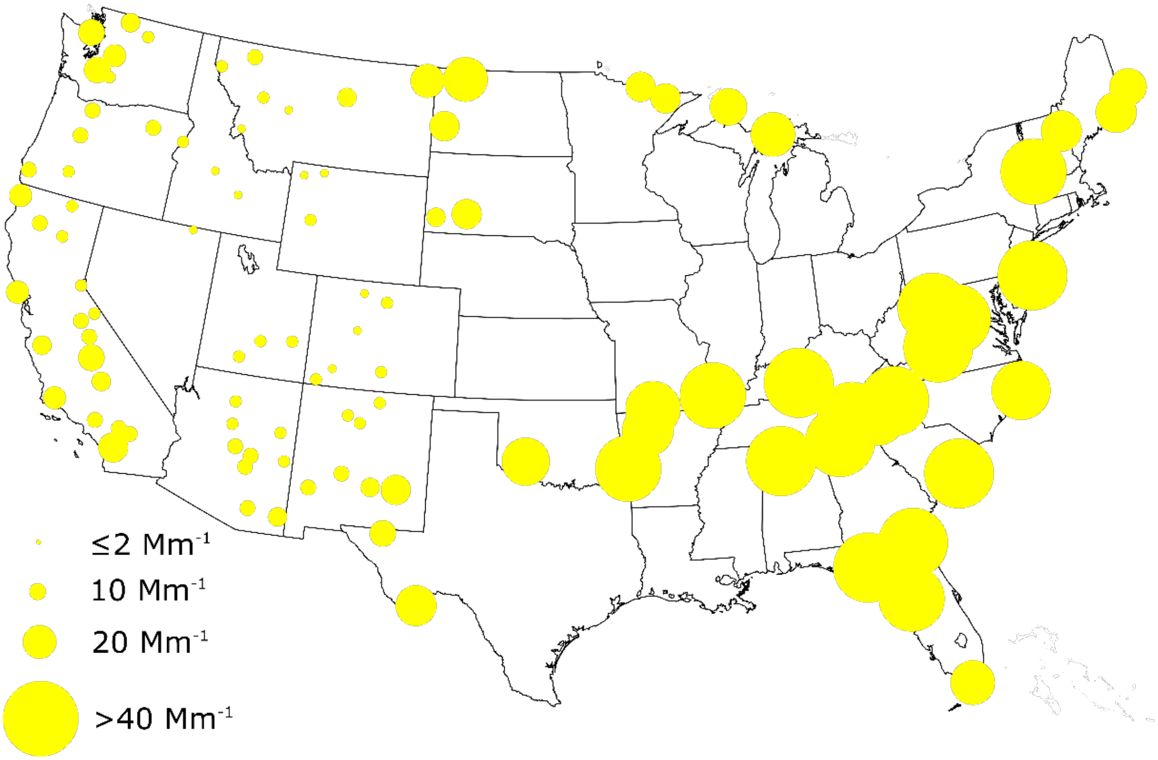

Figure 17. Average anthropogenic sulfate extinction on the 20% most impaired days, 2010-2014

Nitrate. While nitrate generally has its smallest contributions in the inter-mountain west and southwest, in part because of lower humidity, Figure 18 shows that there are a few sites with noticeably higher values. Nitrate is also relatively high at sites in and near North Dakota and many in California, as well as sites from OK thru KY which also have relatively large aerosol extinction from sulfate.

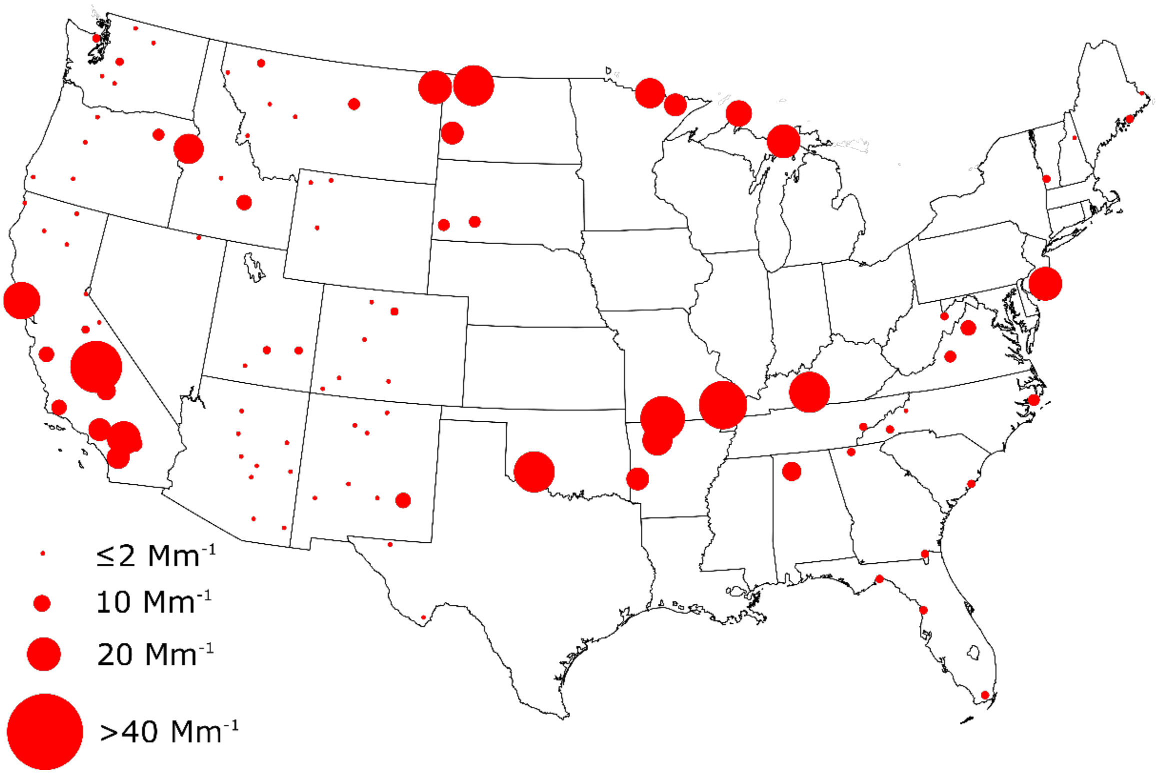

Figure 18. Average anthropogenic nitrate extinction on the 20% most impaired days, 2010-2014

OCM. Figure 19 shows that the estimated anthropogenic extinction from OCM for the most impaired days is typically lower than the estimated anthropogenic contributions from sulfate and nitrate. Like nitrate, the incremental OCM relative to natural contribution is sometimes spatially isolated from neighboring sites and warrant special investigation to see if there are contributing local emissions. As previously identified in Figure 16, this is evident for locations in ID and Western MT where OCM appears to be the highest contributor to estimated anthropogenic extinction. In contrast, there are locations in the Eastern U.S. where average OCM anthropogenic aerosol contribution appears to be unexpectedly very low, given the large number of regional emission sources and proximity of those sites to nearby urban areas. In fact, estimated OCM anthropogenic extinction is zero for some individual site-years, as was seen for 2012 in Figure 15 for Shenandoah. Both of these issues may be an artifact of the use of NCII estimates in the split of daily extinction into anthropogenic and natural fractions in a period of rapidly decreasing anthropogenic emissions. These issues are discussed further in Section 4.

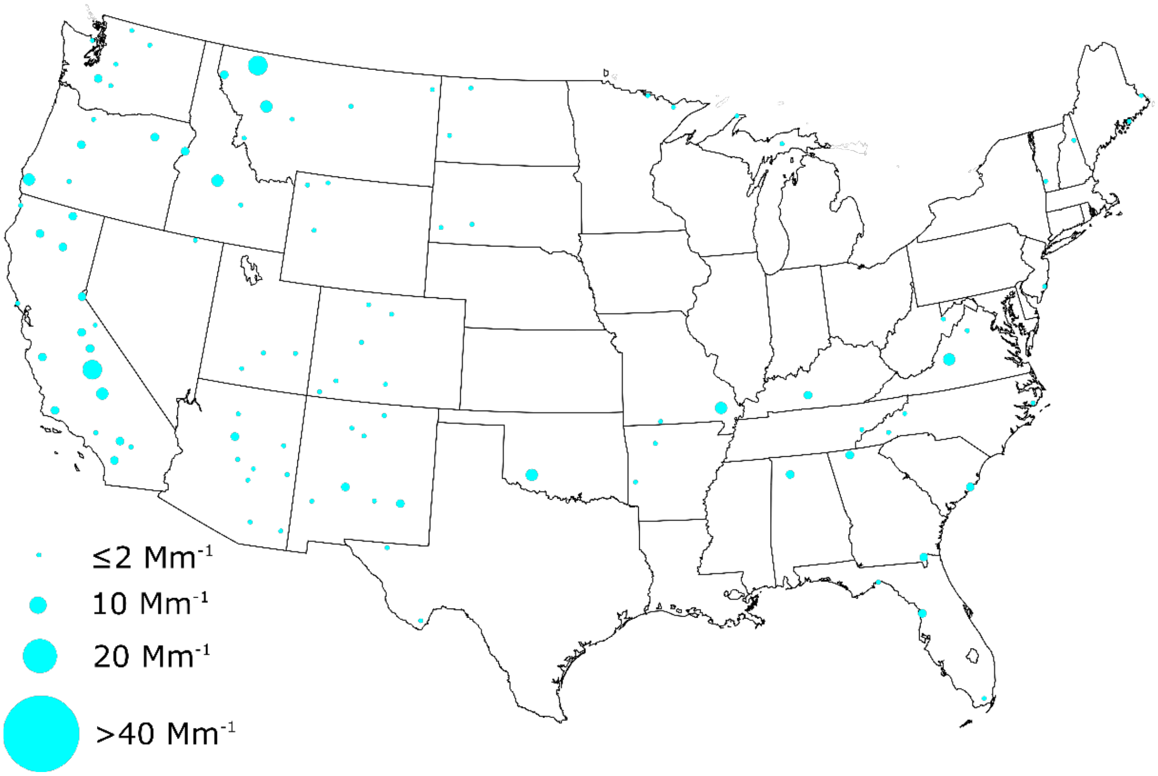

Figure 19. Average anthropogenic OCM extinction on the 20% most impaired days, 2010-2014

EC. Nationally, the estimated anthropogenic extinction from EC on the 20% most impaired days shown in Figure 20 is low at all sites compared to sulfate and nitrate and similar to that of OCM at many sites. Regionally, the estimated anthropogenic EC extinction is highest in the Southeast U.S. and lowest across most sites in the Western U.S.

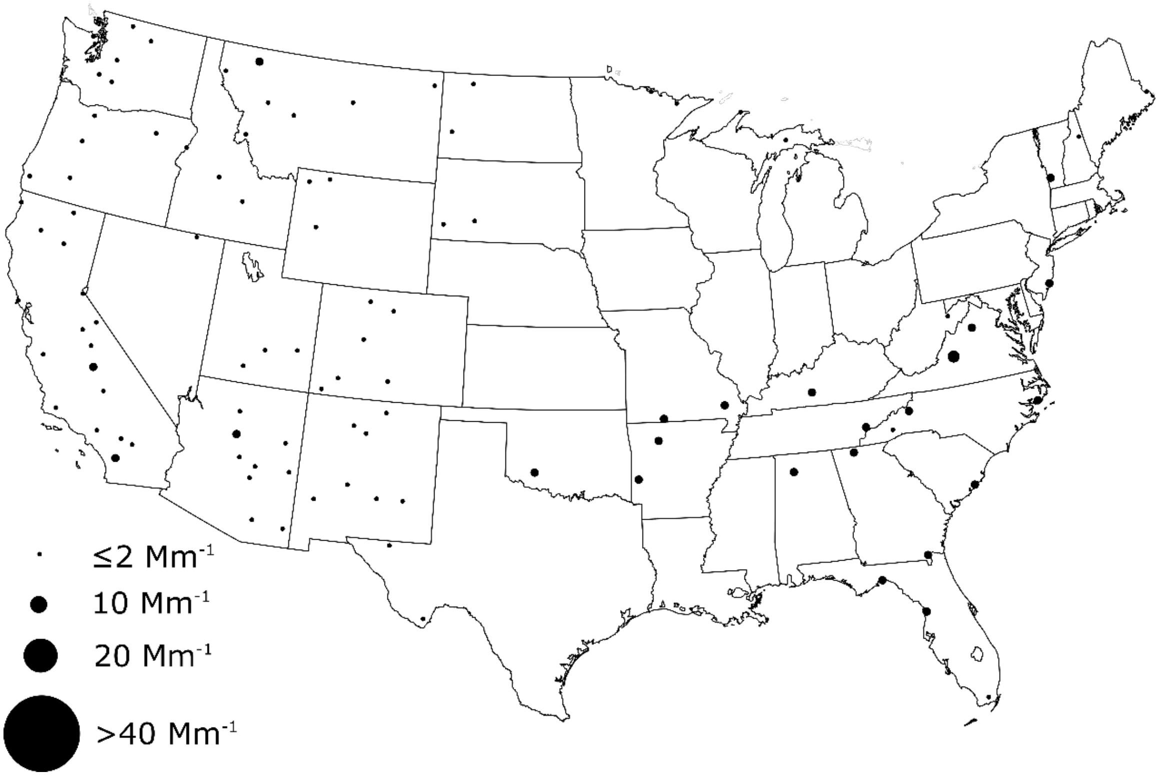

Figure 20. Average anthropogenic EC extinction on the 20% most impaired days, 2010-2014

Fine soil and CM. Despite making up a substantial fraction of the total extinction on the 20% haziest days at many sites in the Western U.S. (as shown in Figure 10), Figures 21 and 22 show that anthropogenic extinction of fine soil and CM are very low at most sites on the 20% most impaired days. This is due to the removal of the e3 dust components from the anthropogenic fraction by the approach described in this document. Also seen in Figure 12, some isolated sites in the Southwestern U.S. have slightly elevated extinction values of CM even on the most impaired days. This potentially results from local dust sources and anthropogenic emission conditions, or the effect of the algorithm in splitting total extinction into anthropogenic and natural portions.

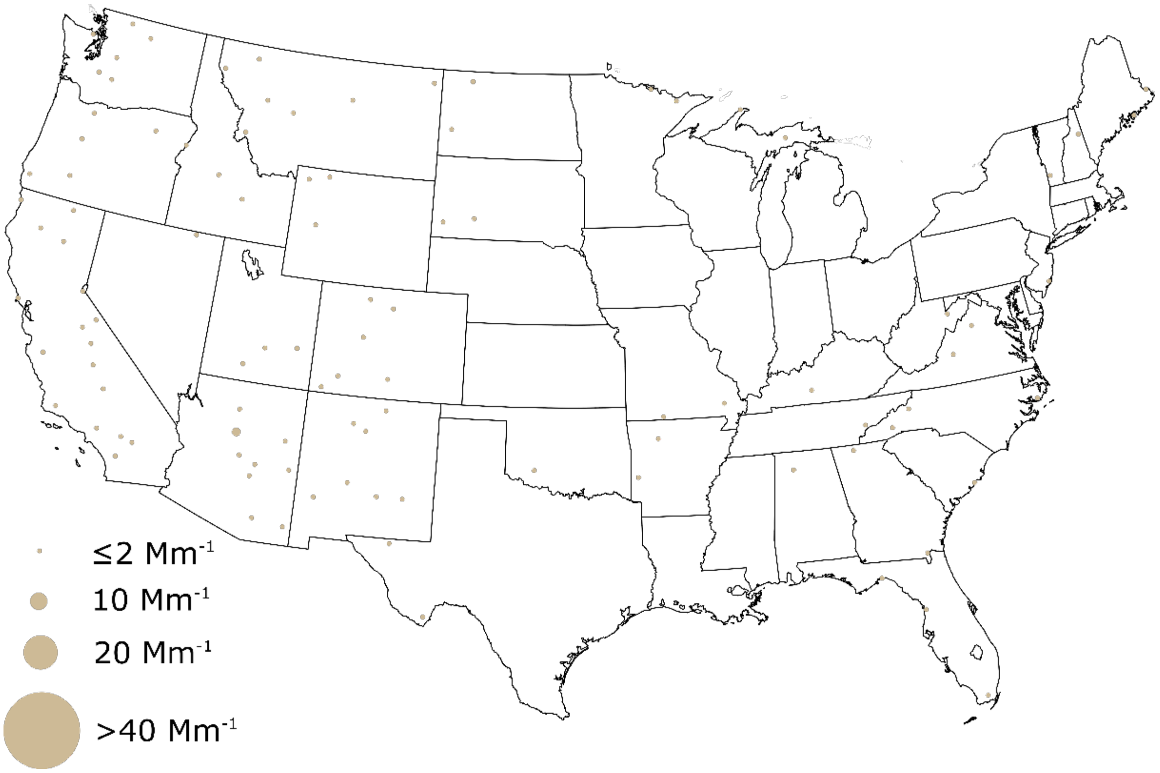

Figure 21. Average anthropogenic fine soil extinction on the 20% most impaired days, 2010-2014

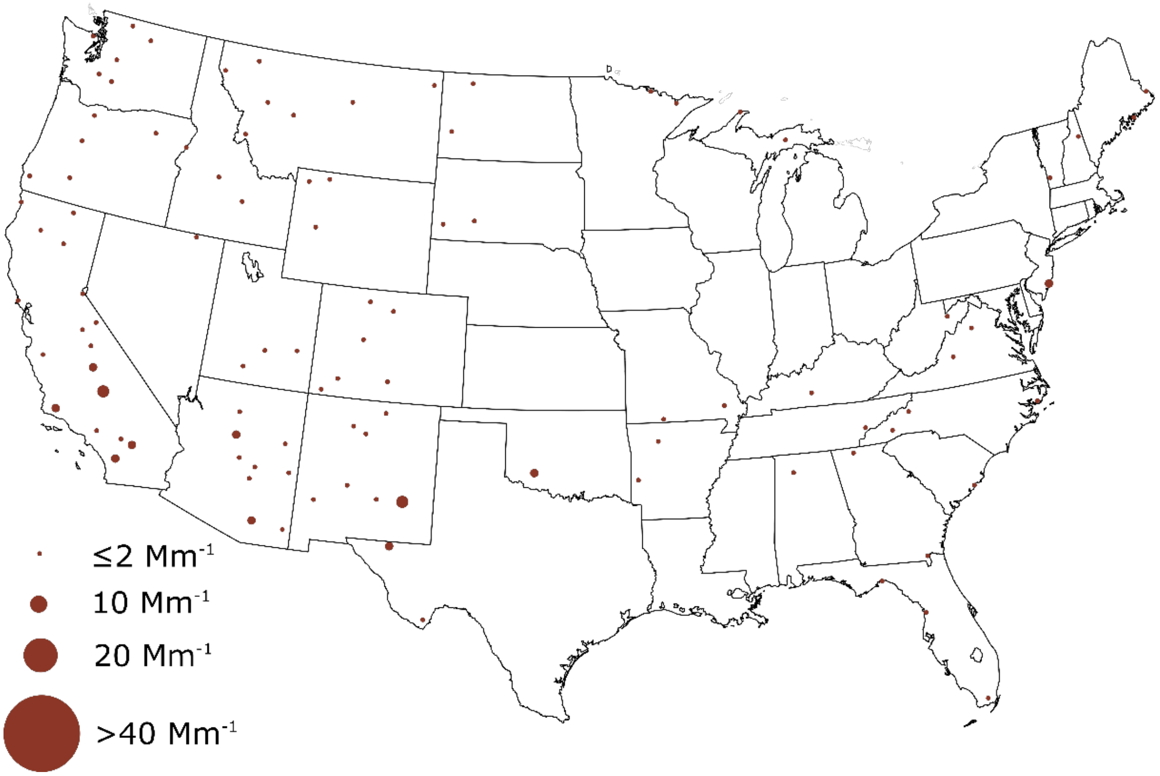

Figure 22. Average anthropogenic CM extinction on the 20% most impaired days, 2010-2014

3.2 Revised natural conditions estimates and glidepaths

Estimates of 15-year annual average natural condition values derived in this analysis for the updated tracking metric are compared to the NCII values. The contrasts among natural conditions indicators can vary by site and can also be different between the haziest and most impaired days.

Because each day has a different estimate of natural contribution, there are corresponding estimates of natural conditions. The ensemble of daily values associated with the most impaired days can be used to estimate a long-term average.[39] Accordingly, this document provides a revised 2064 endpoint for the most impaired days which matches the updated tracking metrics and revised base year values. This results in new estimates of natural conditions and glidepaths for the most impaired days.

3.2.1 Natural conditions for haziest and most impaired days

Figures 23 and 24 provide the natural conditions for the haziest and most impaired days showing that the latter are less than or equal to the current “p90” default values. This is expected as the total haze on the 20% most impaired days is also generally lower than the 20% haziest. Among the haziest days, the values are more variable within CONUS; sites range from 5.7 to 15.8. In contrast, natural conditions are lower among the most impaired days where the site-average values range from 3.0 to 11.5.

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[39] A new estimate for natural conditions for the haziest days can also be constructed.

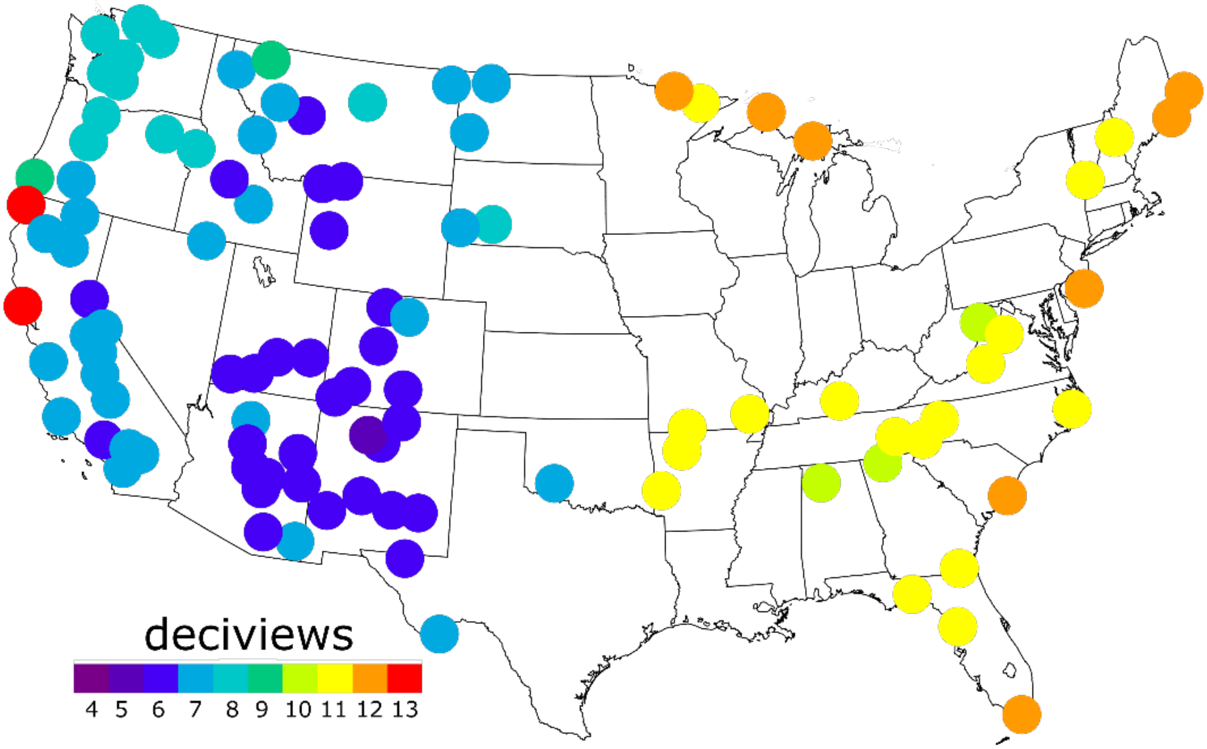

Figure 23. NCII default deciviews associated with natural conditions on the 20% haziest days[40]

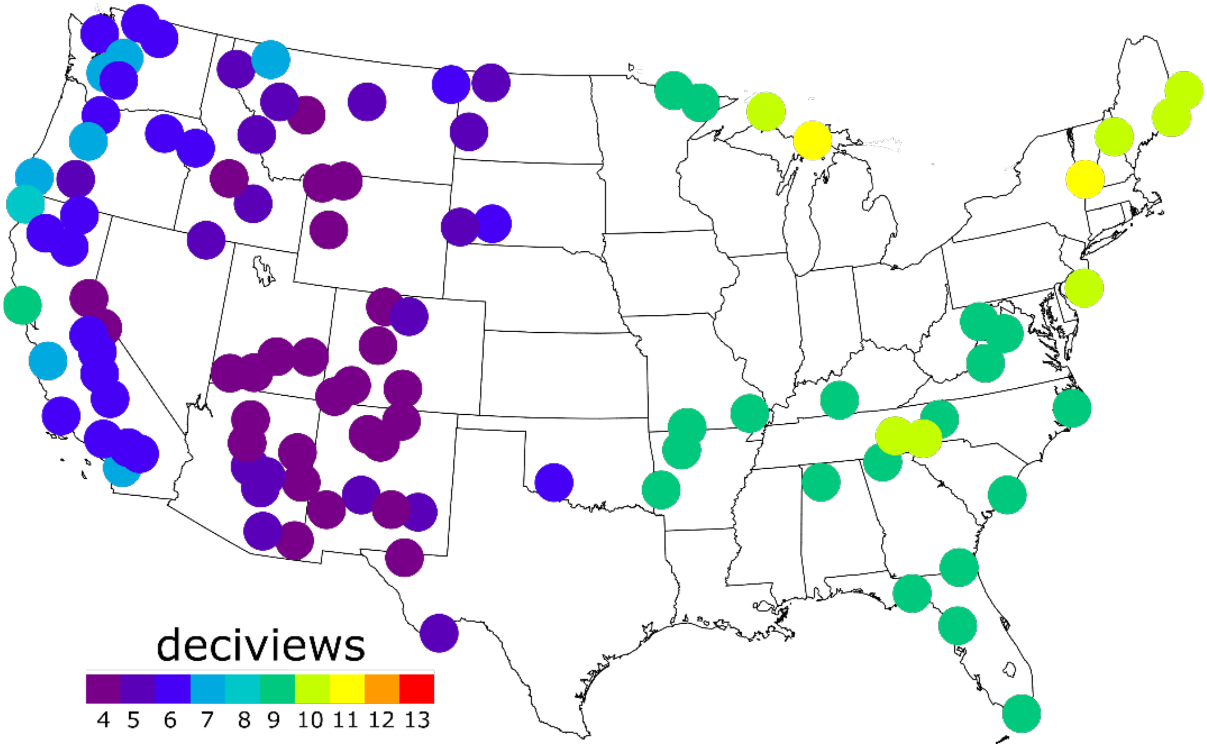

Figure 24. Revised natural conditions for the 20% most impaired days averaged from 2000-2014

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[40] These are the published NCII "p90" values intended to match the 20% haziest days.

While the current “default” estimate of natural conditions for the haziest days depicted in Figure 23 and used by the EPA reflects the within-site variability during 2000-2004, estimated natural conditions for the most impaired days shown in Figure 24 represents a 15-year average. This is because natural conditions are changing and a longer time frame is judged to better serve the intent of the 2064 endpoint. Figure 25 shows the change in natural conditions from 2000-2004 to 2010-2014. The average natural condition values have decreased by 1-2 deciviews at several sites in the Eastern U.S. while the average natural condition values at most Western U.S. sites changed by < 1 deciview.

As presented in Section 3.1.2, baselines for the total extinction are also lower for the most impaired days. This causes the glidepath to shift down. However, the relationship of the glidepath to the updated tracking metric is in fact more important. The changes in glidepath as well as the deviations of current conditions for the haziest and most impaired days are discussed in Section 3.3.

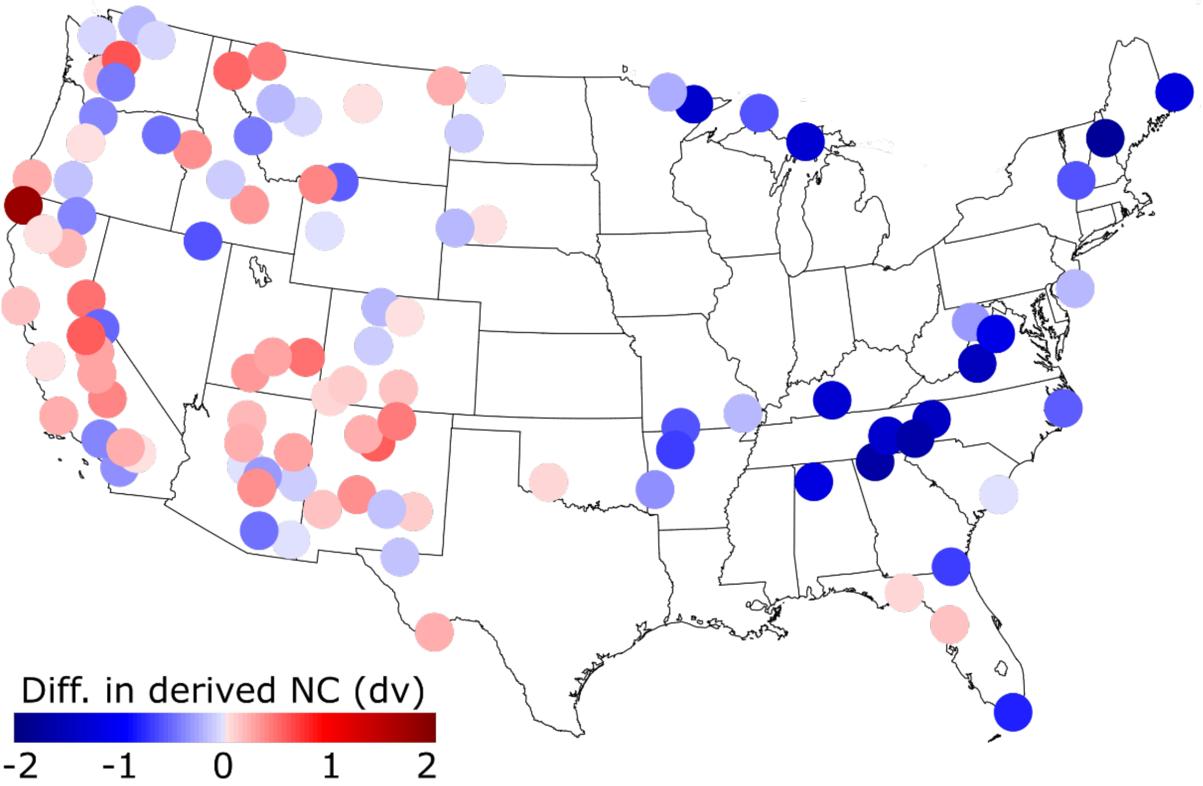

Figure 25. Difference in deciviews of the 2000-2004 and 2010-2014 average natural conditions derived from the 20% most impaired days

Figure 26 next shows the average NCII among all components. There is relative national similarity in these average values. Contrasted with Figure 24, it is evident that the estimated natural conditions for the most impaired days are almost always greater than the average NCII values. The exceptions are two locations - Point Reyes, CA (PORE1) and Simeonof, AK (SIME1) - which are heavily influenced by sea salt where the natural conditions for the most impaired days are slightly less than the average NCII values.

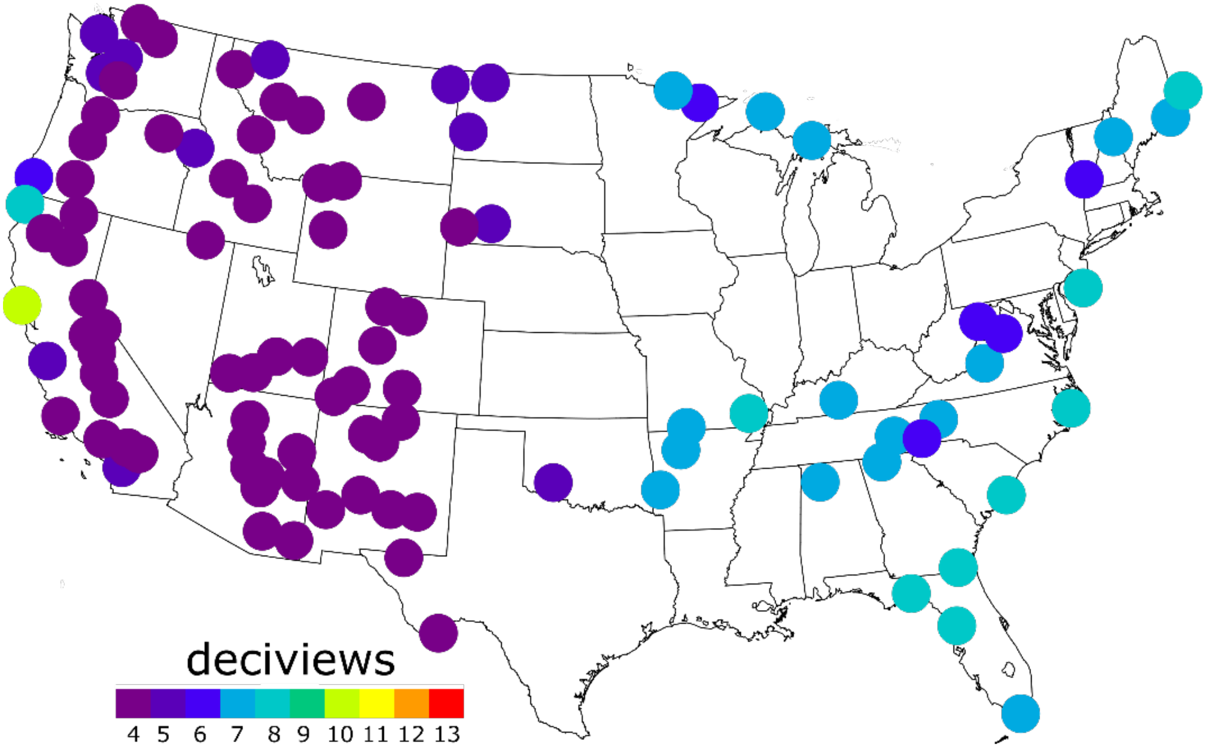

Figure 26. NCII default average deciviews associated with natural conditions

Corresponding to the aforementioned estimates of natural conditions, Figures 27 and 28 show their extinction budgets. On most impaired days, the derived estimates show relatively less carbon and dust. With the new methodology, there are also larger site-to-site differences. Maps showing site-specific differences for the carbon and dust components between the NCII haziest days and impairment-related estimates of natural conditions are provided in Appendix D. There is further discussion about these estimates of natural conditions in Section 5.

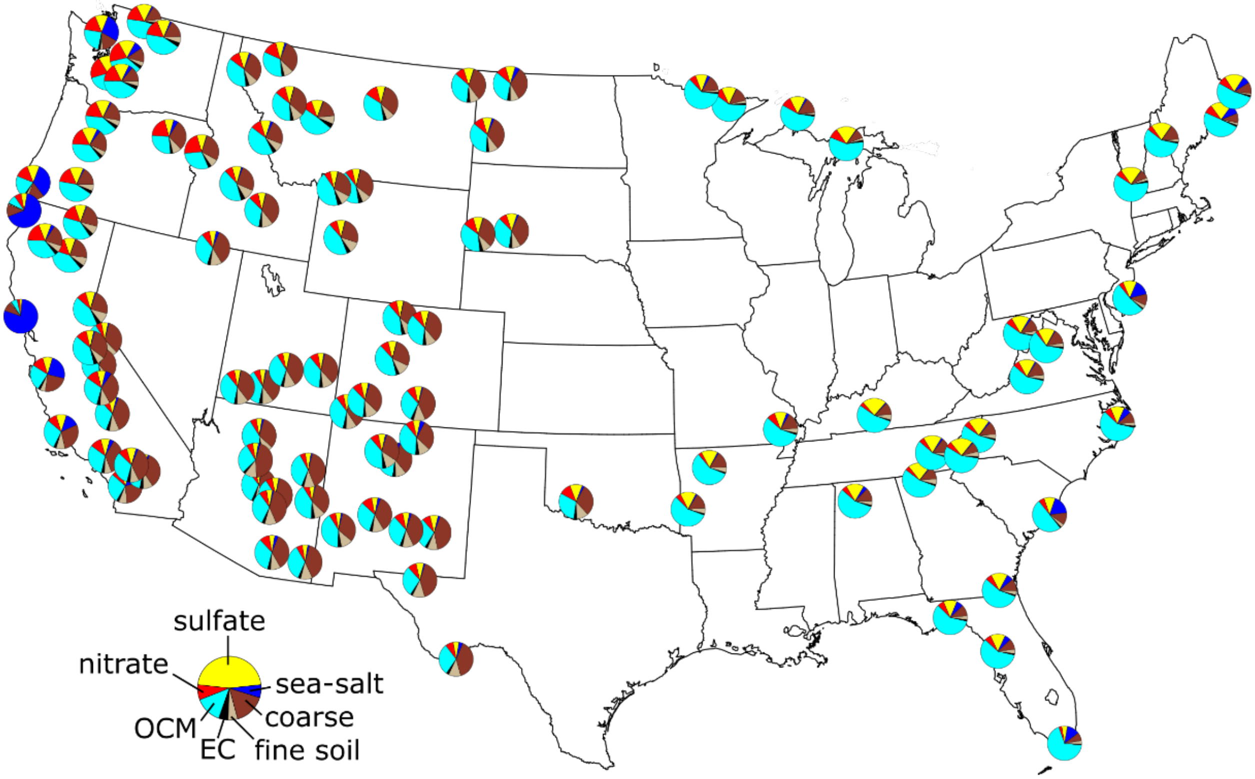

Figure 27. NCII default natural extinction budget on the 20% haziest days

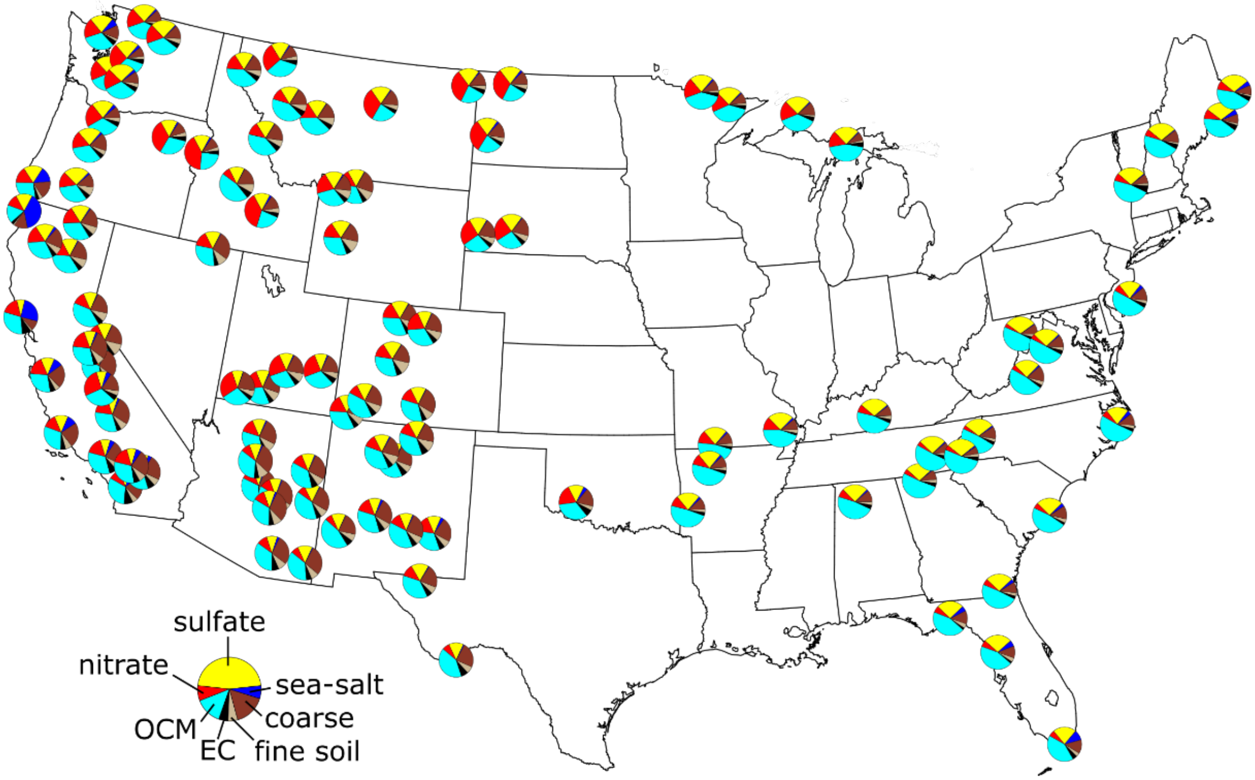

Figure 28. Revised natural extinction budget on 20% most impaired days, 2000-2014.

3.2.2 Change in deciview slope from 20% haziest to 20% most impaired days

Figure 29 shows that changing the selection of days from the 20% haziest to 20% most impaired impacts the slope of the 5-year average deciviews differently at sites in the western and eastern U.S. In the Eastern U.S., changes in the slope between the two approaches are far smaller than the large negative slope between 2000-2004 and 2010-2014. In the Western U.S. near zero or positive slopes in the 20% haziest days are changed to negative for the 20% most impaired days, represented by the cooler colors and large circles indicating a large absolute percentage change. At some sites in Arizona and Colorado, wildfire and dust impacts were greater in the 2000-2004 period than 2010-2014 and selecting the 20% most impaired days actually increases the slope. This glidepath-independent comparison identifies sites where the 20% most impaired approach has the larger impact on the tracking metric.

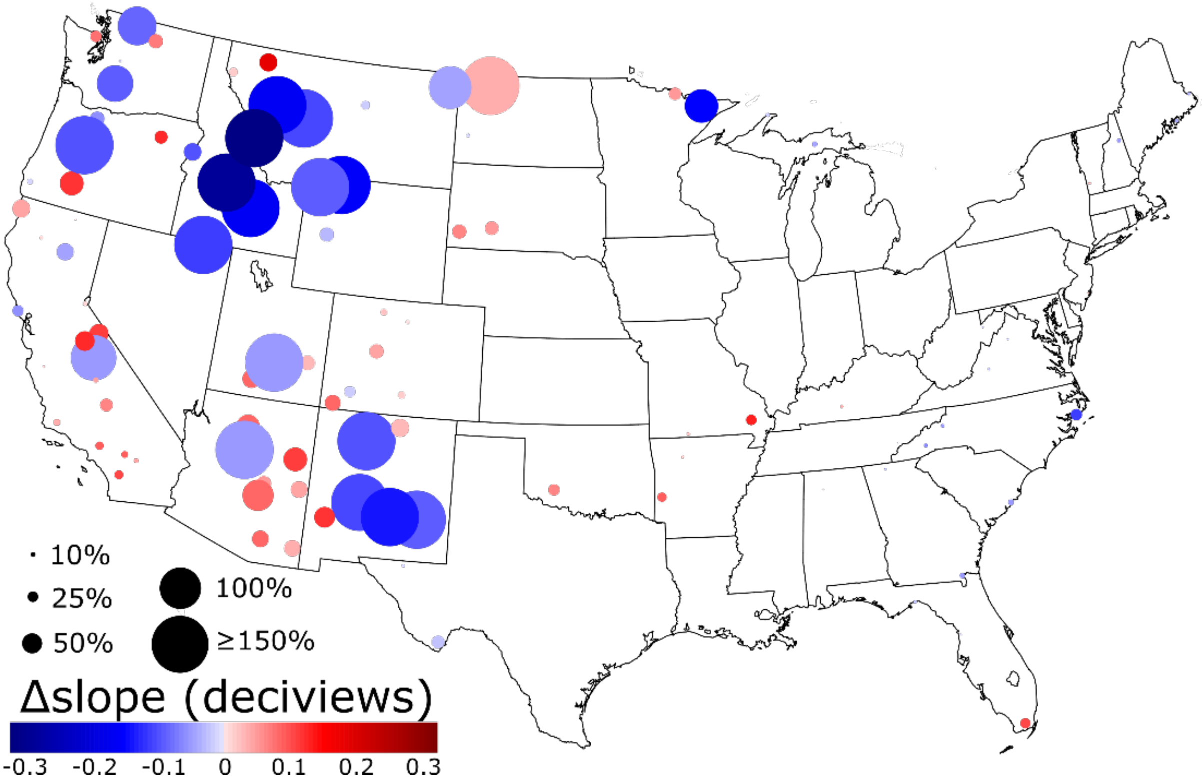

Figure 29. Comparison of trends (slope) between days selected as 20% haziest and 20% most impaired

3.3 Changes in the metric

Tracking regional haze for the most impaired days results in different numerical values of the 20% worst days per year, a new estimate of natural conditions and a new glidepath. This is first illustrated in Figure 30 for the four example locations for 2000-2014, highlighting the new lower glidepath for the most impaired days. As mentioned earlier, the relationship between the tracking metric and the glidepath is more important than their absolute numerical values.

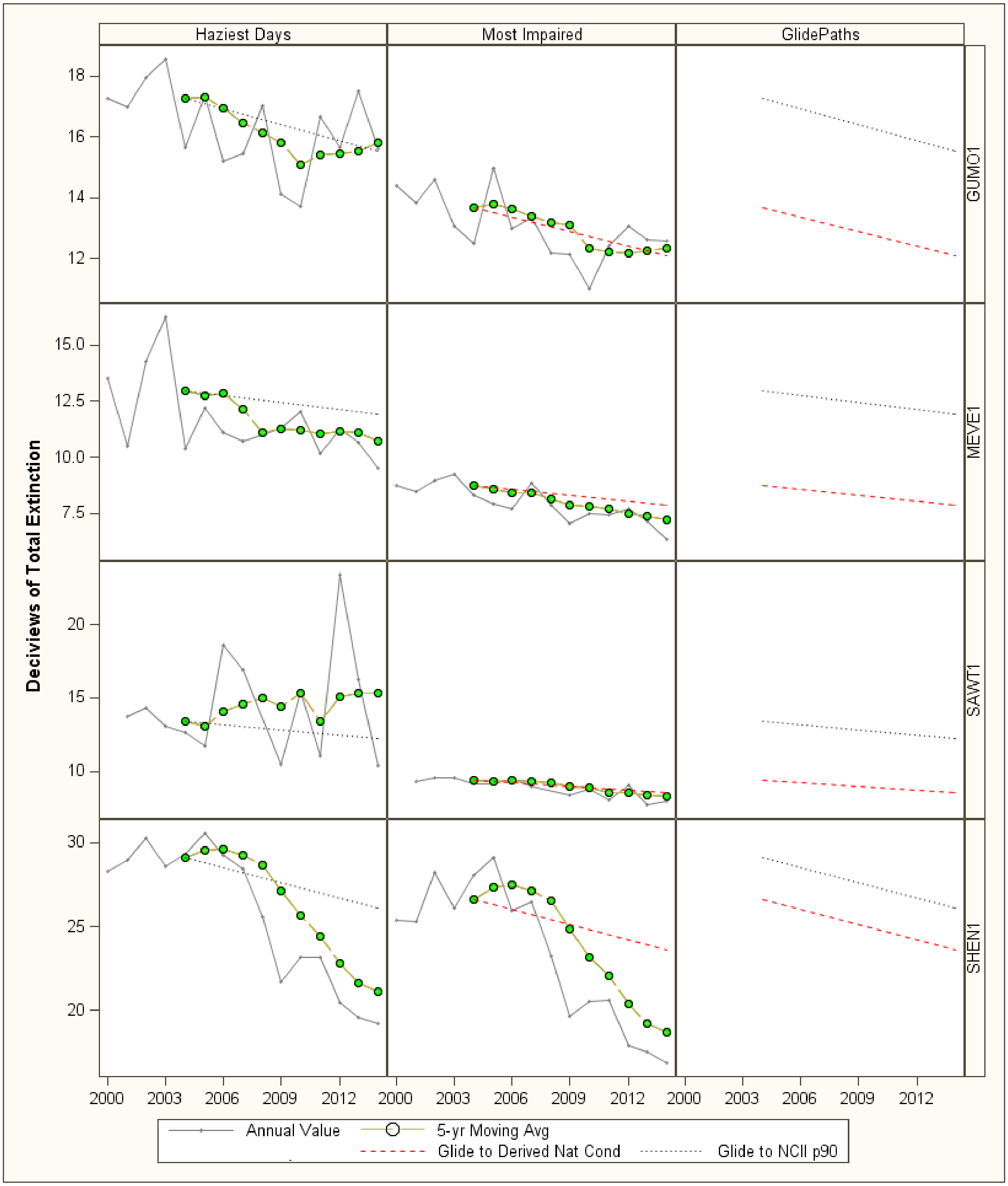

Figure 30. Comparison of trends and glidepaths of 20% haziest and 20% most impaired days

The changes to the impairment-based tracking metric for all sites are next presented in three different ways. First, as the change in the average visibility conditions on the 20% most impaired days compared to the change in the haziest days; second, in terms of the deciview slope for the updated impairment-based metric compared to the one based on the haziest days; and finally as the deviation from the glidepath of the average metric for the most recent five year period.

3.3.1 Change in average visibility conditions for the most impaired and haziest days

Figures 31 and 32 show spatially interpolated national maps of visibility over the two 5-year periods of 2000-2004 and 2010-2014, respectively, using IMPROVE network measurements on the 20 percent of days that had the worst visibility in each of these years. Figure 33 shows the change in this metric of visibility between the two 5-year periods. These results clearly indicate that improvements in visibility have been achieved in most Class I areas.

The results also indicate that visibility has improved more in the Eastern U.S. than in the Western U.S. This difference is due to a several factors. Visibility conditions in the Eastern U.S. in the earlier of the two 5-year periods were worse than in the Western U.S. due to higher emission of air pollutants, particularly SO_2 emissions, providing more room for improvement in deciview terms. Higher humidity levels in the eastern states are also a factor affecting the east versus west comparison.[41] During the 10 years separating these two periods, large reductions in SO_2 and NO_x emissions were required by other CAA provisions and EPA rules and were facilitated by fuel and energy market changes. Also, some of the emission reductions required by regional haze plan in western states are associated with compliance dates after 2015, and so their contribution to progress is not reflected in these figures. In addition to these regional differences, uncontrollable events in the Western U.S. associated with e3 often obscured improvements in visibility even though states were successful in obtaining substantial emissions reductions from contributing sources.

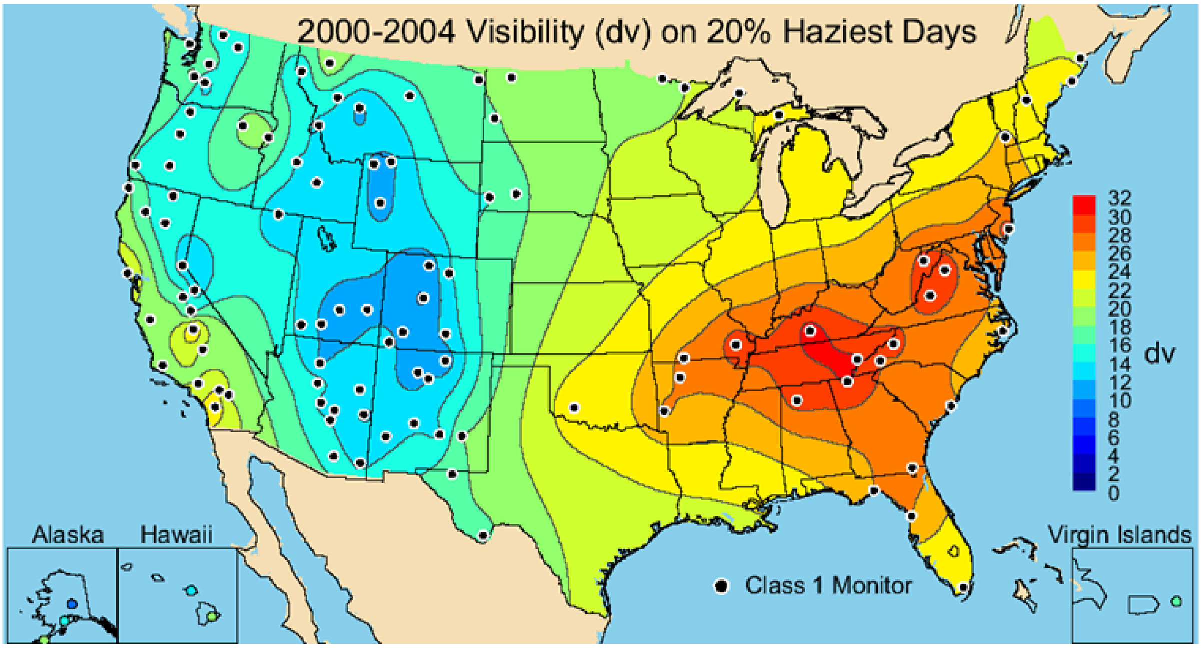

Figure 31. Average visibility conditions over the 2000-2004 baseline period on the 20% haziest days[42]

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[41] Site-specific monthly climatological average humidity values are used in the calculation of extinction, so changes in humidity do not influence the long-term trends.

[42] Figures 31-36 were prepared by staff from the National Park Service and Colorado State University and are derived from visibility data collected by the IMPROVE monitoring network, excluding “IMPROVE protocol” sites

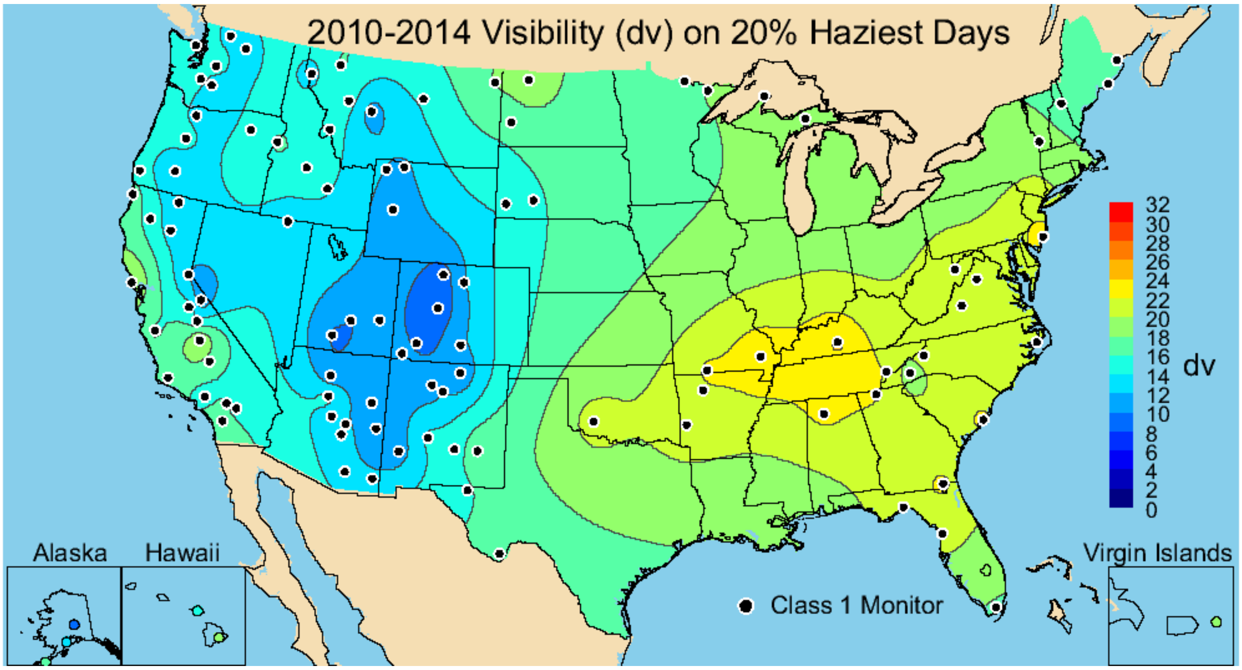

Figure 32. Average visibility conditions over the 2010-2014 period on the 20% haziest days

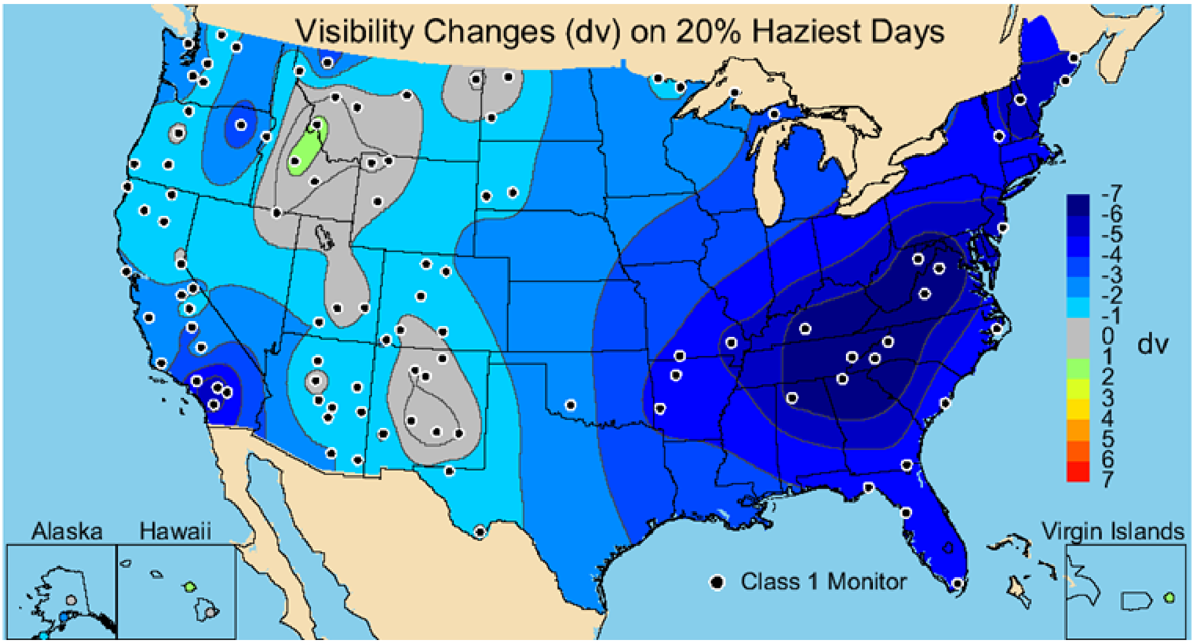

Figure 33. The difference in visibility on the 20% haziest days, 2000-2004 to 2010-2014[43]

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not located in Class I areas. Monitor locations are indicated by the black dots. For easier visualization, data from the monitor locations were spatially interpolated to estimate visibility values at non-monitor locations; estimated values are somewhat uncertain in areas with few monitors (*e.g.*, in Texas). PM data from other monitoring networks were not used in the spatial interpolation and so the coloring on the maps does not represent visibility in urban areas and other areas outside the monitored Class I areas.

[43] Blue colors indicate visibility improvements while visibility degradations are shown in warmer colors. The gray shading indicates areas where only slight visibility improvements or degradations have occurred.

3.3.2 Visibility changes for 20% most impaired days

Because the worst visibility days can include periods when episodic events such as wild fires or dust storms cause poor natural visibility conditions, the trend in visibility on the days with the poorest visibility (as shown in Figures 31-32) may not fully represent actual progress that has been made in reducing visibility impairment since the baseline period. Instead, the trend in visibility conditions on the most anthropogenically impaired days is a more accurate metric for tracking progress in reducing anthropogenic contributions to poor visibility. These most impaired days will typically include days that had relatively good natural visibility conditions (e.g., no large impacts from wildfires or desert dust storms) and relatively large anthropogenic contributions to impairment. Figures 34 and 35 show national maps of visibility conditions over the two 5-year periods of 2000-2004 and 2010-2014, respectively, on the 20 percent most impaired days. Figure 36 shows the changes in this metric of visibility between the two periods. Substantial improvement in visibility conditions are evident in both the eastern and Western U.S.

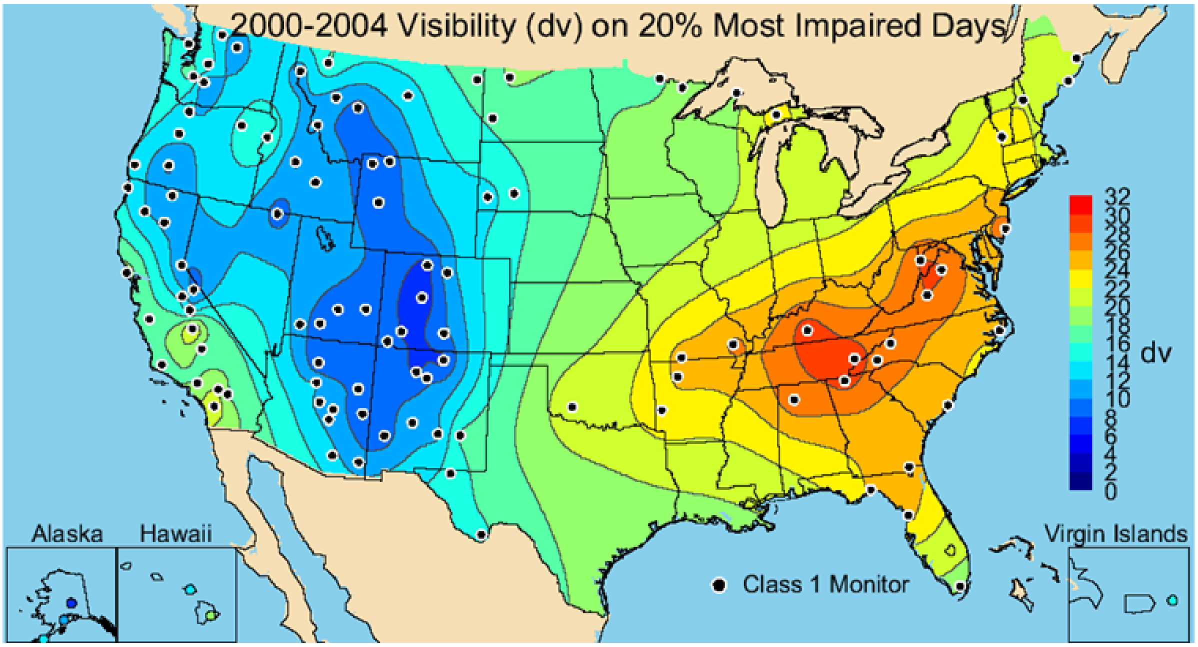

Figure 34. Average visibility conditions over the 2000-2004 baseline period on the 20% most impaired visibility days

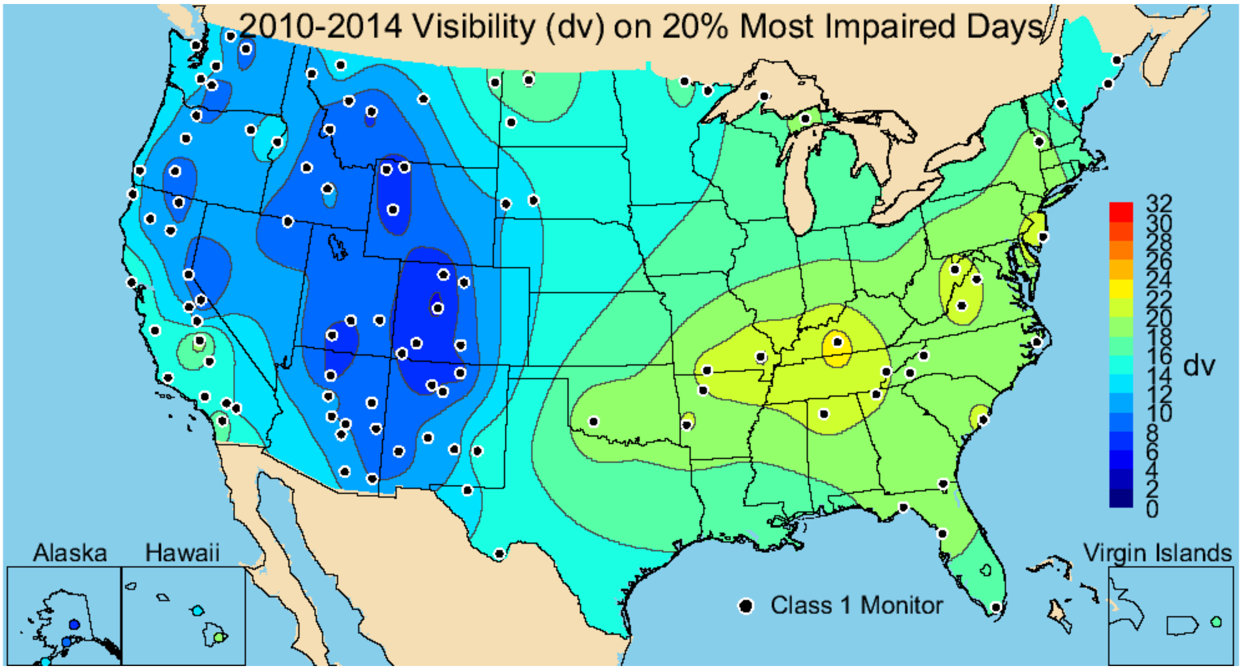

Figure 35. Average visibility conditions over the 2010-2014 period on the 20% most impaired visibility days

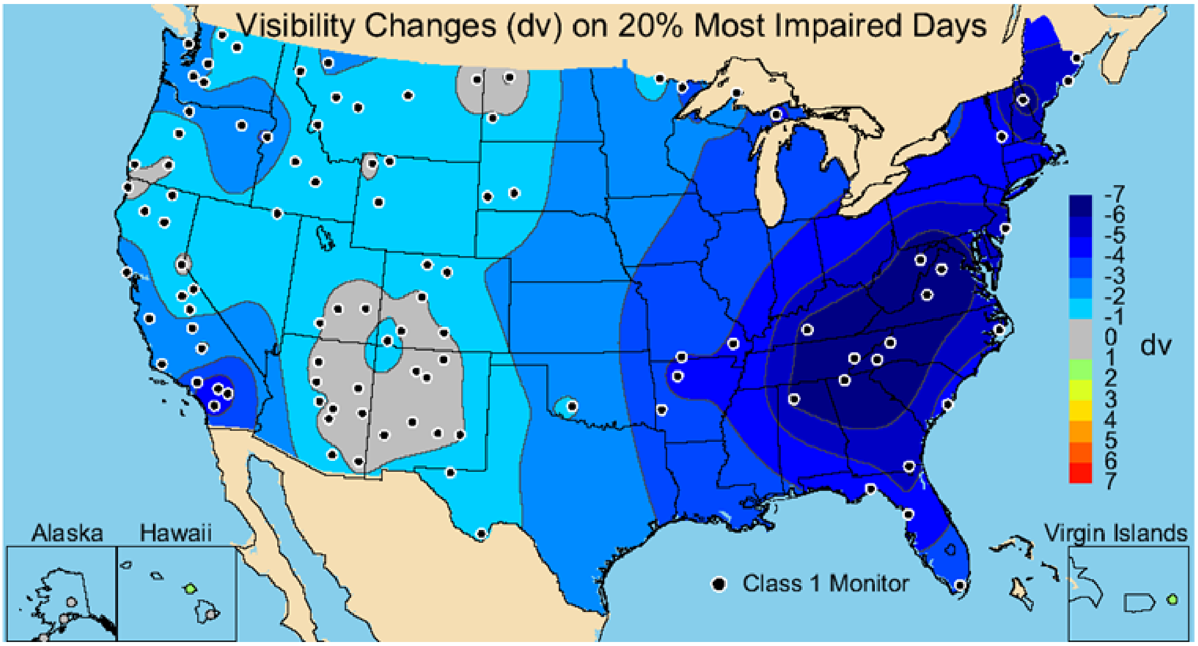

Figure 36. The difference in visibility on the 20% most impaired visibility days between the most recent and baseline periods[44]

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[44] Blue colors indicate visibility improvements while visibility degradations are shown in warmer colors. The gray shading indicates areas where only slight visibility improvements or degradations have occurred.

3.3.3 New glidepath deviation for the 2010-2014 average

Compared to the first implementation period's tracking metric, Figure 37 shows that the glidepath deviation from the updated tracking metric is closer to zero or negative for many sites in the Western U.S. affected by wildfire and dust events. These changes are most notable at sites in the Idaho/Montana and New Mexico wildfire and dust impacts were greatest in the 2010-2014 period. At many other sites, the updated metric had less impact on the deviation. These sites include most of the eastern U.S. and Southern California which remain well below the glidepath, and sites in the Midwest U.S. which remain near or above the glidepath with both metrics. The updated metric also exhibits greater regional consistency in the glidepath deviations, particularly in the Western U.S. where adjacent sites in the Rocky Mountains which initially had different signs of deviation now have similar (mostly negative) deviation values.

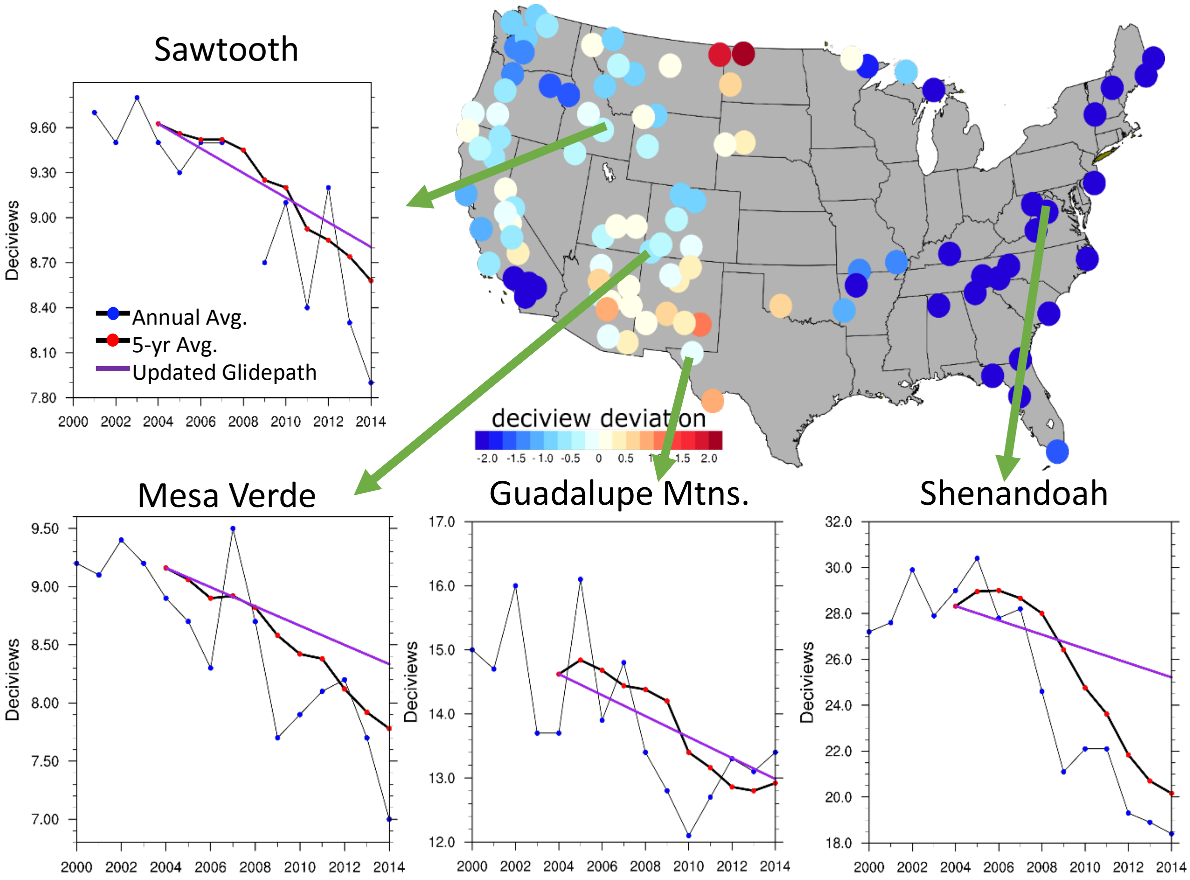

Figure 37. Glidepath deviation in deciviews for 20% most impaired days from 2010-2014 and time series of glidepath and annual/5-year average deciview values for 20% most impaired days from 2000-2014 at selected sites

4 Sensitivity tests and discussion

Through the development of the updated tracking metric, many methods were explored to address the shortcoming in the first implementation period's tracking metric. These include variations in the calculation of e3, routine natural, and anthropogenic components, as well as the use of potential daily impairment indicators which remove or de-emphasize the influence of e3, different ways to sort the daily extinction values in order to establish best and worst days, and to change only the 2064 endpoint in order to formulate an updated glidepath. The following sections describe some of the alternatives and their potential impacts on the tracking metric, glidepath and derived extinction budgets.

These analyses show that an updated metric which is designed to represent worst days without the influence of e3 is not very sensitive to the various statistical approaches used to identify those extreme contributions. Due to the magnitude of e3, the splits between total natural and total anthropogenic contributions are similar and do not appear to be sensitive to the data handling. The current values for various metrics are all much higher than the estimate of natural conditions used to establish the 2064 glidepath endpoint. Thus the tracking metrics and resulting glidepaths based on different objectively defined e3 thresholds and daily impairment indicators provide similar trends. They also result in similar relative deviations from their respective glidepaths. The methodology is also not very sensitive to the draft calculations involving OCM, EC, fine soil and CM.

On the other hand, the results expressed as an extinction budget among contributing "anthropogenic" aerosol components does appear to be sensitive to the estimates of routine natural contribution for each aerosol component. This is discussed in more detail in Section 4.5 and in a separate model-based sensitivity discussion in Section 5. There, alternative estimates of routine natural contribution for OCM based on a hybrid source apportionment model are presented as a potential approach to revise the first implementation period's methodology.

4.1 Extreme episodic extinction threshold

A key step in the methodology to establish a new tracking metric is to identify and remove the influence of e3 which is a major contributor to the variability in the daily HI and annual average and 5-year average estimates of the 20% worst days. A statistical approach is used to identify these large extinction contributions resulting from carbon and dust aerosols. In order to establish a new tracking metric, several approaches were considered which include: 1) the use of a regional 95th percentile value based on a convenient grouping of IMPROVE sites within the National Centers for Environmental Information's U.S. climate regions, which was used for illustrative purposes by the EPA in its initial conceptual discussions with the States and RPOs (Reg95), 2) a site-specific statistical approach suggested by Jim Boylan of Georgia Environmental Protection Division which uses a value which is twice the multiyear median values for carbon and dust aerosols (2xMed), and 3) a site-specific approach, which was a logical outgrowth of the EPA's initial outreach, that selects the minimum annual 95th percentiles for carbon and dust (Min95).

The graphics presented in this section illustrate the impact of alternative estimates of e3 for carbon and dust. First, the trends in the most impaired days are illustrated in Figure 38 for four example sites along with the updated glidepaths. This shows very similar trends between the two site-specific 2xMed and Min95 percentile threshold approaches, and different trends and glidepath with the regional threshold approach. Next, the effect of threshold is examined in terms of the deviation of the 2010-2014 five-year average relative to the glidepath. Figure 39 shows a scatter plot of these deviations (devI) among all sites grouped by broad geographic regions. The deviations, devT, are also shown for the first implementation period's approach in which the selected worst days are based on the ranking of **total** daily extinction. This corroborates the similarities between the two site-specific threshold approaches with close agreement along the red one-to-one lines. The figure also shows the larger number of positive deviations with the first implementation period's approach compared to any of the threshold-impairment based approaches.

These findings are based on the large magnitude of e3 relative to total extinction derived from each threshold approach.

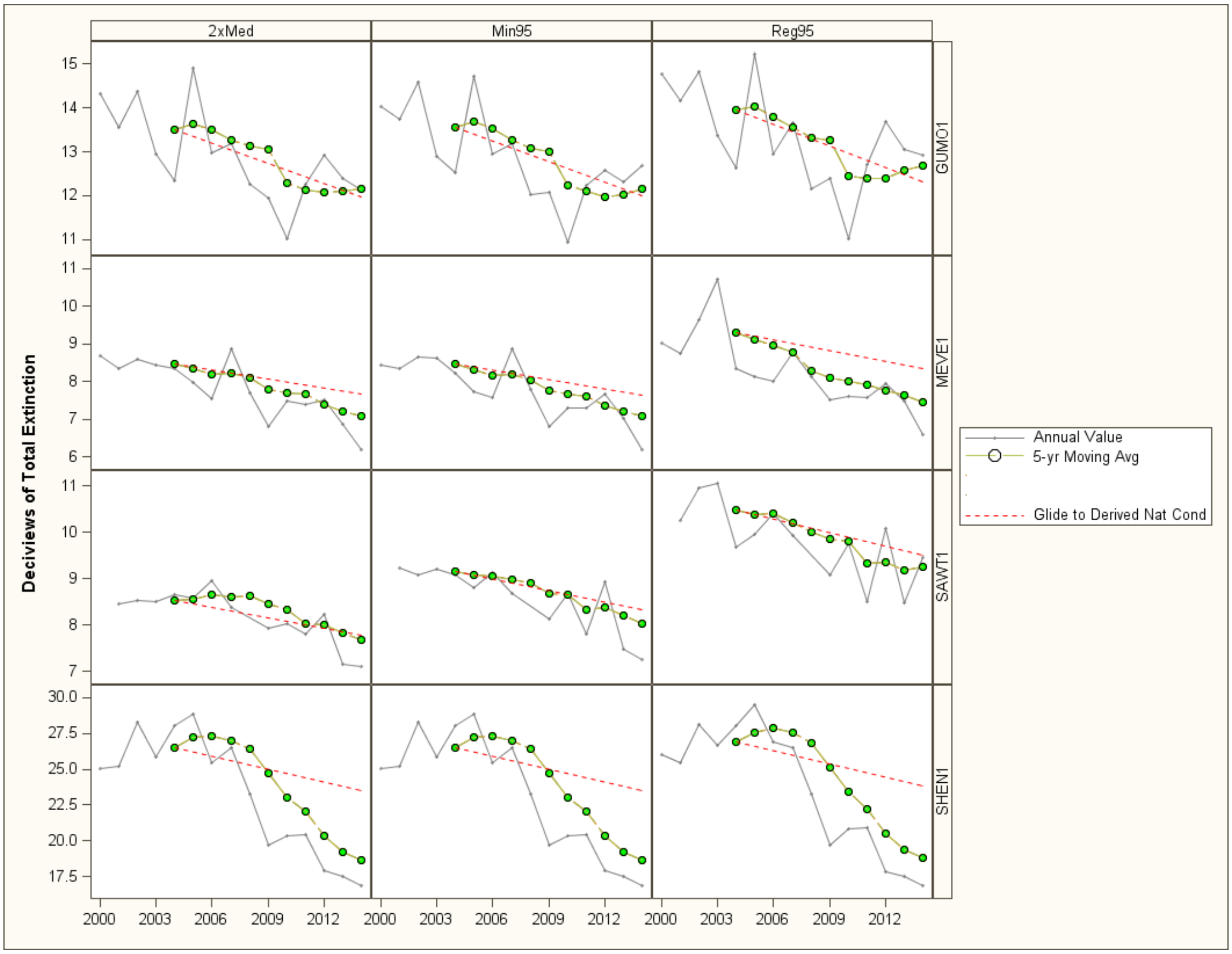

Figure 38. Most impaired day trends for four example sites, where e3 is derived by three different thresholds

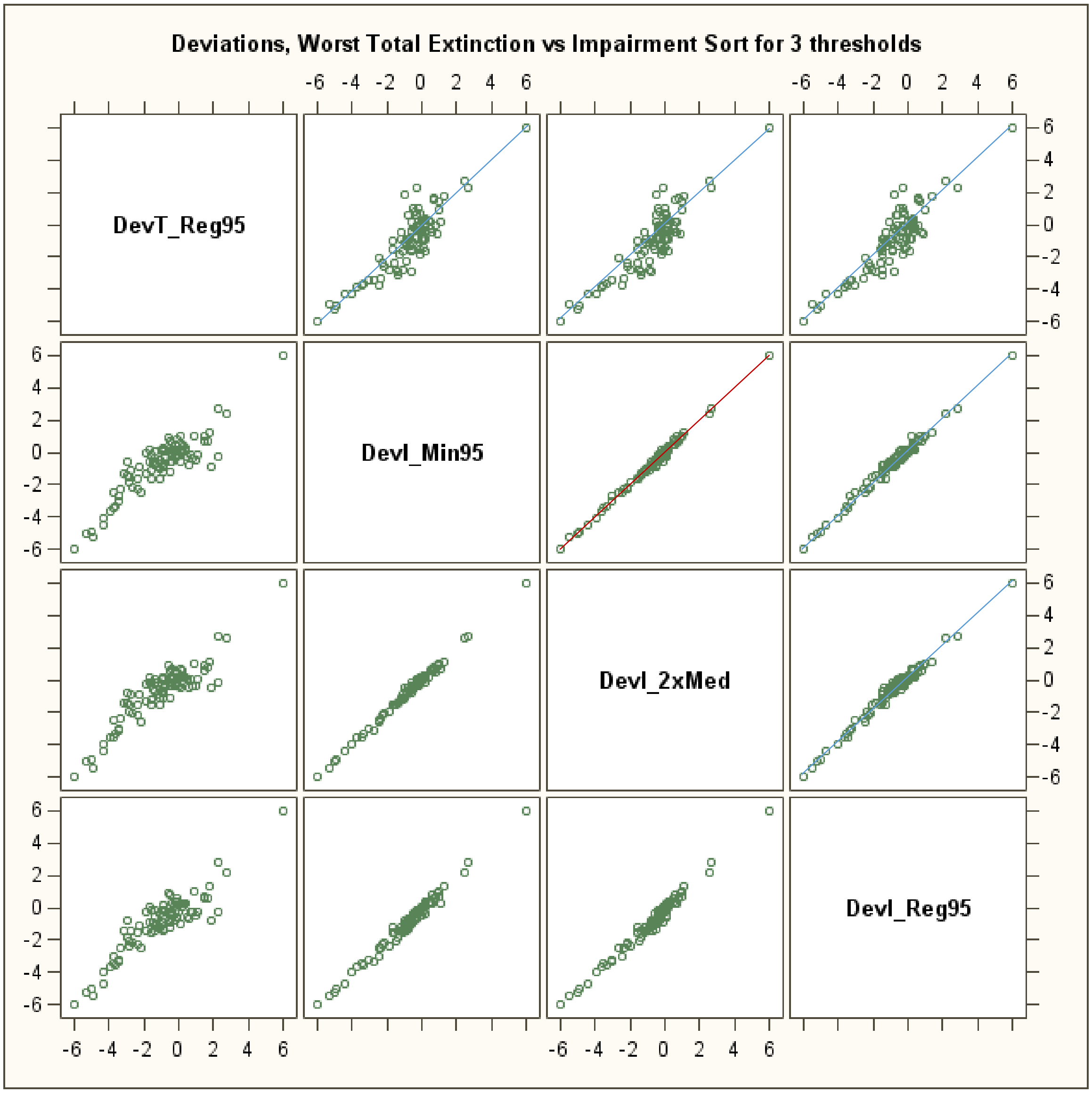

Figure 39. Deviations of 2010-2014 five-year average of the 20% worst days from the impairment-based glide paths, when e3 is derived by different threshold (DevI), compared to the deviations (DevT) for the first implementation period's total extinction approach. Note that the panels on the bottom left are mirror images of the top right panels

Other alternatives that could more directly account for potential trends in e3 (both retrospective and prospective) were not considered at this time. Possibilities include use of more than one year of data to define threshold within 2000-2014, say the use of different thresholds for individual 5-year periods; use of average or median of multiple thresholds; or outlier approaches that consider the relative variability of extinction values. The latter for example can involve examination of the tail of the statistical distribution of annual values.[45] Also, rather than using annual thresholds, seasonal thresholds could be used and considered for future updates to this methodology.

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[45] Curran, T. and Frank, N. Assessing the Validity of the Lognormal Model When Predicting Maximum Air Pollution Concentrations, 1975.

4.2 Selecting days based on anthropogenic extinction

In addition to the selecting the 20% most impaired days after splitting the daily extinction into the natural and anthropogenic fractions, it’s possible to select days for the tracking metric with the 20% highest anthropogenic extinction. Unlike the impairment method described in Section 2, this selection method has the potential benefit of identifying days with high anthropogenic extinction during periods of high natural extinction. However, Figure 40 shows that the glidepath deviation of the total deciviews using this sorting method resembles that of the first implementation period’s approach (shown in Figure 3) with positive deviations at many sites in the Northern Rockies and New Mexico. The deciview time series chart for Sawtooth shows that the highest anthropogenic haze year occurred in 2012 when smoke from wildfires affected the region. Despite the fact that much of the carbon from e3 events is assigned to the natural contribution, a small amount may remain in the estimated anthropogenic fraction. The potential misassignment, when combined with very low anthropogenic emission contributions from the surrounding region, results in several e3 days selected into the 20% highest anthropogenic extinction category.

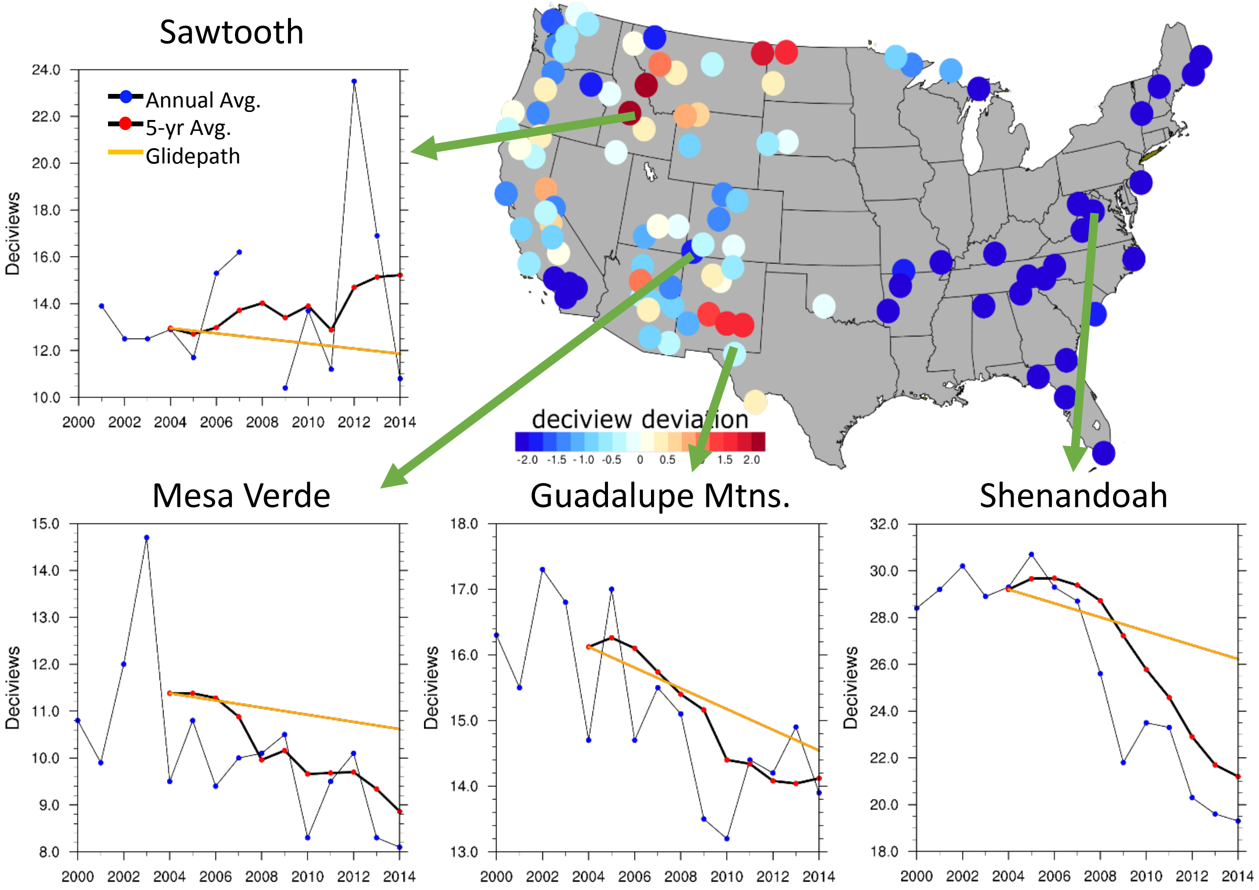

Figure 40. Glidepath deviation in deciviews for 20% highest anthropogenic extinction days from 2010-2014 and time series of glidepath and annual/5-year average deciview values

4.3 The potential role of data substitutions

When a day is identified as e3, there is the question of how to best estimate the carbon and dust extinction if e3 had not occurred. In the preceding discussions and calculations, the e3 and routine natural contributions are treated as mutually exclusive components the sum of which equals the total natural contribution. An alternative approach was considered for these analyses in which the natural contribution is based on a more typical value and is termed data substitution. Such substitution negates the need to split total extinction into an estimated anthropogenic and natural portion. While data substitution was not judged as a desirable approach within the new data analysis framework, its use is presented in this document for completeness.

4.3.1 Use of medians for e3 days

One data substitution approach involved identifying the e3 days as having carbon and dust values two times the 15-year median values and then substituting the median carbon and dust values for days identified as e3. Figure 41 illustrates the tracking metric which results from such a method.

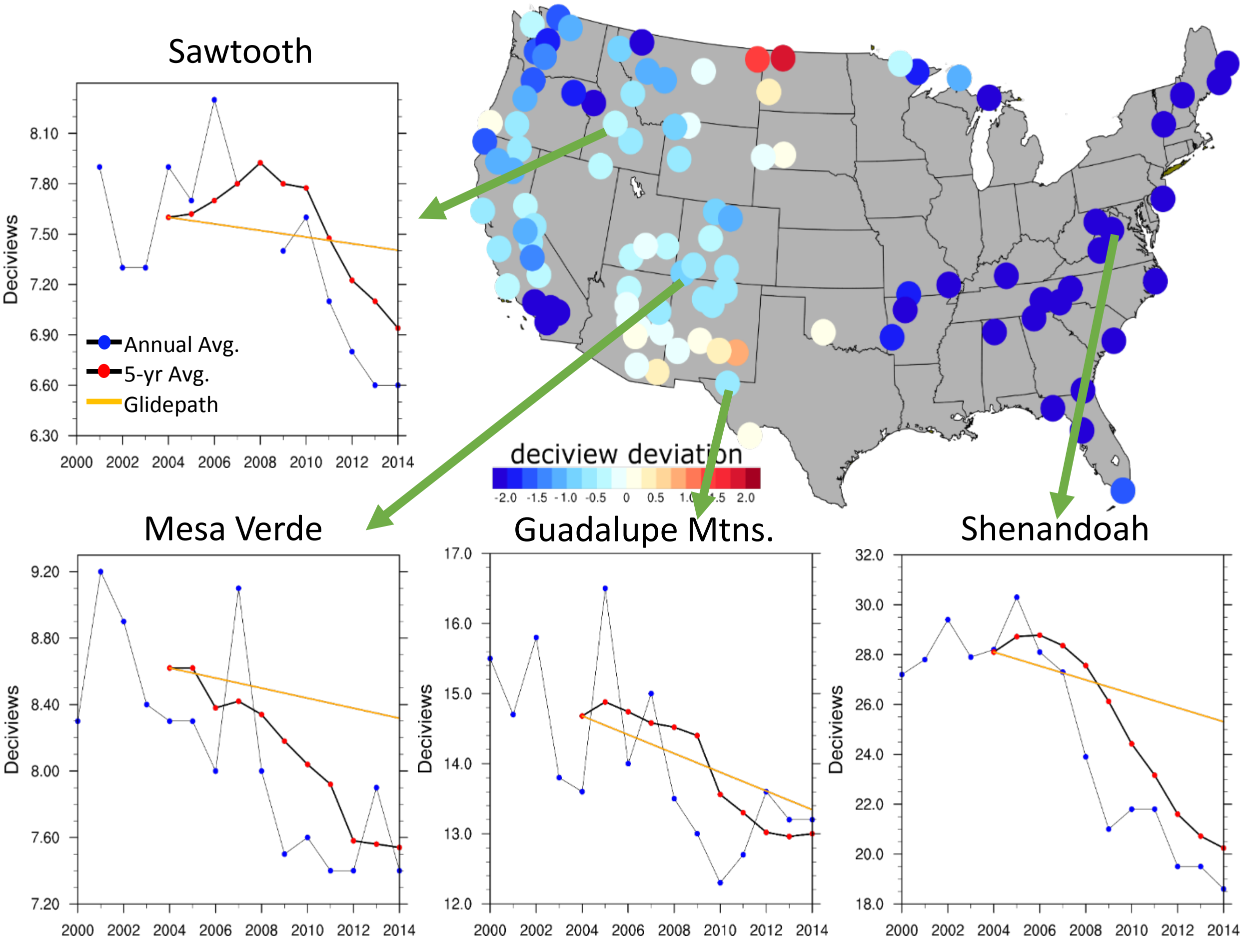

Figure 41. Glidepath deviation in deciviews for 20% haziest days from 2010-2014 and time series of glidepath and annual/5-year average deciview values when carbon and dust extinction are set to the median values on days when a 2xMedian e3 value is exceeded

This approach appears to effectively identify the more extreme values of extinction and remove the variable inter-annual effects of e3 and thus the likely influences of wildfire and dust events.

The substitution of the measurement based extinction with a single median value essentially replaces the observed carbon or dust with an established typical value from the distribution of observed values. In this manner, there is no need to make adjustments to the 2064 endpoint. This approach also appears to provide better tracking of visibility without the need to assign natural and anthropogenic factions to each day's values. It also avoids some of the vagaries of a daily split, such as calling carbon and dust anthropogenic when its levels are just below the established e3 threshold. That said, the substitution approach as presented eliminates the opportunity to provide an estimated anthropogenic extinction budget.

4.3.2 Considering all extinction as natural during e3 days

One potential variation to the natural-anthropogenic split for the impairment-based approach is to consider all extinction on days identified as e3 as natural and not consider them in the selection of the 20% most impaired. The assumption in this approach is that wildfire and dust event emissions may include a large but uncertain quantity of aerosol components other than carbon and dust. Figure 42 illustrates the large impact on tracking metric resulting from such a method.

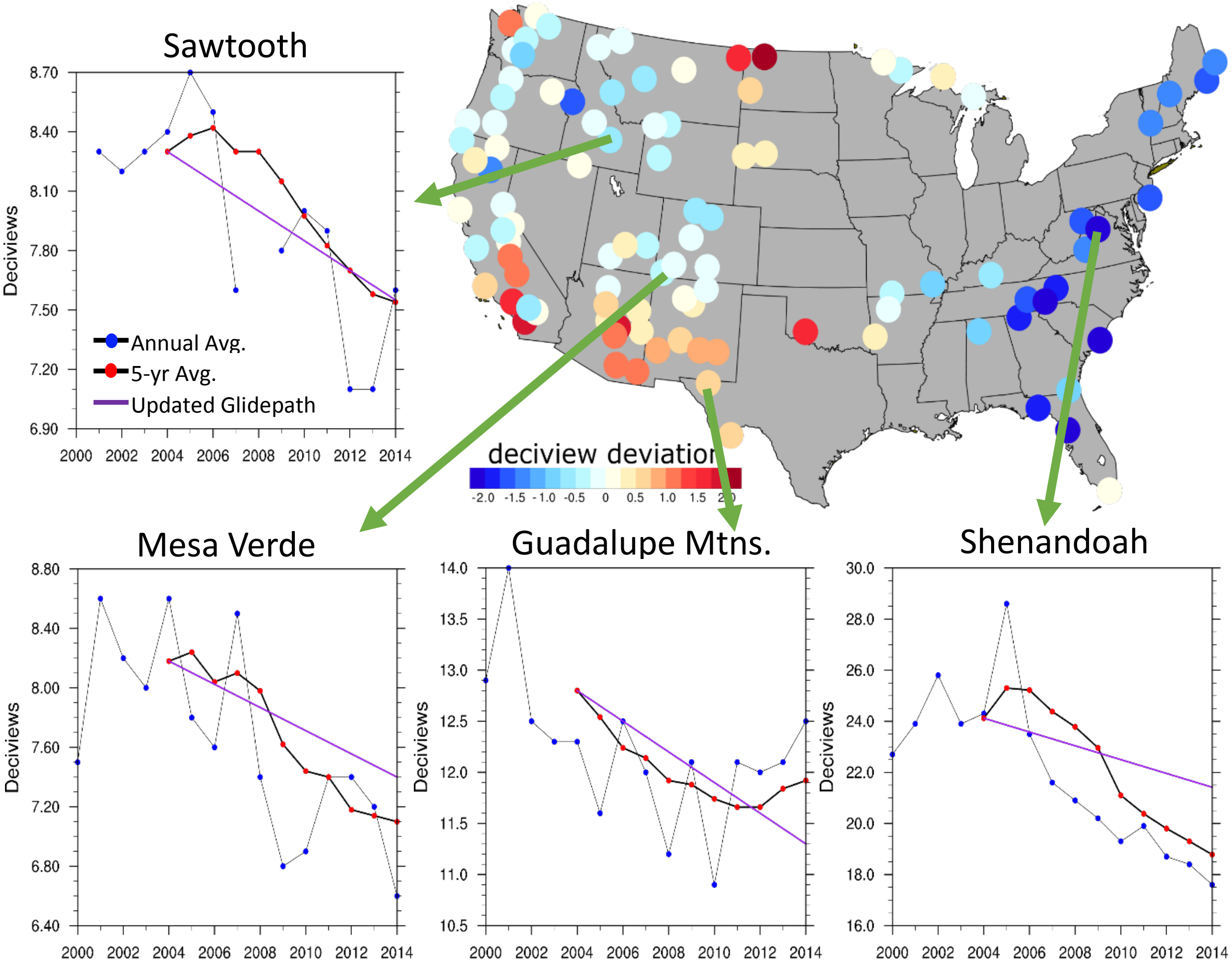

Figure 42. Glidepath deviation in deciviews for 20% most impaired days from 2010-2014 and time series of glidepath and annual/5-year average deciview values when all extinction on e3 days is considered natural

Compared to Figure 37 showing the glidepath deviation without considering all extinction on e3 days as natural, Figure 42 shows much warmer colors (positive deviation) at most sites across the Continental U.S. This is due to the fact that only days with very low natural extincton are considered in the 20% most impaired, resulting in large decreases in deciview values for both the baseline (2000-2004) and endpoint (2064) of the glidepath. Sites with a high number of e3 days and high anthropogenic extinction (such as those in Southern California) are impacted the most by this approach because these e3 days can fall into the 20% most impaired without the data substitution.

4.4 Other factors that affect metric results

While the EPA believes the impairment framework is appropriate for identification of worst days for tracking RH and that revised natural conditions estimates are needed to be consistent with the worst days represented by the draft updated tracking metric, there are limitations with existing input data which result in some anomalous results. Many of these limitations relate to the revised estimates of daily natural conditions, including known limitations of the Trijonis-based values, and relative biases in their representation of spatial and temporal trends in typical natural conditions.[46]

Natural conditions estimates derived in part from the Trijonis-based NCII values are uncertain. In the 1990 NAPAP report, the uncertainty was described as a factor of 2. Due to changes in monitoring techniques used for the underlying NAPAP report data and large changes in ambient concentration from which background in 1990 was estimated, it’s possible that an equivalent uncertainty analysis of the NCII values under current conditions would be quite different. There are also potential and not yet quantified atmospheric interactions between natural and anthropogenic emissions which add an additional complication. The effect of these issues becomes evident for many locations, particularly for the most recent years, where measurement derived annual average extinction for some aerosol components are less than the annual average NCII values. Although the methodology used in these analyses successfully addresses the very large and presumed natural contributions from carbon and dust producing more appropriate metrics for tracking purposes, the incorrect values for the average routine natural contribution can result in uncertain estimates of the anthropogenic extinction budget. This was discussed in Section 3.1.

Finally, it is noted that the uncertainty in the daily estimates of the total extinction split into anthropogenic and natural fractions also translate into 2064 endpoints and glidepaths which are also not without error. Thus the use and interpretation of the general methodology and application of the draft estimates of natural conditions should take these uncertainties into consideration. Section 5 and the remainder of this section provides some suggestions for further improvements to the current estimates of natural contribution and include some recommendations for continued research to improve these data.[47]

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[46] The ideas presented here may require more work and or research to fully implement. EPA welcomes suggested revisions to natural condition estimates by the States as part of their SIPs.

[47] Appendix C provides additional information regarding estimates of natural conditions that may be worth considering as part of any future work.

4.4.1 Natural conditions may have changed with changing anthropogenic pollution

First, the disaggregation algorithm of Trijonis-based estimates could result in annual average routine contributions which are less than the published NCII average values. This can result for example when there have been reductions in calculated aerosol component extinction. This can be a result of changes in anthropogenic emissions. When this situation occurs, the derived routine contributions are set equal to the measurement derived extinction values.

For such site-years, the effective anthropogenic contribution for these aerosol components – calculated as the difference between the total extinction and the estimated natural contribution – can in fact be zero. While anthropogenic contribution can be small relative to natural contributions, zero contribution is not judged to be a realistic situation. Accordingly, there are several IMPROVE sites for which the estimated daily natural contributions and derived natural conditions appears to be too high.

For extinction from OCM, there are 12 such sites for multiple years in the Eastern U.S.; another four sites in the West and six outside CONUS with this feature. In Figures 43-45, the annual average extinction from all measured OCM and the average non-e3 OCM constructed to represent routine contributions are shown. The difference between these two quantities is related to the effect of the e3 trimming algorithm. When the non-e3 OCM is less than the average Trijonis based value, the anthropogenic contribution from OCM becomes zero. This situation is a direct consequence of the data handling and occurs when the Trijonis based values are no longer representative of routine OCM contributions.[48] Because all measured extinction is not believed to result from natural contributions, further adjustments to the presented estimates of daily and average natural conditions are likely needed. This issue is discussed further in Appendix B.

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[48] The issue of average aerosol-based extinction being greater than average NCII values for aerosol components other than OCM is not addressed in this document.

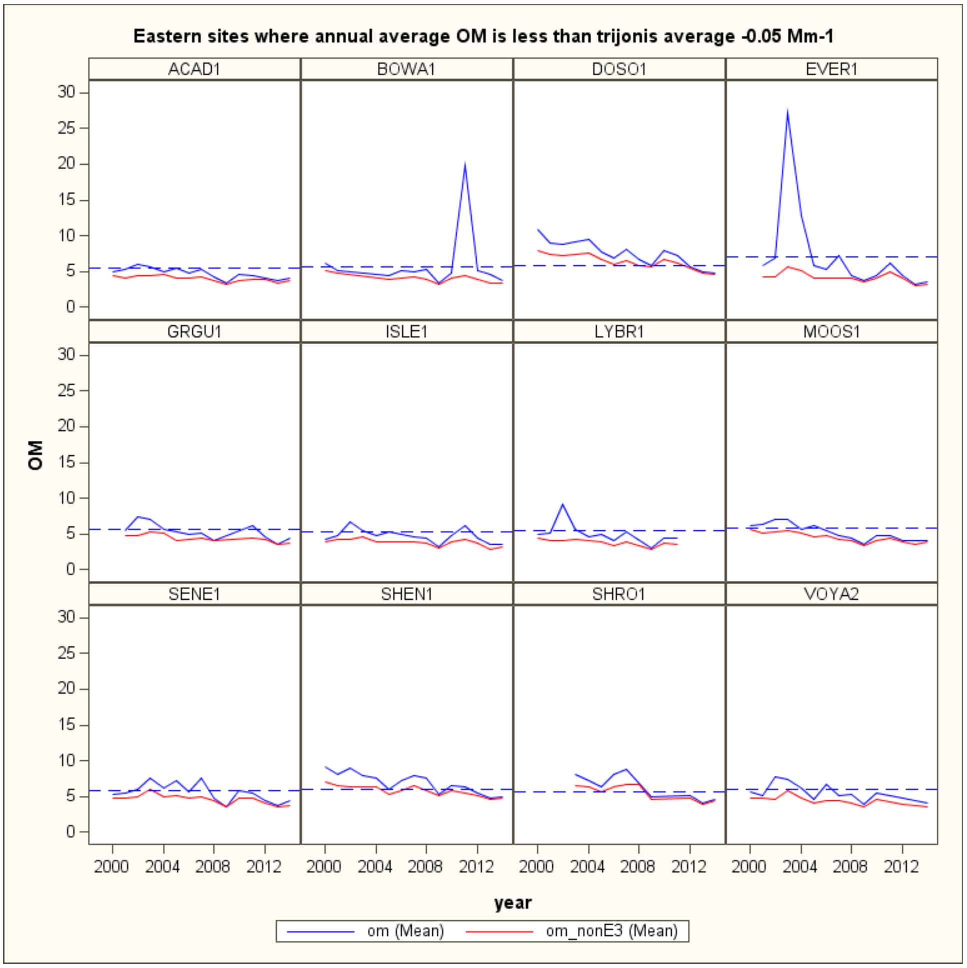

Figure 43. 12 Eastern sites whose annual average OCM is less than the average NCII value, for at least one year. The constant site specific NCII value is shown as the dashed line (OCM < Trijonis minus 0.05 used for selection of sites).

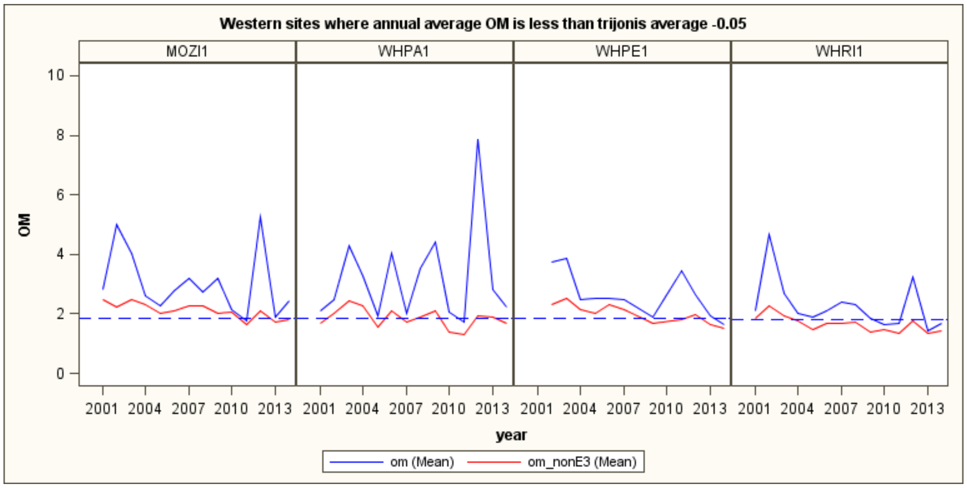

Figure 44. Four western sites where OCM < average NCII (Trijonis) value for at least one year.

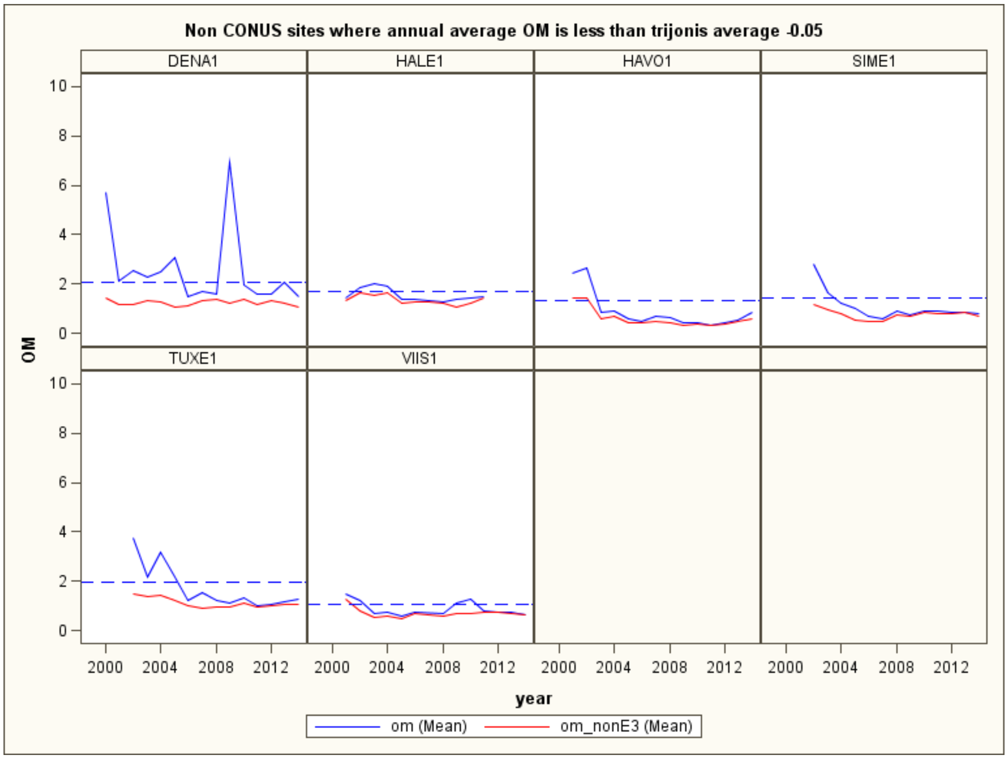

Figure 45. Six non-CONUS sites where OCM < average NCII value for at least one year

4.4.2 Consideration of elevation effects

One potential modification to the estimates of natural contribution is consideration of elevation differences in translating the simple Trijonis based regional average concentrations to better site level values.[49,50] Site-specific corrections have been previously shown to range from 0.86 (SHRO1) to 1.05 (SWAN1) in the Eastern U.S. and 0.79 (WHRI1) to 1.20 (TUXE1) in the Western U.S. These factors reduce the Trijonis-based values at high elevation locations. In deciview units, the elevation adjustment utilizes the magnitude of extinction, and its effect is smaller for clearer natural conditions.[51] For SHRO1 and SHEN1, whose Trijonis-based average extinction is 10.6 Mm^{-1}, consideration of elevation effects results in a 0.75 and 0.42 deciview reduction, respectively. For the high elevation White River National Forest (WHRI1) site in Colorado, consideration of elevation effects results in a 0.24 deciview reduction in the average extinction value.

4.4.3 Alternatives to the threshold approach

One consequence of a measurement driven threshold approach is the potential misassignment of high e3 values as natural. For example, in the Southeastern U.S., high OCM may not be

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[49] Rao et al. Chemical Speciation of PM2.5 in Urban and Rural Areas. EPA Trends Report. 2002, http://www3.epa.gov/ttn/caaa/t1/reports/cspm25_bid.pdf.

[50] Copeland S. A Statistical Analysis of Visibility-Impairing Particles in Federal Class I Areas, JAWMA, 55(11), 1621-1635, 2005.

[51] The dv dependence on Mm^{-1} means there is a larger change in dv units for days with high extinction. A factor of 0.79 and 100 Mm^{-1} translates to 2.1 less dv.

associated with fire and instead be associated with secondary organic aerosol (SOA). However, evidence suggests that the majority of SOA in remote locations results from biogenic contribution and that it is reasonable to assume that biogenic emissions and thus percent biogenic SOA (bSOA) are higher during the warmest months and days when concentrations of secondarily formed particles tend to be higher.[52,53,54,55]

In addition, the use of a threshold based on the lowest annual value can select a year which results at least in part from lower anthropogenic emissions. With decreasing extinction from a downward trend in such emissions, some high daily carbon extinction values could then be misclassified as e3 in the early years. To the extent that such extinction does not dominate the total, this categorization into natural is not expected to be consequential to the determination of worst days or estimation of the 2064 endpoint.[56]

Finally, the objectively defined threshold approach for carbon and dust does not make use of source receptor information. For example it does not require estimates of emissions, back trajectories to known emission sources or source apportionment modeling. One of the strengths of the approach is its simplicity. Source receptor analyses, albeit resource intensive, could supplement the analysis and provide important corroboration that the high carbon and dust in fact resulted from natural contributions. This topic is explored in Section 5.

4.4.4 Disaggregation using concentration-based thresholds

Second, e3 trimming and derivation of routine natural contributions could start with statistical thresholds based on measured concentration and calculated concentration values instead of derived extinction. This would be more consistent with the features of the revised IMPROVE algorithm and consider the different extinction efficiencies of small and large particles. In turn, this would result in a different seasonalized distribution of daily contributions. Thus, the concentrations associated with routine natural contributions for each aerosol component proportional to their measured concentrations (instead of assuming proportional extinction), would result in a different time series of natural conditions values. Although this approach would produce a different time series and relatively more extinction from natural contribution during the most polluted days, it will not resolve the consequence of annual average measurements less than the regional Trijonis concentrations.

4.4.5 Re-interpretation of data produced by older monitoring methods

Another source of uncertainty in the NCII average natural condition estimates is the measurement protocols for the data which were used by Trijonis in 1990 to establish regional average aerosol component concentrations. These may not be consistent with the current

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[52] Kleindienst et al (2007) “during the 6-month period between May and October, SOA from the precursor hydrocarbons contributed more than 40% of the measured OC concentration.

[53] Carlton et al (2009) A review of Secondary Organic Aerosol (SOA) formation from isoprene…..abundances highest in the periods of highest photochemical activity (daytime (Plewka et al., 2006) and summer months (Xia and Hopke, 2006; Kleindienst et al., 2007a)).

[54] Edgerton et al (2003) estimated the fractions of modern carbon to total ranged from 59 to 96% during july 2001 and Jan 2002.

[55] Lewis and Stiles (2006) 52-89% in Tampa Florida during May 2002.

[56] It is noted however that trends in bSOA are uncertain and may be affected by many factors including temperature and changing catalytic conversion with downward trending SO_2 and sulfates.

IMPROVE protocol.[57] For example, different quantities of organic carbon result from thermal optical analyses, e.g. use of TOT vs IMPROVE TOR protocol. A more significant difference may involve the lack of corrections for sampling artifacts (ie. blank correction) in studies during the 1980's.[58,59]

5 Source apportionment modeling results in the development of revised estimates of natural visibility conditions

One issue that is particularly worthy of discussion is the need for better estimates of natural contribution. The described Trijonis-based daily estimates of routine natural conditions use the assumption that the natural contribution portion of each aerosol component is proportional to the observed daily extinction. When the annual average extinction for a component is less than the Trijonis-based extinction value, however, all of the observed extinction is called natural. As discussed earlier, this results in zero estimated anthropogenic contribution for some components for such years. Rather than assume that the proportion of natural contribution is the same for each day, information from source apportionment modeling shows that the proportions vary throughout the year. This is something to consider as a potential revision to the draft procedure described earlier in this document, as discussed in more detail below.

5.1 Percent natural OCM

Using a "hybrid source apportionment model" developed by Schichtel, the monthly average natural contributions of OCM for 2006-2008 have been calibrated to ambient OCM for 20 groupings of IMPROVE sites.[60] A map showing regional site groupings is included in Appendix G of this document. These results are depicted in Figure 46 which compares these model-based natural contribution values (blue line) to those of the Trijonis-based method together with the assumption that the routine natural contribution has the same percentage of the non-e3 portion of OCM throughout the year.

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[57] Chow J.C., Watson J.G., Chen L.-W.A., Chang M.C.O., Robinson N.F., Trimble D., and Kohl S. The IMPROVE-A temperature protocol for thermal/optical carbon analysis: maintaining consistency with a long-term database. Journal of the Air & Waste Management Association, 57, 1014-1023, 2007.

[58] One of the papers referenced by Trjonis was Huntzicker et al (1986) Combustion as the Principal Source of Carbonaceous Aerosol in the Ohio River Valley http://www.tandfonline.com/doi/pdf/10.1080/00022470.1986.10466105 . In this study, concentrations of organic and elemental carbon were measured by a thermal-optical carbon analysis procedure on quartz filters collected by hivolume samplers. Steve McDow, one of the co-authors, does not believe that corrections were made for sampling artifacts during such early studies and could have been responsible for a large portion of the reported OC. A second paper referenced by Trijonis is Shah (1986) who derived his results from analysis of fiberglass filters with high volume samplers. Because they were stored at room temperature for 6 years, he believes the findings are underestimates. Nevertheless, those results are subject to sampling artifacts and are also very uncertain.

[59] Chow, J. C., Watson, J. G., Chen, L.-W. A., Rice, J., and Frank, N. H. Quantification of $PM_{2.5}$ organic carbon sampling artifacts in U.S. networks, Atmos. Chem. Phys., 10, 5223–5239, 2010.

[60] Schichtel, B.A, Rodriguez, M.A., Barna, M.G., Gebhart, K.A., Pitchford, M.L., Malm, W.C. A semi-empirical, receptor-oriented Lagrangian model for simulating fine particulate carbon at rural sites. Atmos.Environ., 61, 361-370, 2012.

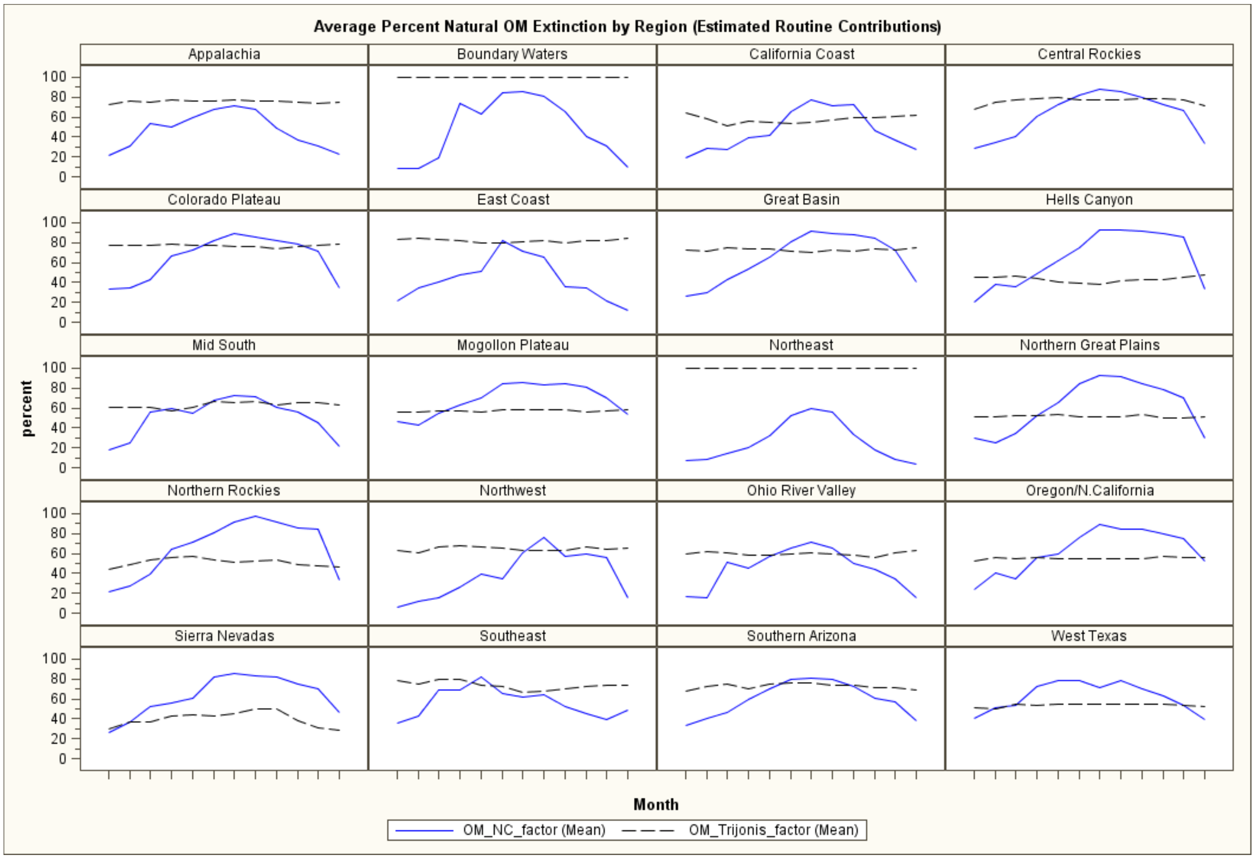


Figure 46. Comparison of monthly average percent of routine OCM extinction associated with natural OM by region using two different methods

Although these results are not available for California and non-CONUS sites, they clearly show a strong seasonality which is in obvious contrast to the relatively constant proportions in the Trijonis-based methodology used in this document. Moreover, it shows that on average, the percent natural contribution is much lower during the summer for IMPROVE sites in the aforementioned eastern regions (e.g. Appalachia – which includes SHEN1; Boundary Waters; East Coast; North East). Use of such values in the split algorithm would assign more anthropogenic OCM to SHEN1 and other eastern IMPROVE sites. Conversely, these model-based data suggest that seasonal natural contributions may be much higher than the Trijonis based values for several western regions (e.g. Hells Canyon – which includes SAWT1; Northern Great Plains Northern Rockies). The latter would translate to less impairment for those individual days and thus can lead to a selection of different days. It also means less estimated anthropogenic OCM for those IMPROVE sites than assigned by the draft default method. This can be important for a derived extinction budget for estimated anthropogenic contribution to allow observation data to assist with the identification of potential emissions sources and development of control strategy options for demonstrating reasonable further progress.

5.2 Estimated routine natural contributions from OCM

To the extent that OCM is a large contributor to the total haze (after consideration of e3), these model-based results could potentially alter the selection of the most impaired days, estimated total natural contribution and resulting glidepath. To initially explore this issue, the estimated monthly routine OCM is first provided for the Trijonis- and model-based data as shown in Figure 47. Additionally, Figure 48 shows the difference in estimated average deciviews of total natural contributions for each method. In both figures, only the most impaired days are included. While the former shows a large difference for the individual OCM component for most regions, the latter figure indicates that the effect may only be important for some of the western regions in which the estimated natural contributions are higher for the summer months.

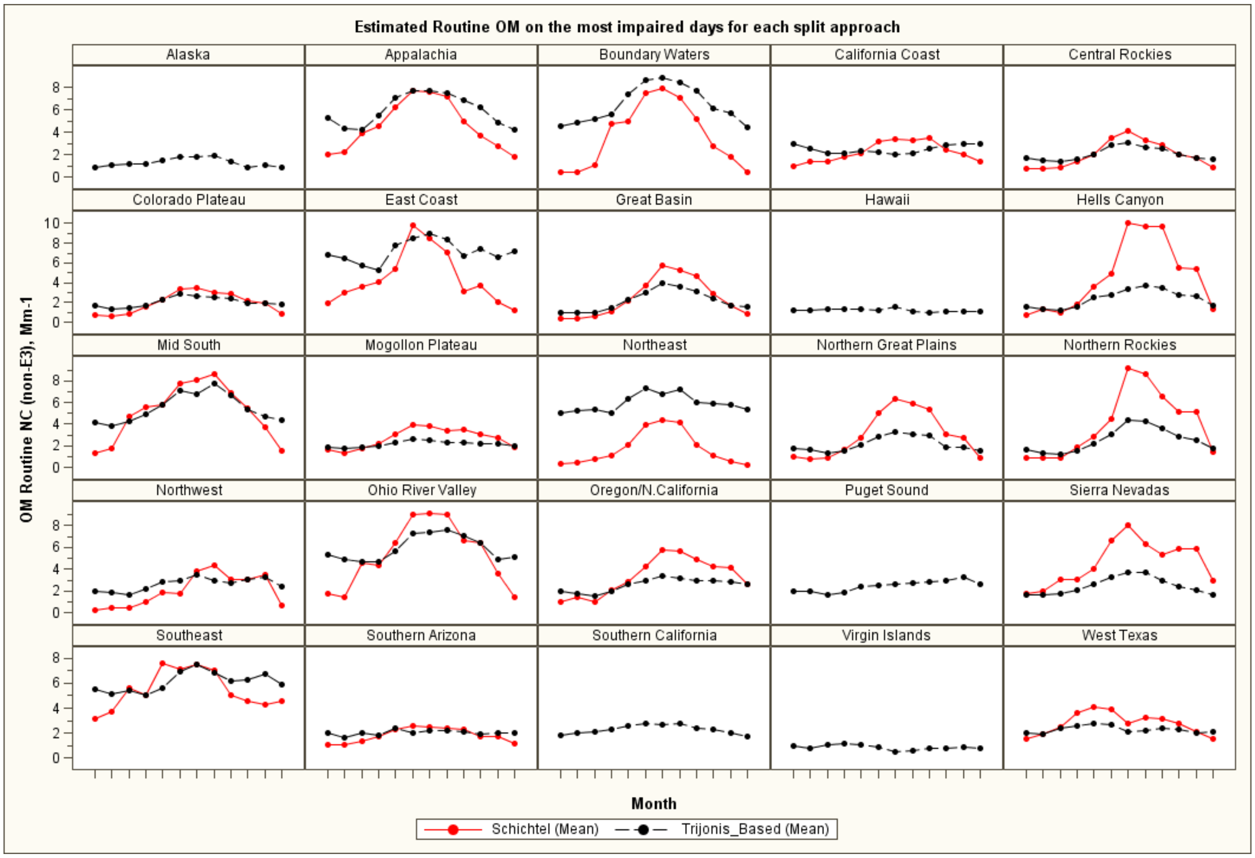


Figure 47. Comparison of monthly average extinction of routine OCM associated with natural OM by region using two different methods.

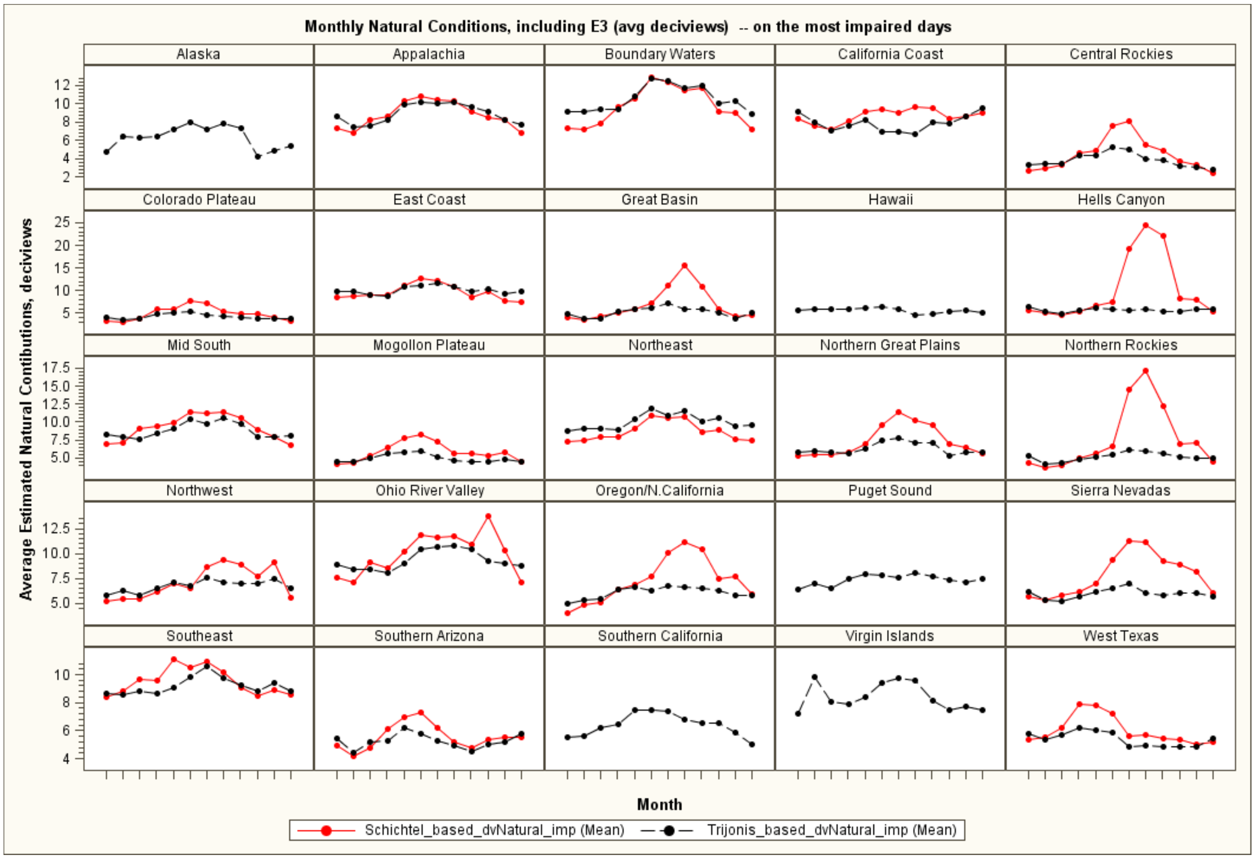


Figure 48. Comparison of monthly average deciviews associated with natural extinction by region using two different methods to estimate daily natural contributions.

Next, the typical effect of the model-based estimates for the OCM portion of natural conditions is examined in terms of the resulting estimated impairment attributed to anthropogenic emission sources. For those regions where the estimated natural contributions are lower, albeit by a small amount, the amount of impairment is higher. This is apparent for Appalachia, Boundary Waters and the Northeast regions as shown in Figure 49. For those western regions where the estimated natural conditions are higher (e.g. Hells Canyon, Northern Rockies), the change in summer time impairment is lower or relatively unchanged, while the temporal distribution is somewhat modified for some regions. In Hells Canyon, for example, the estimated impairment is higher in the winter for the model-based estimate.

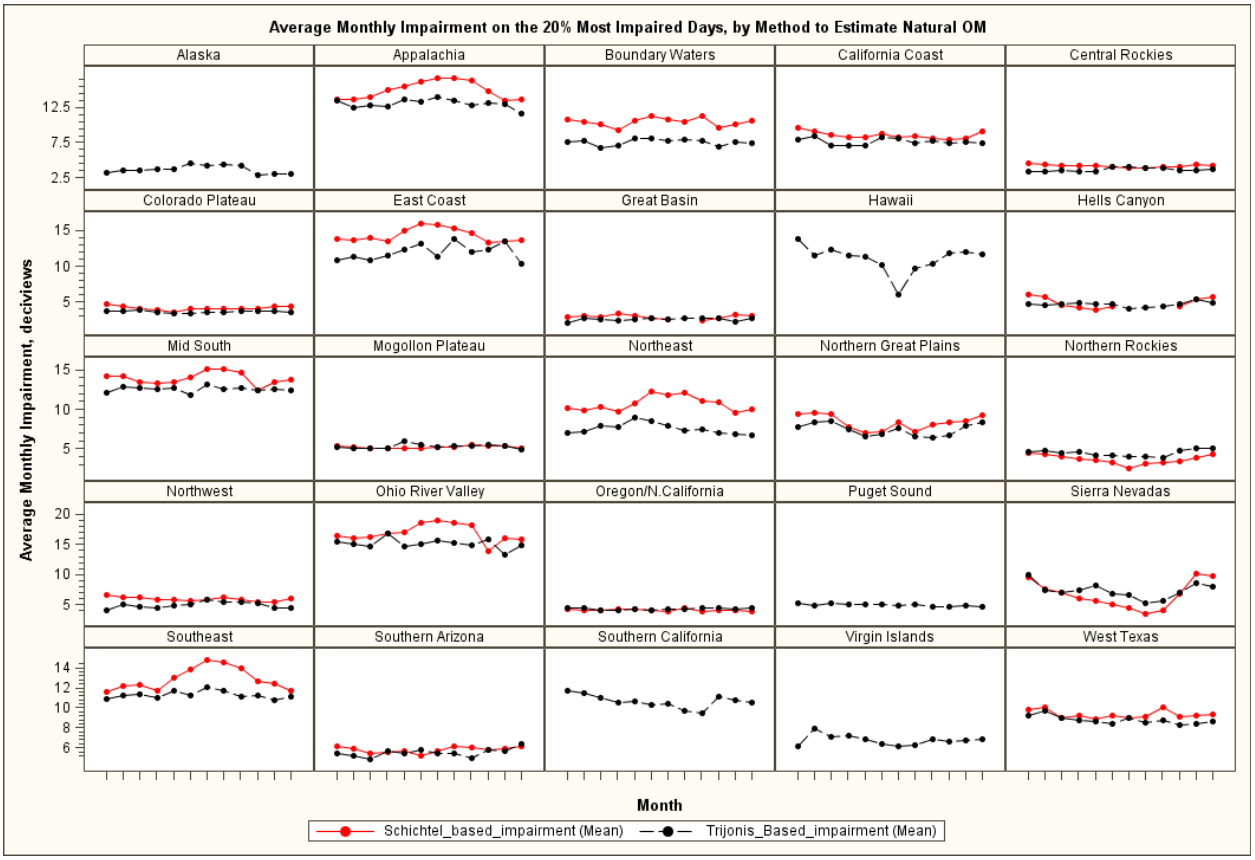


Figure 49. Comparison of monthly average anthropogenic impairment by region using two different methods to estimate daily natural contributions.

5.3 Effect of alternative estimated natural conditions on the tracking metric

The effect of the alternative model-based hybrid estimates are examined in terms of the new tracking metric. Figure 50 presents the annual average of the total deciviews on the most impaired days using the default and alternative estimates of daily natural contributions. The figure suggests that on average, for the scale illustrated and for the regions with model-based estimates, the method to estimate natural conditions does not appear to substantially affect the resulting trends.

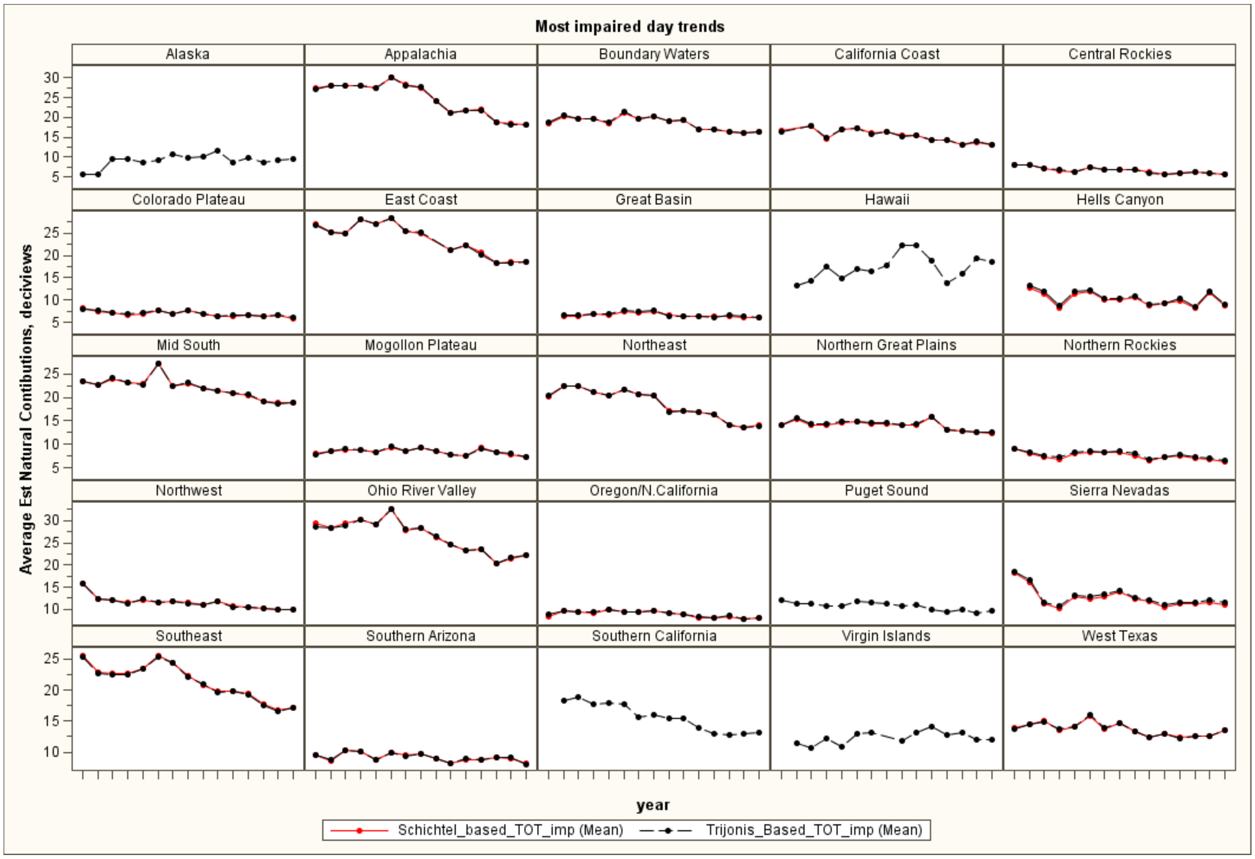


Figure 50. Comparison of annual average trend in deciviews on the 20% most impaired days by region using two different methods.

While the average results above are suggestive that the manner in which natural contributions for a component such as OCM may be important, the results for specific sites are obviously most relevant. Furthermore, the estimated impairment (and particularly, the total haze on the most impaired days) must be examined relative to average natural conditions and the glidepath which is anchored by the 2064 value of average natural conditions. Section 3.3 shows the combined results of changes in 5-year average impairment and long-term average natural conditions in terms of the slope and deviations from the respective glidepaths. Those results suggest that the combined effect resulting from changes to the estimated daily natural contributions from OCM may not be important for the vast majority of IMPROVE locations.

Similar to the regional trends presented earlier, Figure 51 shows that the impact of these different approaches is relatively small at both Sawtooth and Shenandoah. At Sawtooth, the very low deciview values make the small impacts relatively more important. The complete set of all site trends including 5-year running averages relative to their glidepaths is presented in Figure 52. Please keep in mind that the uniform vertical scales used for each row in the two panels of this figure compress the differential trends for many western locations with their lower total haze on their most impaired days.

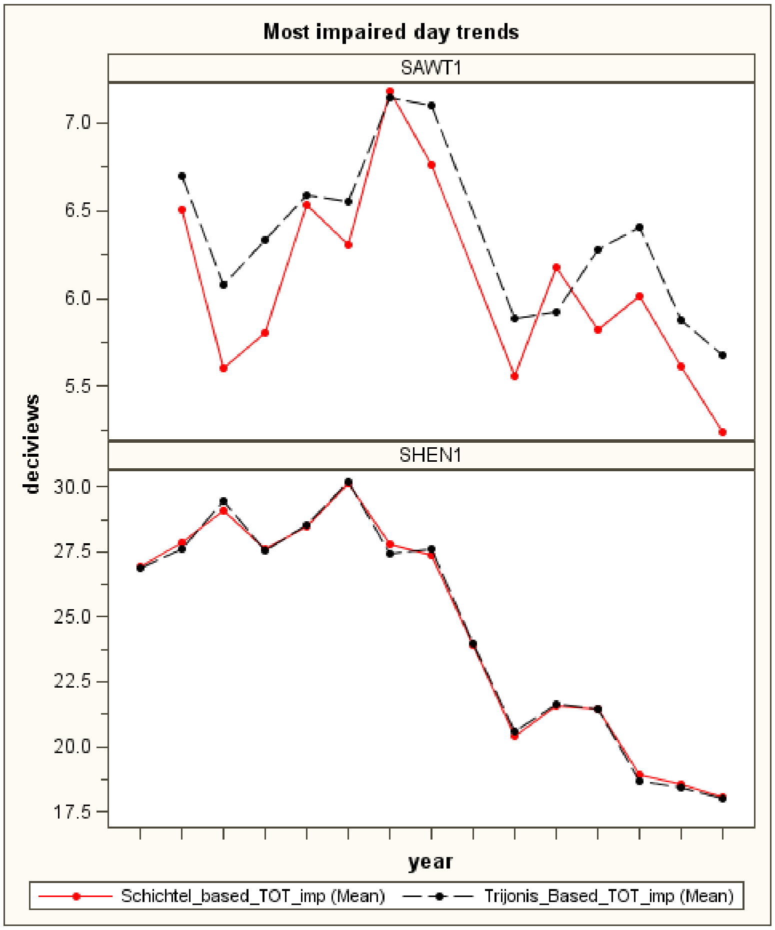
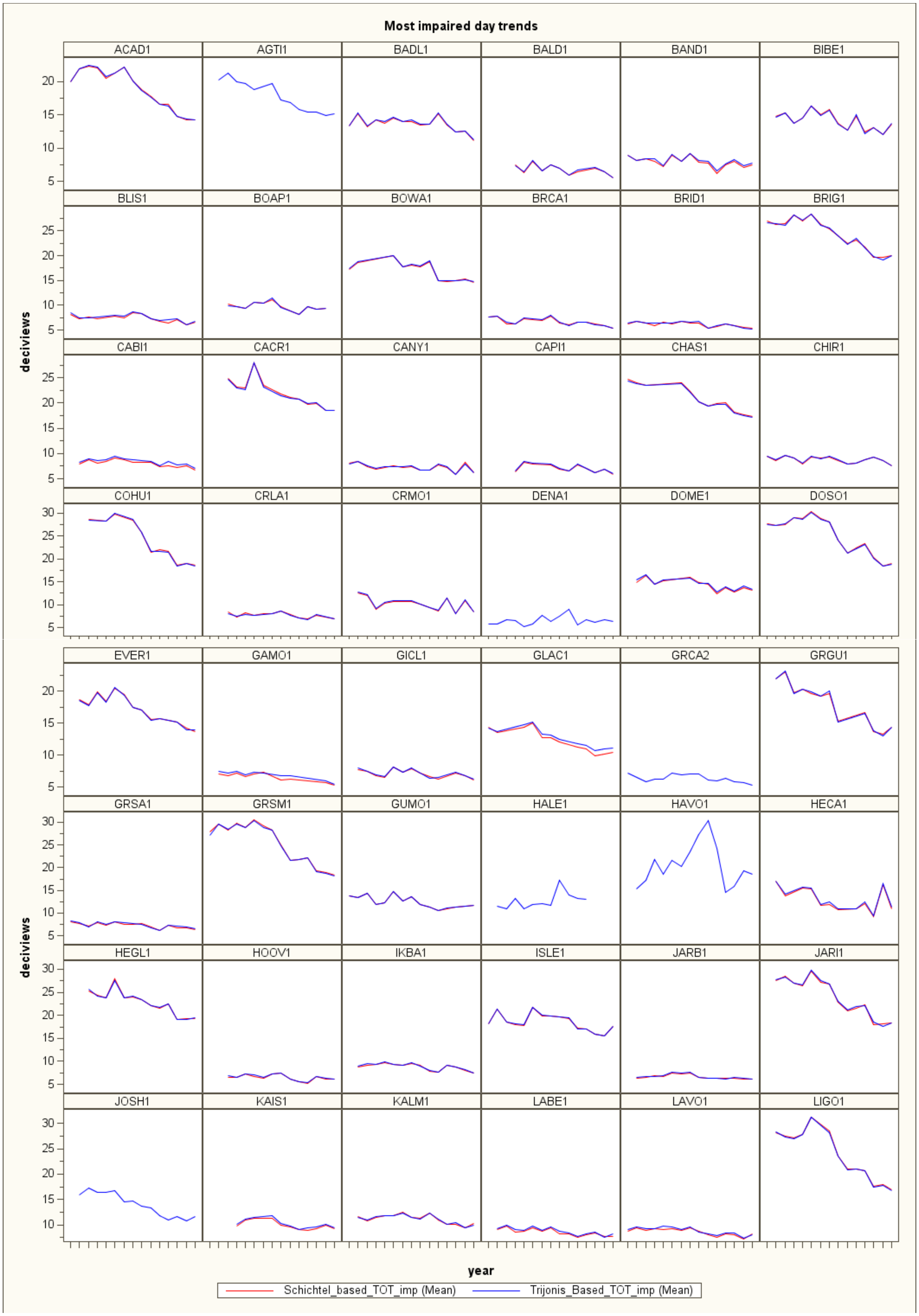
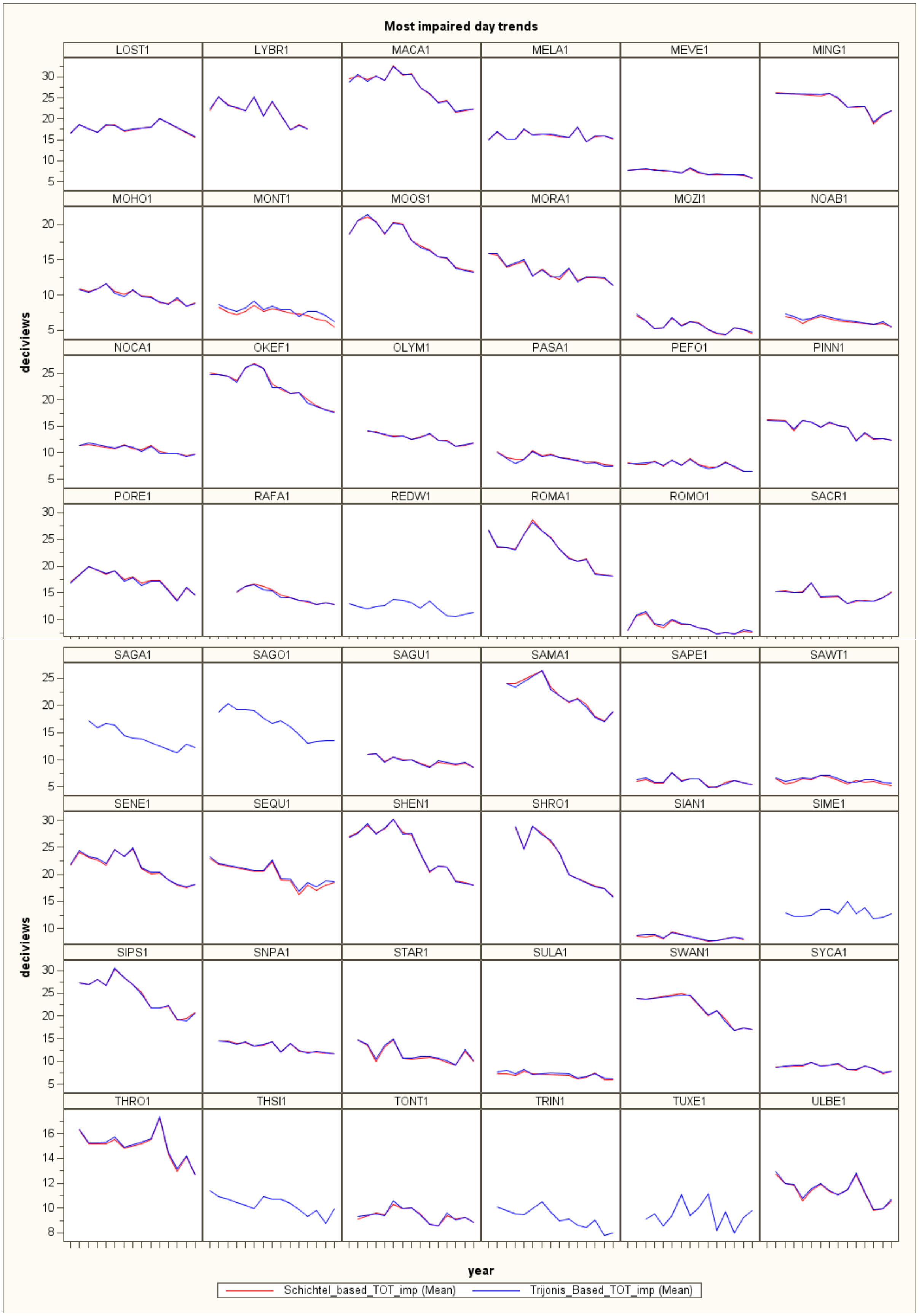


Figure 51. Comparison of annual average trend in deciviews on the 20% most impaired days at Sawtooth (SAWT1) and Shenandoah (SHEN1) using two different methods.


Most impaired day trends
ACAD1
AGTI1
BADL1
BALD1
BAND1
BIBE1
BLIS1
BOAP1
BOWA1
BRCA1
BRID1
BRIG1
CABI1
CACR1
CANY1
CAPI1
CHAS1
CHIR1
COHU1
CRLA1
CRMO1
DENA1
DOME1
DOSO1
EVER1
GAMO1
GICL1
GLAC1
GRCA2
GRGU1
GRSA1
GRSM1
GUMO1
HALE1
HAVO1
HECA1
HEGL1
HOOV1
IKBA1
ISLE1
JARB1
JARI1
JOSH1
KAIS1
KALM1
LABE1
LAVO1
LIGO1
deciviews
5
10
15
20
25
30
year
Schichtel_based_TOT_imp (Mean)
Trijonis_Based_TOT_imp (Mean)


Most impaired day trends
LOST1
LYBR1
MACA1
MELA1
MEVE1
MING1
MOHO1
MONT1
MOOS1
MORA1
MOZI1
NOAB1
NOCA1
OKEF1
OLYM1
PASA1
PEFO1
PINN1
PORE1
RAFA1
REDW1
ROMA1
ROMO1
SACR1
SAGA1
SAGO1
SAGU1
SAMA1
SAPE1
SAWT1
SENE1
SEQU1
SHEN1
SHRO1
SIAN1
SIME1
SIPS1
SNPA1
STAR1
SULA1
SWAN1
SYCA1
THRO1
THSI1
TONT1
TRIN1
TUXE1
ULBE1
deciviews
deciviews
year
Schichtel_based_TOT_imp (Mean)
Trijonis_Based_TOT_imp (Mean)

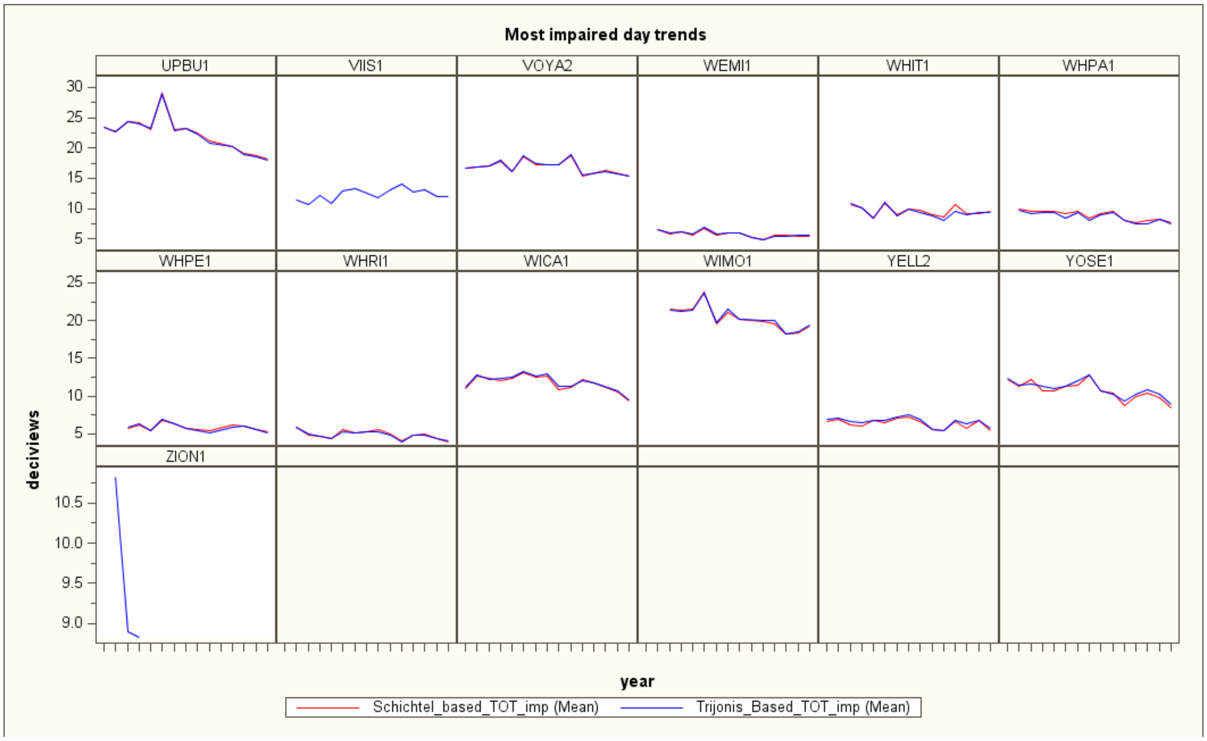


Figure 52. Comparison of annual average trend in deciviews on the 20% most impaired days at all sites using two different methods.

5.4 Effect of alternative natural conditions on the estimated extinction budgets

As shown in Section 5.2, changing the estimates of the routine natural contribution can also affect the estimated anthropogenic portion of the extinction budget. Figure 53 contrasts those estimates for two locations: Sawtooth and Shenandoah. The use of the Trijonis-based estimates (with the assumption that percent natural contribution is the same each day) seem to result in a budget with too much residual OCM on the days at Sawtooth with estimated wildfire impacts, and zero OCM at Shenandoah during the most recent years when annual average of measured OCM is less than the Trijonis-based values. With the varying proportions of daily natural conditions from model-based approach, a different set of days are selected as the most impaired. These days shown in the figure are different than that of the Trijonis-based approach and do not include the e3 days. Thus, the revised set of the most impaired days have less estimated anthropogenic contribution from OCM producing emission sources. The selected most impaired days are essentially the same at Shenandoah with both routine natural contribution methods. With the hybrid modeling, which is not constrained by the relative level of the Trijonis value, OCM is now included in the anthropogenic extinction budget. The Shenandoah budget is still sulfate dominated, but the small amount of OCM and EC remaining in the anthropogenic budget is more consistent with previous studies.[61]

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[61] Schichtel, B.A, Malm, W.C., Bench, G., Fallon, S., McDade, C.E., Chow, J.C., Watson, J.G. Fossil and contemporary fine particulate carbon fractions at 12 rural and urban sites in the United States, J. Geophys. Res., 113, D02311, 2008.

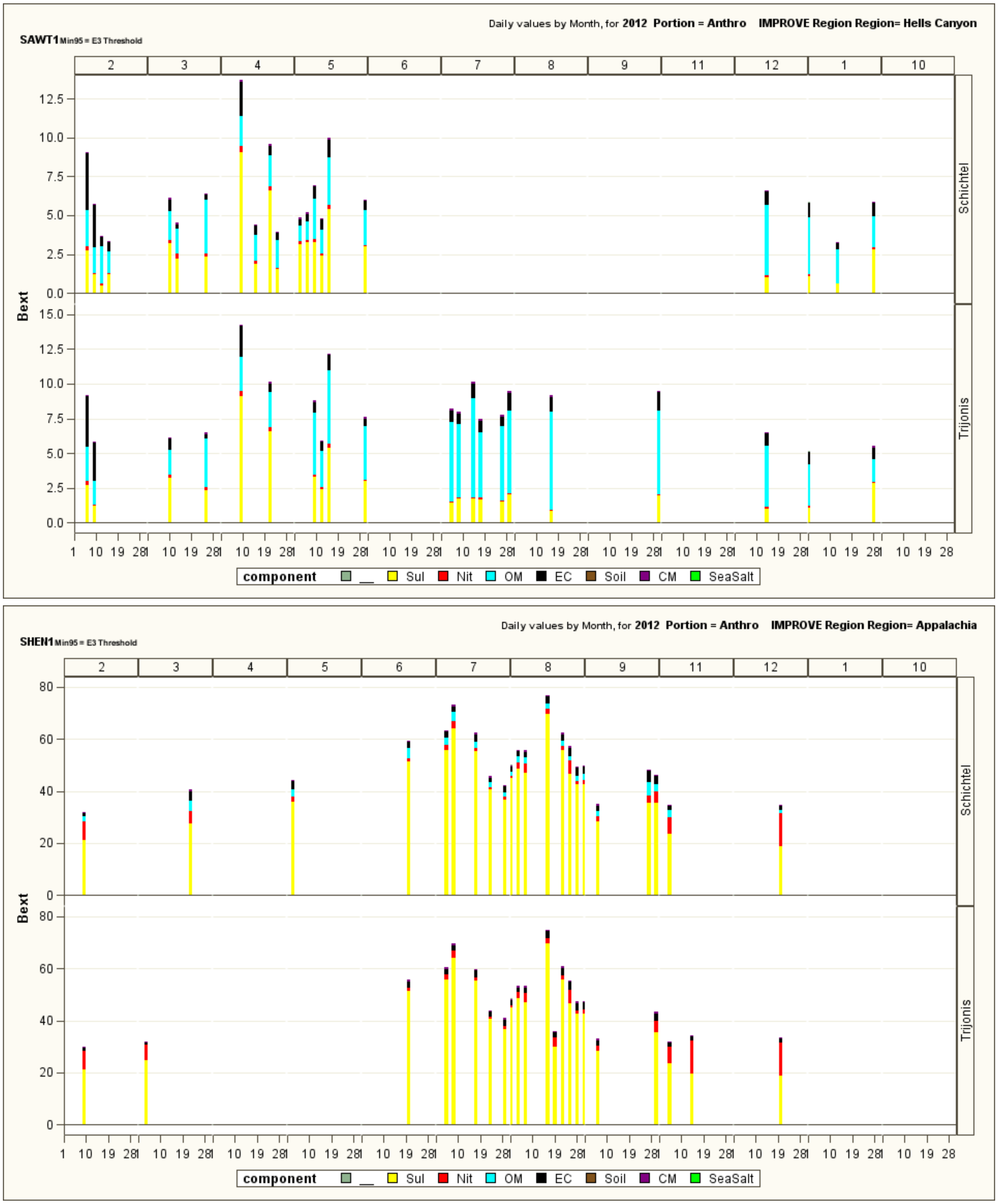

Figure 53. Comparison of daily anthropogenic extinction budgets on the 20% most impaired days in 2012 at Sawtooth (SAWT1) and Shenandoah (SHEN1) using two different methods.

The effect of the alternative approach is shown in Figure 54 in terms of the trends in the worst 20% of the days. Similar to Figure 53, Figure 54 shows that the anthropogenic OCM is lower at Sawtooth and higher at Shenandoah. The alternative estimates of the total haze on the most impaired days and the responsible differences in estimated natural contributions are also shown, albeit at different scales. The trends in annual extinction presented here in Mm^{-1} correspond to the trends previously presented in deciview units. A graphical summary of the average anthropogenic extinction budgets by season for all sites in the continental U.S is presented in Appendix F.

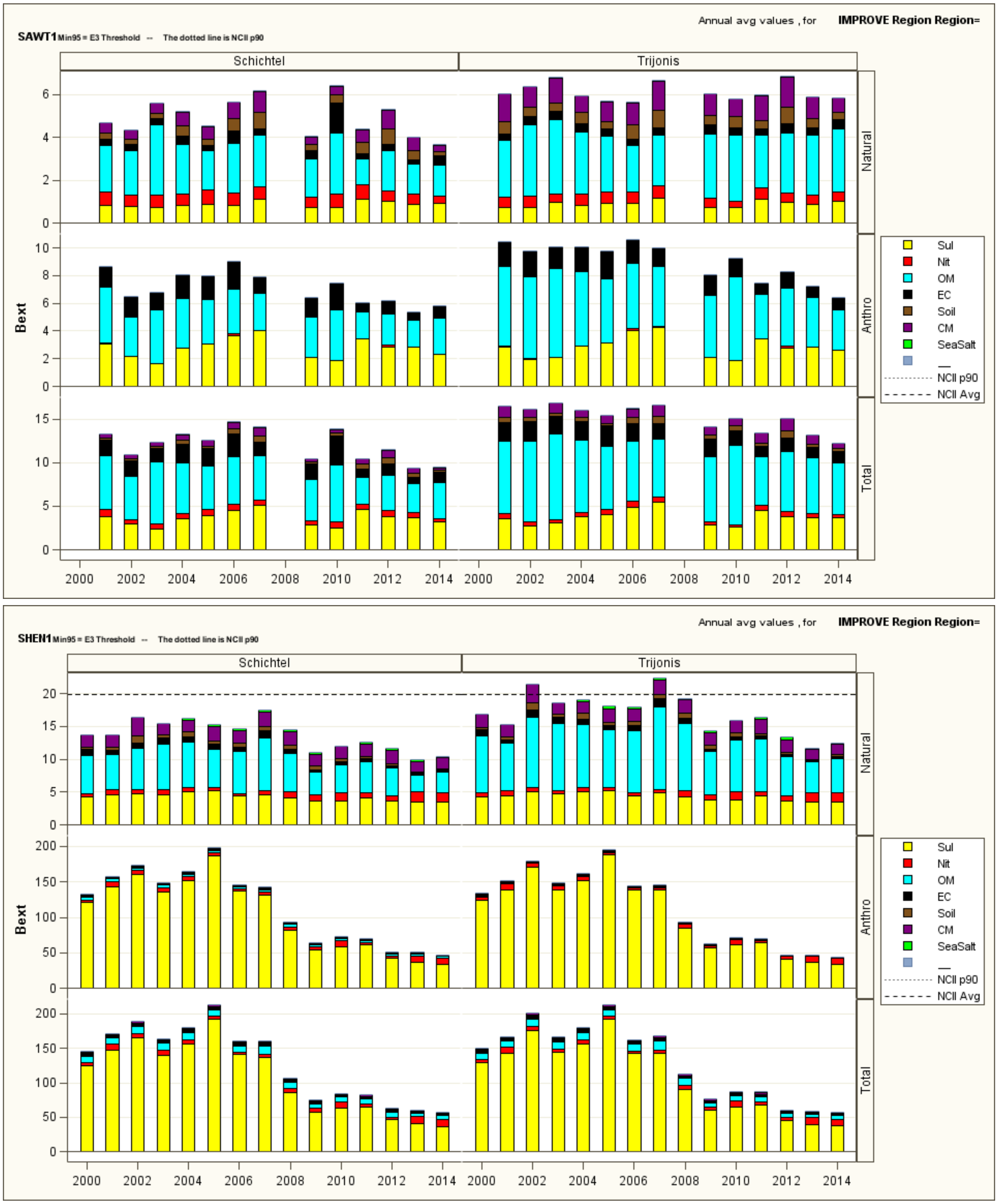

Figure 54. Comparison of the annual average anthropogenic, natural and total extinction budget on the 20% most impaired days at Sawtooth (SAWT1) and Shenandoah (SHEN1) using two different methods.

6 Evalution of revised natural conditions and extinction on the clearest days

The magnitude and extinction budgets of the clearest days play a useful role in the evaluation of natural conditions estimates for the most impaired days. Comparisons to the clearest days help us further understand these estimates and provide additional confidence in their use. Examination of the clearest days also confirm the value of splitting total extinction into estimated anthropogenic and natural contributions. In addition, examination of the clearest days provide additional information about changes in visibility conditions during 2000-2014.

Figure 55 shows the regional differences in the relative magnitude of the estimated natural conditions on the most impaired days compared to the 15-year average deciviews on the clearest days. The impaired day natural conditions estimates are less than the clearest days in the Southeastern U.S. and at a few other locations including several in the southwest. Otherwise, the average visibility conditions depict less haze on the clearest days throughout other areas of the U.S.

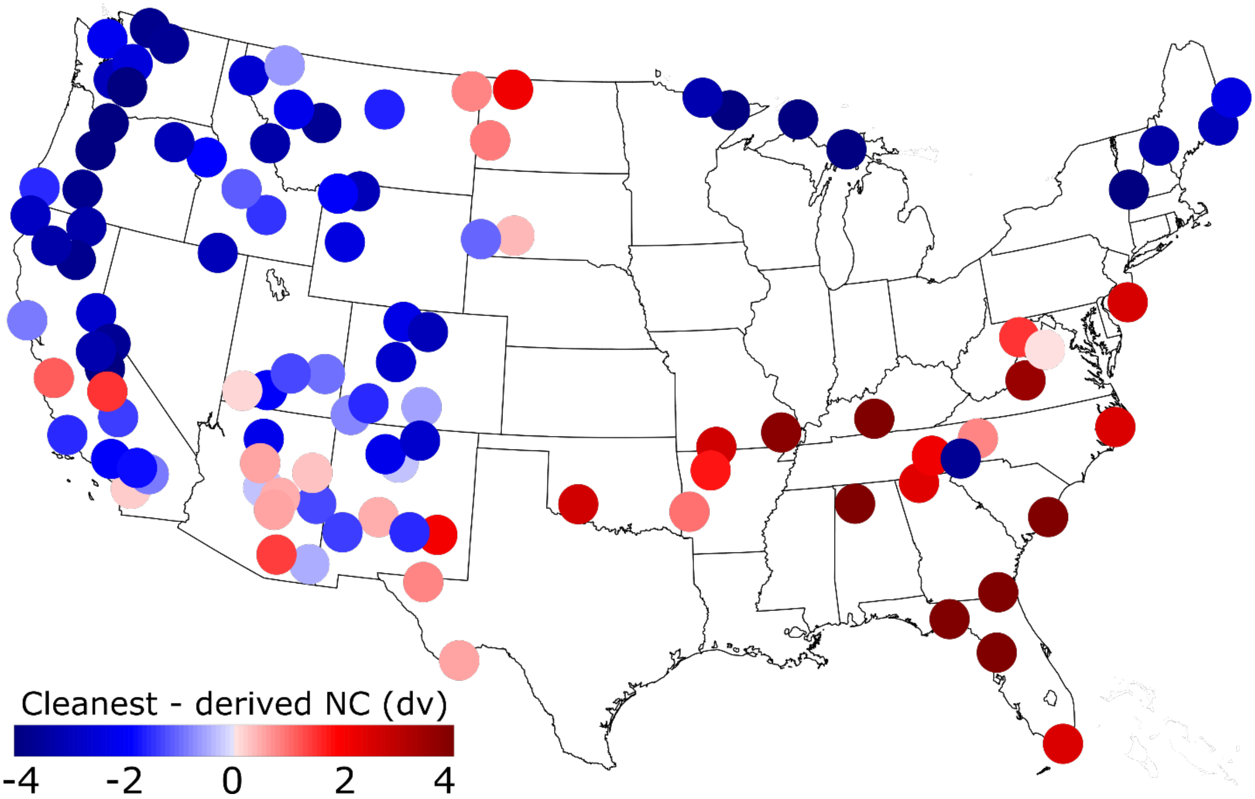

Figure 55. Relative magnitude of the estimated natural conditions on the most impaired days compared to the 15-year average deciviews on the clearest days.

These findings are likely due at least in part to three potential reasons:

- Anthropogenic contributions on the clearest days, some of which have been lessening during 2000-2014, and which can continue to decline;

- Clearest and most impaired days occurring during different seasons of the year and under different climatological conditions that can result in different contributions from natural emission sources; and
- Uncertainty in the estimates of natural conditions, due to the use of the Trijonis-based average NCII values and the approach to disaggregate into estimated daily contributions. The default approach used by the EPA and described in this document assumes that the percent natural contribution is the same throughout the year for the non-e3 portion of the aerosol-based total extinction.

The remainder of this section discusses the trends and seasonality in extinction budgets.

6.1 Trends in extinction budgets for the clearest days

To help us understand these findings, we present site-specific graphical summaries of the 5-year annual average clearest day extinction budgets, the portion of the clearest day haze attributed to natural contribution and the estimated average natural contribution for the most impaired days. The three 5-year budgets reveal the status and trends in the anthropogenic contribution to the clearest days. The difference between total and natural contribution shown for the clearest days represents the estimated anthropogenic portion. For further context, the 2064 estimates of natural conditions (presented in Mm^{-1} units) are provided. The discussion below illustrates the data for a few example locations which are presented in Figure 56. Graphical summaries of the 5-year annual average budgets for all sites, organized according to 25 regional groupings of IMPROVE sites are provided in Appendix H.

The 5-year annual average budget diagrams show that the haze on the clearest days has decreased at many locations. They also show an estimated anthropogenic fraction whose emission sources could be examined for further reduction. This is evident, for example, in the graphic below for SHEN1 where b_{ext} on the clearest days (for 2010-2014) has a large amount of sulfate. In comparison, the estimated, total natural extinction on the clearest days is less than 5 Mm^{-1}. The large estimated anthropogenic sulfate component of b_{ext} is evident throughout the Eastern U.S. and to a lesser extent for many sites in other parts of the U.S. This helps explain why the extinction on the clearest days are greater than the natural contribution of the most impaired days. It is also worth noting that the estimated natural fraction of the clearest days is similar to the 2064 "p10" value representing natural conditions for the clearest days. This lends credibility to the estimated natural portion of the clearest days and shows consistency with the split approach used throughout this analysis.

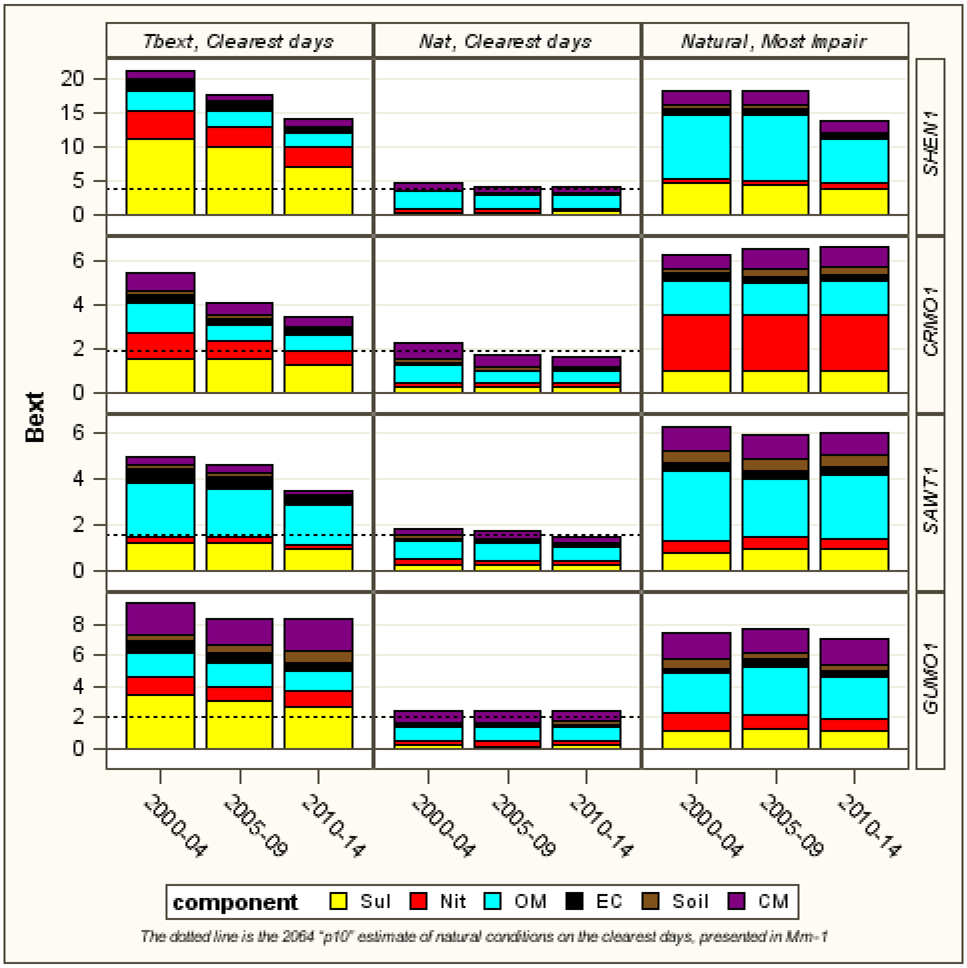

Figure 56. Trends in clearest days compared to estimated natural conditions for the most impaired days at Shenandoah, Craters of the Moon, Sawtooth and Guadalupe Mountains.

In contrast to many sites in the Eastern U.S., the clearest days for sites in the Western U.S. on average generally have less extinction than the estimated natural contribution on their most impaired days. We also see that the estimated amount of anthropogenic contribution on the clearest days is generally lower in the west than in the east. As we saw for the east, the clearest days in the west are also getting clearer. This is illustrated for SAWT1 in Figure 56.

Better understanding of the comparison to the clearest days is possible by looking at the relative levels of individual components. At SAWT, the clearest days are dominated by OCM. Both estimates of natural contribution on the clearest days have much less OCM. This implies that there may be an anthropogenic OCM component on the clearest days for each 5-year period shown. The OCM portion of the budget at SAWT does not appear to be typical of other sites in the Hells Canyon region, but the relatively large contribution from OCM on the clearest days is also evident at other sites in the Western U.S. For some sites in the West and Midwestern U.S., there is also an estimated contribution from nitrate on the clearest days. The data show a decline in nitrate as well as other aerosol components. This is the case at Craters of the Moon National Park (CRMO1).

A more common characteristic of the clearest days for most parts of the U.S., as previously noted for the east, is the relatively large amount of anthropogenic sulfate. For example, this can be seen at GUMO1 in West Texas which shows a decline in this component. Maps of the anthropogenic portions for the clearest days by component could help further delineate regions and/or isolated sites with potential for further visibility improvement from emission reductions.

6.2 Seasonal differences in the clearest days and natural conditions

The differences in annual values can result from seasonal differences in magnitude and frequency. Figure 57 shows that clearest days generally occur during different seasons of the year than the most impaired days which was illustrated in Figure 8. While the most impaired days often occur during the summer, the clearest days infrequently occur during that season. Instead, they most often occur during the winter and other seasons for many areas of the U.S. when natural emissions may be lower and meteorological conditions are less conducive to high concentrations.

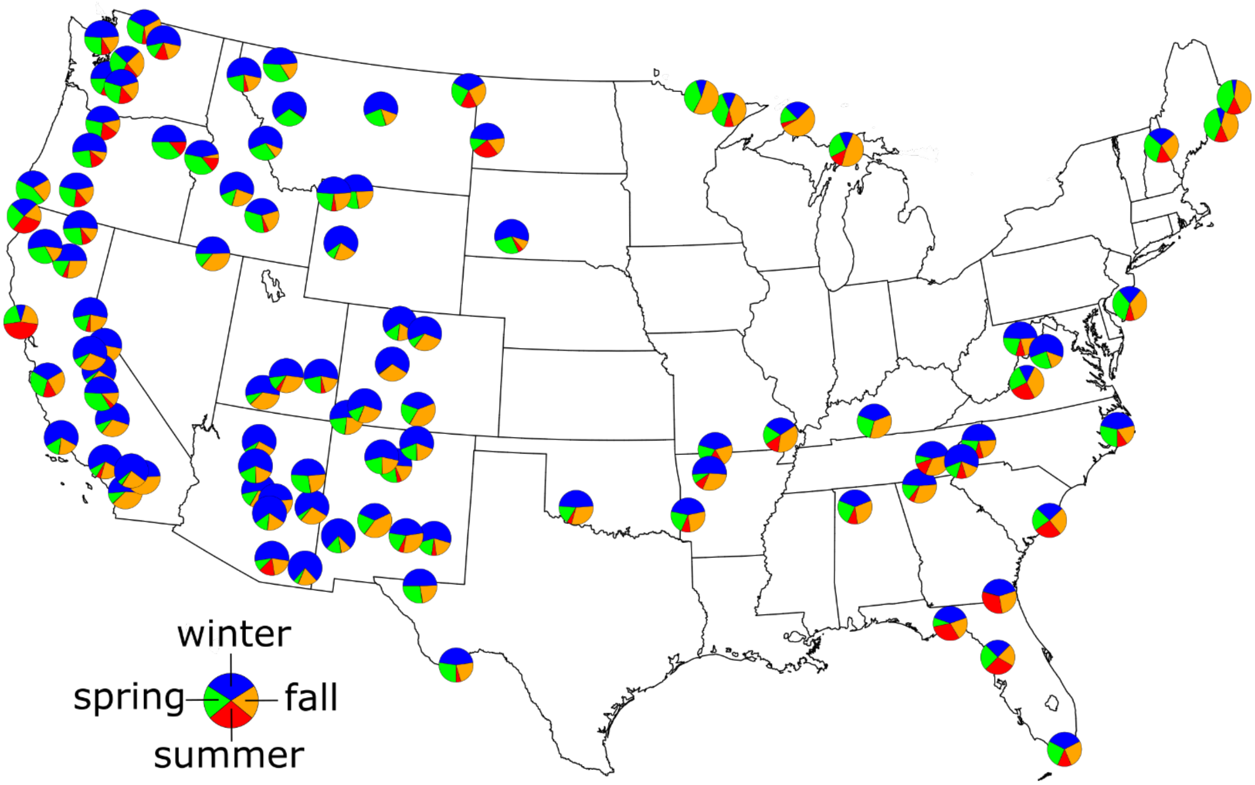

Figure 57. Seasonal distribution of the 20% clearest days, 2012.

The seasonal differences in the average extinction budgets provide additional insights in the different seasonal distributions of the clearest and most impaired days. Five-year seasonal average budgets for 2010-2014 are presented in Figure 58 below for the example sites. Two estimates of the natural contributions by season are shown: the default revised estimate and alternative site-specific contribution values for the most impaired days discussed earlier in Section 5 based on hybrid modeling of OM. Showing two estimates of natural contribution provide information related to the potential uncertainty in these estimates and the potential benefit for refinements. The data for all locations are provided in Appendix I.

As indicated earlier, the data for SHEN1 show that the most impaired days occur during the summer whereas the clearest days more frequently occur during the other seasons. This is common for sites in the Eastern U.S. The data for the clearest days reveal large sulfate contributions in all seasons and thus potential for further reductions throughout the year. Nevertheless, the clearest days appear to generally have less contribution from other aerosols, most notably carbon and dust. This may suggest that these days occur during conditions with lower emissions and/or during meteorological periods less conducive to high concentrations.

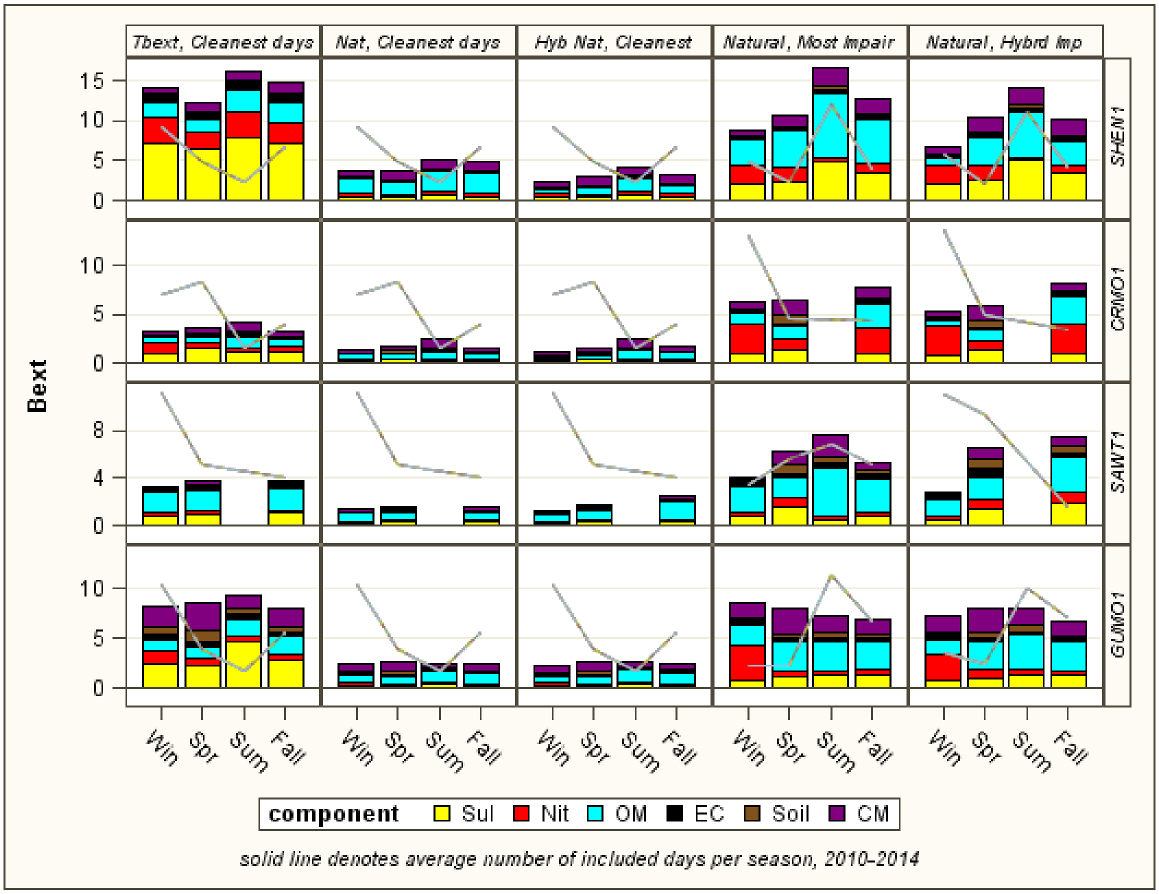

Figure 58. Seasonality in clearest days compared to estimated natural conditions for the most impaired days at Shenandoah NP, Craters of the Moon NP, Sawtooth NF and Guadalupe Mountains NP, 5-year average extinction budgets, 2010-2014

The clearest days at SAWT and other western sites shown in Figure 55 and Appendix I have average total extinction values less than the natural fraction of extinction on the most impaired days. This can be explained in part by looking at the seasons during which these two sets of days occur. At SAWT1, Figure 58 shows that the clearest days do not occur during the summer. In contrast, the most impaired days using the new estimates do frequently occur during the summer and the estimated natural contributions have larger amounts of carbon and dust. While this appears as a potential contradiction, the seasonal distribution of the most impaired days can depend on the method used to estimate natural contribution. With the alternative estimate of natural contribution from OCM using the hybrid model, the summer months no longer include days selected as the 20% most impaired. This finding confirms uncertainty in the estimated natural contribution and that further changes in these estimates, particularly for carbon and dust, may be needed to produce better concordance with the clearest days.

Depending on the differences in the time of the year when the clearest and most impaired days occur, the nitrate contribution to the latter may be larger than its contribution to the former. This is the case at Craters of the Moon National Park (CRMO1), where the most impaired days often occur during the colder months of the year. Figure 58 shows the seasonal extinction budgets and the average number of days per season for CRMO1 during 2010-2014. There, the highest number of impaired days occur in the winter while the largest number of the clearest days occur in the spring. The most impaired winter days show large natural contributions from nitrate which may partly be an outcome of the splitting algorithm.

7 Summary

The first implementation period's metric to track regional haze in Class I areas as described in the EPA's published guidance focuses on a characterization of the haziest and clearest 20% of days per year. The metric is based on a daily haze index derived from aerosol measurements produced by 109 IMPROVE samplers which represent one or more Class I areas. For many locations, particularly in the Western U.S., the haziest days are frequently and significantly dominated by carbon and dust aerosols which result from uncontrollable wildfires and dust events. For these situations, tracking the haziest days does not make it easy to judge impairment from controllable anthropogenic emissions. In addition, the haziest day metric does not make it convenient to identify the long-term trend in haze and progress towards achieving natural conditions in 2064 resulting from changes in those controllable emissions.

An analysis of IMPROVE data at 109 locations with sufficient long-term data from 2000-2014 quantifies the impact of extreme episodic extinction events and shows that focusing on days without e3 reveal more consistent trends. This provides a basis for a new paradigm to portray the days for tracking changes in regional haze which most closely reflects changes in controllable emissions. A variety of approaches have been considered to describe the worst haze days without the influence of e3. While each alternative approach results in different numerical values of a tracking metric, their performance is relatively similar at all locations and highlights the sharp contrast to the first implementation period's haziest day metric for locations with significant and frequent e3 events. For each approach, a new and complementary estimate of worst day natural conditions for 2064 can be provided.

Rather than focusing on the haziest days, a new tracking metric is recommended which portrays the daily haze index for days with the 20% most anthropogenic impairment. This requires an estimate for the daily contribution from natural sources which includes e3. A step-by-step procedure to implement this new paradigm is described. The method provides revised estimates of current conditions, trends of recent visibility and average natural conditions, a revised glidepath connecting those points and an estimated extinction budget for the contributing aerosol-based extinction resulting from anthropogenic emissions. Limitations of this draft procedure are identified with suggestions for improvement. No change is suggested for the tracking and characterization of visibility for the clearest days. For more information on the Regional Haze Program, check out the following website: https://www.epa.gov/visibility.

Appendices

Appendix A: Database and data handling conventions used in this analysis

- Daily IMPROVE aerosol measurements, calculated aerosol values and associated aerosol based extinction are obtained from the CIRA web site; the data cover the period 2000-2014; only “good” years from the 110 locations representing 156 Class I areas are included.[62] All daily values of the haze index are based on calculated extinction for seven aerosol components (sulfate, nitrate, OCM, EC, fine soil, CM, and sea salt) derived with the new IMPROVE algorithm together with a site-specific value for Rayleigh scattering.
    - The daily IMPROVE extinction data are routinely “patched” whereby missing values which are expected to have little effect on deciviews are filled in with historical seasonal median values. Patched data is regularly included (and flagged) in the RHR data sets on the IMPROVE web site.
    - A good year is determined from the ‘good year’ flag within the IMPROVE dataset. Consistent with current protocols used by the EPA and the IMPROVE program, an average of three or more good years are needed to compute 5-year running averages for tracking purposes.
    - Five-year averages presented in this document are based on all available "good" years of data. The data reporting protocol used by the IMPROVE program as described in the 2003 regional haze tracking guidance recommend a minimum of three good years.[63] Even after patching, there are several sites which did not have the requisite 3 of 5 years required. See Table 1 for summary of sites with incomplete data. For regional haze statistics presented on the IMPROVE web site, data was substituted from regressions with a nearby donor site, determined on a case by case basis.
- Rounding and number of decimal places for extinction and deciviews consider the precision for the intended purpose, the uncertainty in underlying measurements and the coefficients in the extinction algorithm. One (rounded) decimal place is suggested for total extinction and deciviews. Two decimal places are appropriate for multi-year average values of the 20% worst days.
- Conversion of daily extinction value to a deciview value. For pristine conditions at high elevation sites (i.e. >2200m) these deciview values are sometimes negative. While counterintuitive, this is mathematically appropriate and negative or zero values are retained.
- The end year of a 5-year average is the convention for plotting these values. For example, the value for the 2000-2004 average value is plotted at 2004.
- The default natural conditions estimates for the six aerosol components are based on NCII values. These include the average, p10 and p90 values.[64] The latter two statistics were developed to correspond to the clearest and haziest 20 percent of the days.

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[62] Based on data availability, 109 sites are used for these analysis.

[63] The 2003 tracking guidance states that “estimates for baseline or current conditions should be prepared in consultation with the Environmental Protection Agency’s Office of Air Quality Planning and Standards (EPA/OAQPS).

[64] http://vista.cira.colostate.edu/Docs/IMPROVE/Aerosol/NaturalConditions/NaturalConditionsII_Format2_v2.xls

Table 1. List of IMPROVE sites with less than 3 years of available data during the 2000-2004 or 2010-2014 periods

Site Name	Sitecode	Meets Data Completeness?	
		2000-2004	2010-2014
Mount Baldy, AZ	BALD1	No	Yes
Boundary Waters Canoe Area, MN	BOWA1	No	Yes
Capitol Reef, UT	CAPI1	No	Yes
Cohutta, GA	COHU1	No	Yes
Gates of the Mountains, MT	GAMO1	Yes	No
Haleakala National Park, HI	HALE1	Yes	No
Kaiser, CA	KAIS1	No	Yes
Lostwood, NC	LOST1	Yes	No
Lye Brook Wilderness, VT	LYBR1	Yes	No
Mingo, MO	MING1	No	Yes
North Cascades National Park, WA	NOCA1	No	Yes
San Rafael, CA	RAFA1	No	Yes
St. Marks, FL	SAMA1	No	Yes
Shining Rock Wilderness, NC	SHRO1	No	Yes
Swanquarter, NC	SWAN1	No	Yes
Zion National Park, UT	ZION1	Yes	No

Appendix B. Carbon and dust in routine natural calculation

There are two potential issues identified in the calculation of routine natural contribution of carbon and dust. First, is the issue previously identified for sites like Shenandoah when the measurement derived extinction is less than the Trijonis-based values. This is briefly discussed in Section 4.3.1. Second is a potential data processing artifact with the design and implementation of the currently computer-coded algorithm which appears to contribute to a separate slight potential relative bias in the derived natural conditions estimates.

Rather than perform calculations on combined carbon and dust as described in Equations [3] and [4], an alternative set of calculations can be performed separately for OCM, EC, CM and fine soil. This would result in different daily natural conditions and 15-year average estimates of natural conditions which are presented in Table 2 as dvNatural2. The change in estimated natural condition is believed to be caused in part by a lower value of a_{RNC} associated with EC.

These alternative daily estimates of natural contribution would also produce a different estimate of daily impairment and thus a different ranking of the days in the year. Potentially, this could result in a different set of worst days per year.

From the small magnitude of the difference in average natural conditions, the effect is believed to not be consequential to the results presented in this document but could be considered in subsequent revisions to this default methodology. The impact on selection of the most impaired days is not included in this document. These include many locations in the Eastern U.S. (as well as other locations) whose extinction budgets have large contributions from sulfate.

Table 2. 15-year average of derived natural conditions for the 20% most impaired days per year, with 'carbon' and 'dust' based adjustments relative to NCII values (=dvNatural) and with OCM, EC, fine soil and CM based adjustments (=dvNatural2)

Sitecode	dvNatural	dvNatural2	Difference
ACAD1	10.9	10.4	0.5
BOWA1	9.5	9.0	0.5
DENA1	5.0	4.8	0.2
EVER1	9.0	8.3	0.7
GRGU1	10.1	9.7	0.5
HALE1	5.8	5.6	0.2
ISLE1	10.6	10.1	0.5
LYBR1	11.3	10.6	0.7
MOOS1	10.3	9.9	0.4
SENE1	11.5	11.0	0.5
SHEN1	9.7	9.5	0.2
SHRO1	10.2	10.0	0.2
SIME1	8.7	8.5	0.2
VIIS1	8.8	8.7	0.1
VOYA2	9.8	9.3	0.5
WHRI1	3.0	2.9	0.1

Appendix C: Additional background on natural conditions

- The 2003 NCII guidance establishes a default approach's use of a statistical method to estimate the highest and lowest natural haze. This describes the 2064 endpoint as the primary role of these 'default' estimates. Emphasizes the state's right to derive "refined" estimates. I believe the tracking guidance states that atypical extreme annual contributions reflected in the 5-year average values (not effectively averaged out) would be explained in the SIP. This contrasts with the exceptional event approach used to support NAAQS which is designed to remove such contribution a priori.

- The NCII estimates for the best and haziest days are also derived from the average Trijonis component specific values included in the revised IMPROVE algorithm with re-scaling in order to better depict the average worst and best 20% of daily total haze per year. "East" and "West" are defined as east or west of the 98th meridian respectively for purposes of determining default natural conditions.[65] The resulting values may not adequately reflect the true spatial variability in natural conditions.[66]

- NCII considered e3 in terms of the behavior during 2000-2004 base period both in an endpoint to properly characterize natural conditions for the haziest days. It does not consider changes in the within year variability that has occurred since 2004.

- Efforts of the NCII committee resulted in better spatial temporal chemical characterization particularly for the "worst" days.[67,68] The NCII values includes sea salt, elevation-specific estimates of Rayleigh scattering and other updates.

- The NCII approach adjusts each sample period's species concentration to generate a simulated natural haze distribution with the annual mean for each species being equivalent to the Trijonis estimated natural concentration for that species. For each species that is not determined to be consistent with natural conditions—ammonium sulfate (AS), elemental carbon (EC), ammonium nitrate (AN), and organic carbon mass (OCM)—if the average of the yearly average concentration, for complete years in the period 2000-2004, is greater than Trijonis' estimate of the regional multi-annual mean natural concentration (RAM-NC) for that species, then all measurements of that species are rescaled such that the annual average concentration is set equal to Trijonis' estimate of the RAM-NC for that species.[69]

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[65] Trijonis, J.C., Characterization of Natural Background Aerosol Concentrations, Appendix A in Acidic Deposition: State of the Science and Technology, Report 24, Visibility Existing and Historical Condition – Causes and Effects, National Acid Precipitation Assessment Program, 1990.

[66] Note: the use of the 98th meridian was not used elsewhere in this document when categorizing CONUS locations as east or west. Instead groupings of NCDC regions are used. Updates to this document should consider that change.

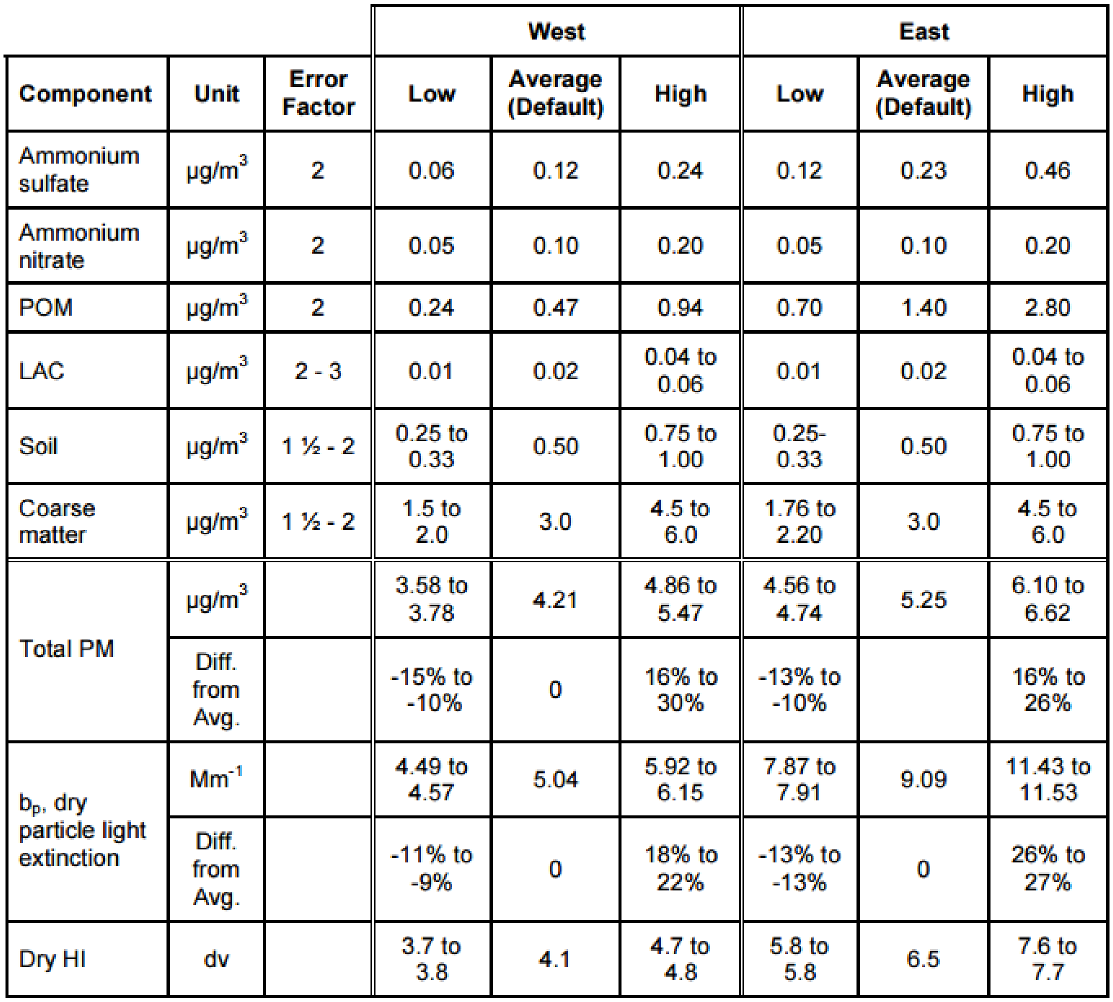
[67] Natural Haze Levels II: Application of the New IMPROVE Algorithm to Natural Species Concentration Estimates, a final report presentation by the Natural Haze Levels II Committee to the RPO Monitoring/Data Analysis Work Group, July 2006, available at http://vista.cira.colostate.edu/improve/Publications/GrayLit/029_NaturalCondII/naturalhazelevelsIIreport.ppt.

[68] Copeland et al. Regional Haze Rule Natural Level Estimates Using the Revised IMPROVE Aerosol Reconstructed Light Extinction Algorithm, 2008, http://vista.cira.colostate.edu/improve/publications/graylit/032_NaturalCondIIpaper/Copeland_etal_NaturalConditionsII_Description.pdf.

[69] Text from http://www.tceq.state.tx.us/assets/public/implementation/air/sip/haze/Appendix5_2.pdf. It may have jargon different than Pitchford 2006.

- In cases where the baseline annual mean concentration of a species is less than the default estimated concentration, the baseline values are retained (i.e. the scaling factor is 1), resulting in values less than the default.
- The average natural conditions concentrations developed by Trijonis (1990) assigned an error factor to the concentration estimate for each component, as listed in Table 2. These error factors range in value from 1.5 to 3, depending on component. A error factor value of 2 indicates that he assessed the uncertainty in his average concentration estimates to be a factor of two, i.e., he estimated that the true regional average value of each concentration is likely to lie between roughly half and twice the average concentration he presented. As Tombach explains: his discussions with Trijonis (2005, 2007) have clarified that he interpreted the error factor to describe the range 5-5 within which it is 80% probable that the regional-average (i.e., East or West) natural conditions concentration value will lie between the low and high values shown in Table 2.

Table 3. "Table 5.1 from Tombach (2008)"



			West			East		
Component	**Unit**	**Error Factor**	**Low**	**Average (Default)**	**High**	**Low**	**Average (Default)**	**High**
Ammonium sulfate	µg/m^3	2	0.06	0.12	0.24	0.12	0.23	0.46
Ammonium nitrate	µg/m^3	2	0.05	0.10	0.20	0.05	0.10	0.20
POM	µg/m^3	2	0.24	0.47	0.94	0.70	1.40	2.80
LAC	µg/m^3	2 - 3	0.01	0.02	0.04 to 0.06	0.01	0.02	0.04 to 0.06
Soil	µg/m^3	1 ½ - 2	0.25 to 0.33	0.50	0.75 to 1.00	0.25-0.33	0.50	0.75 to 1.00
Coarse matter	µg/m^3	1 ½ - 2	1.5 to 2.0	3.0	4.5 to 6.0	1.76 to 2.20	3.0	4.5 to 6.0
Total PM	µg/m^3		3.58 to 3.78	4.21	4.86 to 5.47	4.56 to 4.74	5.25	6.10 to 6.62
	Diff. from Avg.		-15% to -10%	0	16% to 30%	-13% to -10%		16% to 26%
b_p, dry particle light extinction	Mm^{-1}		4.49 to 4.57	5.04	5.92 to 6.15	7.87 to 7.91	9.09	11.43 to 11.53
	Diff. from Avg.		-11% to -9%	0	18% to 22%	-13% to -13%	0	26% to 27%
Dry HI	dv		3.7 to 3.8	4.1	4.7 to 4.8	5.8 to 5.8	6.5	7.6 to 7.7

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[25] Rigorously, only for the "East" and "West" as defined by Trijonis, which are geographically smaller areas than the East and West in EPA's guidance.

Appendix D: Changes in carbon and dust in revised natural condition estimates

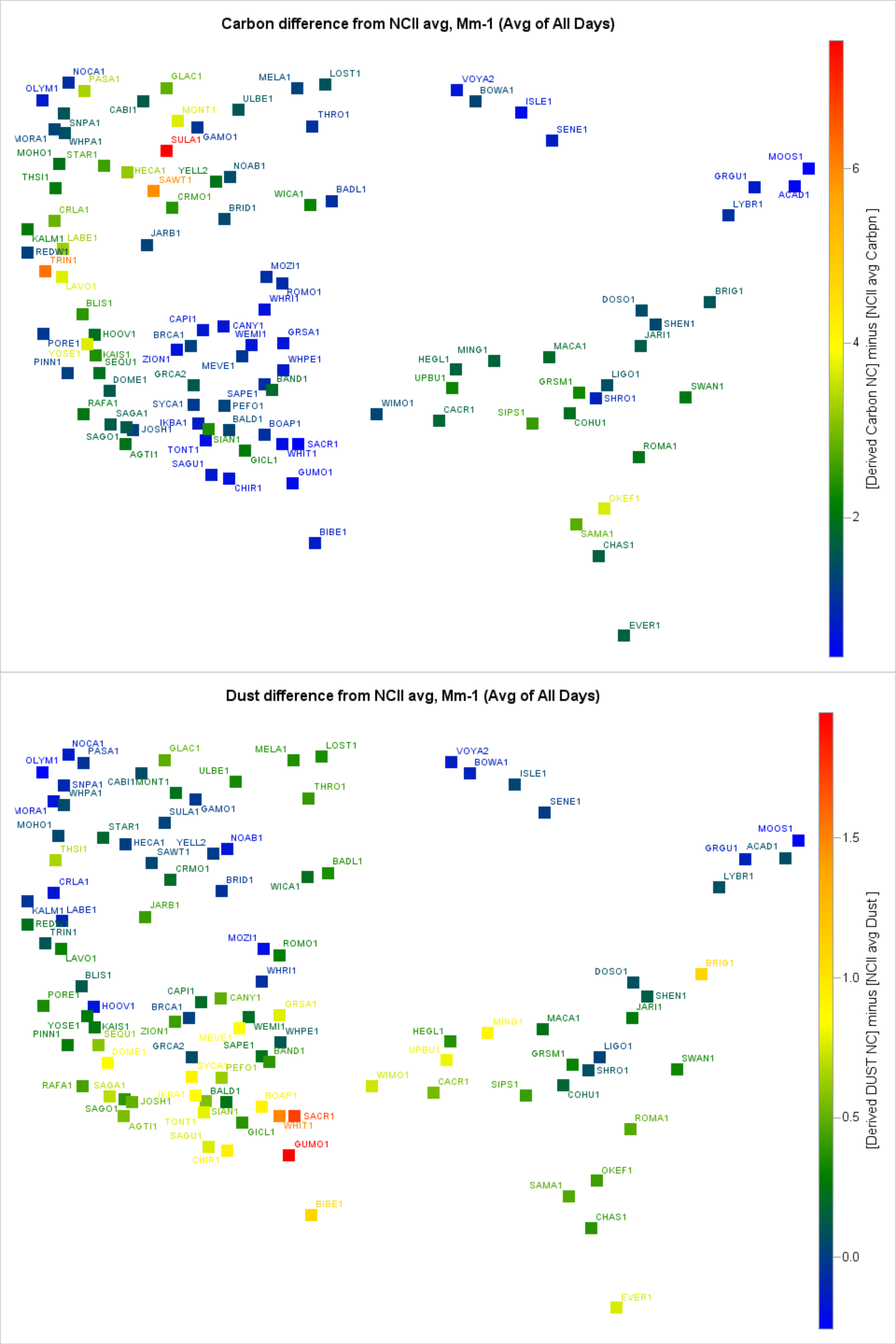

Figure 59. Difference between revised natural conditions estimates averaged for all days in 2000-2014 vs NCII average values for carbon and dust (Mm^{-1})

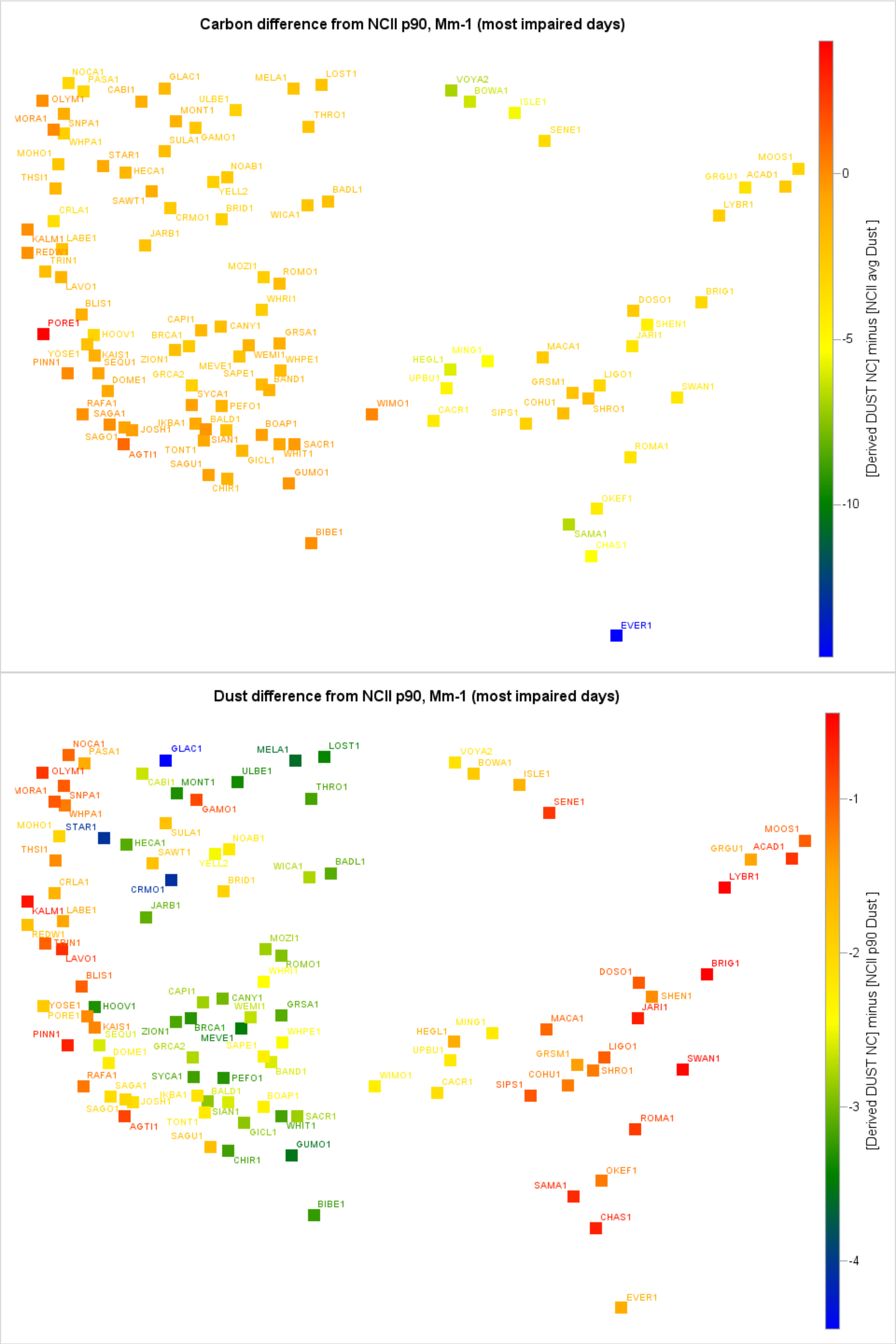

Figure 60. Difference between revised natural conditions estimates averaged for the 20% most impaired days in 2000-2014 vs NCII average values for carbon and dust (Mm^{-1}).

Appendix E: Summary table for deciviews associated with the first implementation period and updated approaches as well as the e3 values for carbon and dust

Table 4. Deciview values for 2000-2004, 2010-2014, 2064, and e3 used to create the glidepath and deviation figures for the first implementation period and updated approaches

Site	First Implementation Period			Updated			e3	
	2000-2004	2010-2014	NCII P90	2000-2004	2010-2014	Derived-NC	carbon	dust
ACAD1	22.9	17.5	12.4	22.0	16.2	10.9	10.4	3.1
AGTI1	23.5	18.2	7.6	21.6	17.4	7.6	10.8	8.9
BADL1	17.1	15.5	8.1	15.0	13.9	6.1	9.2	7.5
BALD1	11.5	10.4	6.2	8.6	8.0	4.0	6.7	5.4
BAND1	12.2	11.8	6.3	9.6	9.1	4.6	5.6	4.4
BIBE1	17.3	16.5	7.2	15.6	14.6	5.3	7.6	8.6
BLIS1	12.7	11.9	6.1	10.1	9.4	4.9	11.1	2.8
BOAP1	13.8	14.6	6.7	11.6	11.3	5.4	9.4	7.8
BOWA1	20.0	18.1	11.6	19.0	15.6	9.5	11.1	3.2
BRCA1	11.6	9.7	6.8	8.4	7.4	4.1	6.1	4.3
BRID1	11.1	10.3	6.5	8.0	6.9	3.9	7.7	2.8
BRIG1	29.0	23.3	12.2	27.4	21.9	10.8	20.1	9.1
CABI1	14.1	13.1	7.5	10.7	9.9	5.7	13.1	4.1
CACR1	26.3	21.8	11.6	24.0	20.4	9.5	16.8	7.8
CANY1	11.2	10.3	6.4	8.8	8.2	4.1	5.6	5.0
CAPI1	10.0	9.9	6.0	8.5	8.0	4.1	5.1	5.3
CHAS1	26.1	21.2	11.0	24.6	19.6	9.0	24.7	6.7
CHIR1	13.4	12.4	7.2	10.5	9.9	4.9	4.8	7.9
COHU1	30.3	22.2	10.8	28.9	20.5	9.6	18.2	4.4
CRLA1	13.7	11.7	7.6	9.4	8.6	5.2	8.7	2.4
CRMO1	14.0	14.1	7.5	11.9	10.4	5.0	7.3	4.7
DENA1	9.8	8.9	7.3	7.0	7.3	5.0	3.6	1.6
DOME1	19.5	17.2	7.5	17.2	15.7	6.2	14.1	11.6
DOSO1	29.0	22.0	10.4	28.3	21.1	9.0	13.6	3.4
EVER1	22.3	17.9	12.1	19.5	16.1	9.1	10.0	8.5
GAMO1	11.3	10.9	6.4	9.0	7.6	4.8	11.0	3.0
GICL1	13.1	10.8	6.7	8.9	8.2	4.2	5.7	4.4
GLAC1	20.5	16.2	9.2	16.2	13.8	7.0	22.2	8.1
GRCA2	11.7	10.2	7.0	7.9	7.3	4.2	6.0	4.7
GRGU1	22.8	16.6	12.0	22.0	15.2	10.1	12.1	3.2
GRSA1	12.8	11.7	6.7	9.6	8.7	4.5	8.0	6.7
GRSM1	30.3	21.9	11.2	29.2	20.7	10.1	16.1	4.5
GUMO1	17.2	15.6	6.7	14.6	12.9	4.8	6.2	13.0
HALE1	13.3	14.6	7.4	12.7	13.8	5.8	3.8	2.9
HAVO1	18.9	19.0	7.2	18.7	18.9	5.7	1.7	1.9
HECA1	18.6	16.3	8.3	16.5	13.3	6.6	13.9	5.0
HEGL1	26.8	22.5	11.3	25.2	21.1	9.3	20.5	6.9
HOOV1	12.9	10.5	7.7	9.0	7.7	4.9	8.9	4.1
IKBA1	13.4	12.0	6.7	11.2	9.9	5.2	6.8	6.1
ISLE1	20.7	18.6	12.4	19.4	17.1	10.6	12.1	4.2
JARB1	12.1	12.2	7.9	8.7	7.7	5.2	7.5	8.0
JARI1	29.1	22.1	11.1	28.1	20.7	9.5	26.3	3.1
JOSH1	19.6	14.8	7.2	17.7	13.4	6.1	7.8	9.8
KAIS1	14.8	14.3	7.1	12.7	11.7	6.0	11.2	5.2
KALM1	15.5	14.6	9.4	13.3	12.2	7.8	12.5	2.4
LABE1	15.1	13.6	7.9	11.3	9.9	6.2	10.4	3.8
LAVO1	14.2	13.2	7.3	11.5	10.1	6.2	12.4	2.6
LIGO1	28.8	20.9	11.2	28.1	19.6	9.7	18.2	2.8
LOST1	19.6	19.5	8.0	18.3	18.6	5.9	10.2	9.3
LYBR1	24.4	19.7	11.7	23.6	19.1	11.3	11.4	2.8
MACA1	31.4	24.5	11.1	29.8	23.3	9.8	19.4	4.3
MELA1	17.7	18.2	7.9	16.6	16.6	6.0	9.2	9.3

MEVE1	13.1	10.8	6.8	9.2	7.8	4.2	5.1	5.3
MING1	29.5	24.1	11.6	26.6	22.5	9.3	28.5	10.8
MOHO1	14.9	13.2	8.4	12.1	9.8	6.6	7.8	2.7
MONT1	14.5	14.9	7.7	10.9	9.5	5.4	14.9	4.9
MOOS1	21.7	16.5	12.0	20.6	15.1	10.3	11.2	2.6
MORA1	18.3	15.1	8.5	16.5	13.8	7.7	13.3	2.5
MOZI1	10.5	8.9	6.1	7.3	5.9	3.2	5.7	3.2
NOAB1	11.5	11.5	6.8	8.8	7.2	4.6	10.2	4.2
NOCA1	14.0	13.0	8.4	12.6	10.7	6.8	8.2	2.0
OKEF1	27.1	22.3	11.4	25.3	20.0	9.5	20.6	5.5
OLYM1	16.8	13.9	8.4	14.9	12.8	6.9	8.8	1.8
PASA1	15.2	13.1	8.3	10.5	9.1	6.0	9.4	2.6
PEFO1	13.2	11.2	6.5	9.8	9.0	4.2	6.7	7.8
PINN1	18.5	15.7	8.0	17.0	14.4	7.0	11.5	5.9
PORE1	22.8	20.6	15.8	19.3	16.6	9.8	6.8	8.2
RAFA1	18.9	16.3	7.6	17.0	14.8	6.9	7.6	8.2
REDW1	18.5	17.4	13.9	13.6	13.0	8.6	5.9	4.4
ROMA1	26.5	22.5	12.1	25.2	20.7	9.8	23.4	5.4
ROMO1	13.8	11.9	7.2	11.1	9.2	5.0	8.5	5.3
SACR1	18.0	18.1	6.8	16.6	15.7	5.5	9.0	14.4
SAGA1	19.9	15.0	7.0	17.9	13.9	6.1	8.5	7.1
SAGO1	22.2	16.1	7.3	20.4	15.3	6.2	11.9	7.8
SAGU1	14.8	12.7	6.5	12.6	11.3	5.2	6.1	9.6
SAMA1	26.1	21.8	11.7	24.3	19.8	9.2	21.3	5.2
SAPE1	10.2	10.5	5.7	7.6	6.9	3.4	5.7	4.5
SAWT1	13.8	15.7	6.4	9.6	8.6	4.7	12.4	2.6
SENE1	24.2	20.3	12.7	23.6	19.3	11.5	13.7	2.5
SEQU1	24.6	20.9	7.7	23.2	19.9	6.3	23.1	11.5
SHEN1	29.3	21.4	11.4	28.3	20.2	9.7	15.1	3.9
SHRO1	27.9	18.9	11.5	27.3	17.6	10.2	14.0	3.1
SIAN1	13.7	12.3	6.6	10.8	9.9	5.1	6.8	5.9
SIME1	18.5	17.3	15.6	13.6	13.9	8.7	3.4	4.6
SIPS1	29.0	22.7	11.0	27.7	21.4	9.6	21.7	4.8
SNPA1	17.8	15.8	8.4	15.4	13.3	7.2	12.3	1.8
STAR1	18.6	14.5	8.9	14.6	11.8	6.6	13.1	5.7
SULA1	13.4	15.0	7.4	10.1	8.4	5.5	11.8	3.2
SWAN1	25.5	21.4	11.5	24.4	19.2	9.8	16.5	5.0
SYCA1	15.3	15.1	6.7	12.2	11.5	4.7	13.1	15.9
THRO1	17.7	16.6	7.8	16.3	15.1	5.9	9.9	8.7
THSI1	15.3	15.0	8.8	12.8	11.4	7.3	12.6	4.0
TONT1	14.0	12.9	6.5	11.3	11.1	5.1	7.1	8.8
TRIN1	16.3	14.9	7.9	12.0	10.6	6.3	10.4	3.6
TUXE1	14.1	12.1	11.3	10.5	10.0	7.0	3.4	2.3
ULBE1	15.1	14.3	8.2	12.8	11.8	5.9	9.8	6.2
UPBU1	26.3	21.6	11.6	24.3	19.8	9.4	17.2	7.7
VIIS1	17.1	19.0	10.7	14.5	16.1	8.8	2.6	21.5
VOYA2	19.3	17.5	12.1	17.7	16.4	9.8	11.5	4.1
WEMI1	10.4	9.6	6.2	7.8	6.9	4.0	6.5	3.9
WHIT1	13.7	14.5	6.8	11.3	10.7	4.9	7.2	7.1
WHPA1	12.7	11.7	8.4	10.4	8.5	6.1	6.9	2.4
WHPE1	10.4	9.8	6.1	7.3	7.0	3.6	5.1	3.5
WHRI1	9.6	8.3	6.1	6.3	5.4	3.0	4.9	3.6
WICA1	15.8	14.0	7.7	13.1	11.9	5.6	8.0	4.6
WIMO1	23.8	21.3	7.5	22.2	20.3	6.9	13.9	9.9
YELL2	11.8	12.0	6.4	8.3	7.6	4.0	10.1	3.1
YOSE1	17.6	15.0	7.6	13.5	12.2	6.3	13.3	5.2
ZION1	13.2		7.0	11.1		4.8	8.4	7.3

Appendix F: National maps of the seasonal anthropogenic extinction budgets

This appendix provides information on average extinction budgets for the most impaired days for the anthropogenic portion during 2010-2014, presented on a seasonal basis.[70] Figures 61-64 present these budgets on a fractional basis using pie charts for winter (December, January and February), spring (March, April and May), summer (June, July and August) and fall (September, October and November).

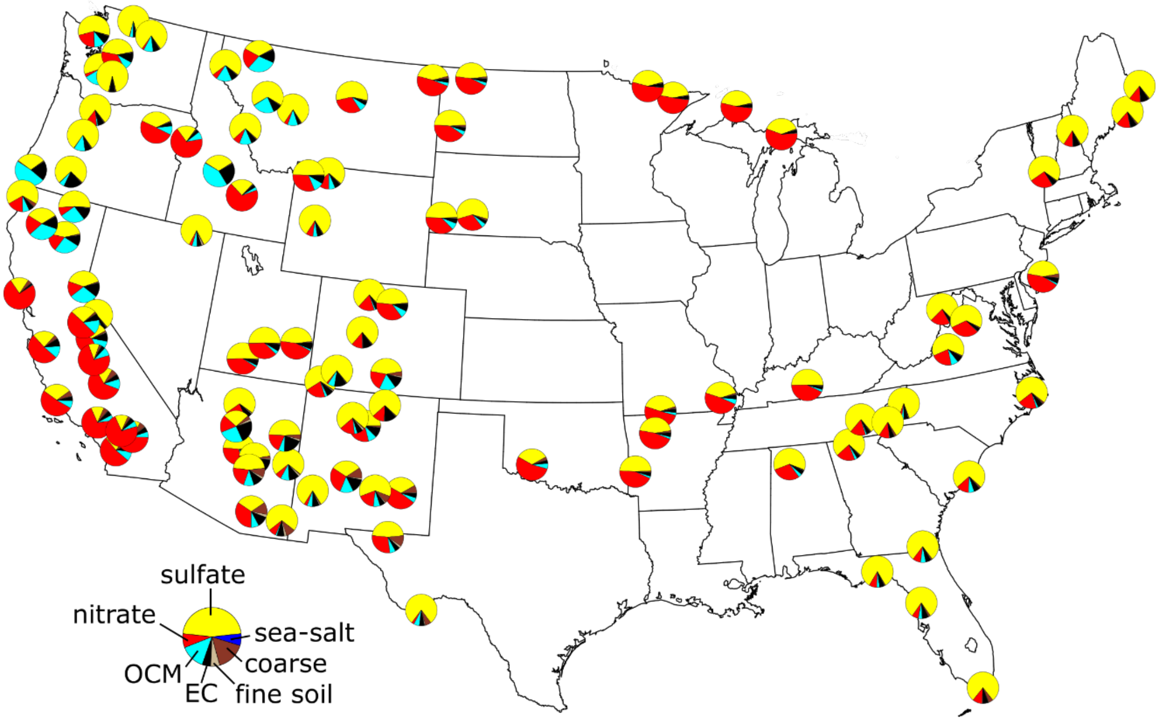

Figure 61. Average anthropogenic extinction budget on the 20% most impaired days in winter months (DJF), 2010-2014

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[70] Consistent with the approach used in this document, the anthropogenic extinction is the portion of total aerosol-based extinction which is not associated with estimated natural contributions.

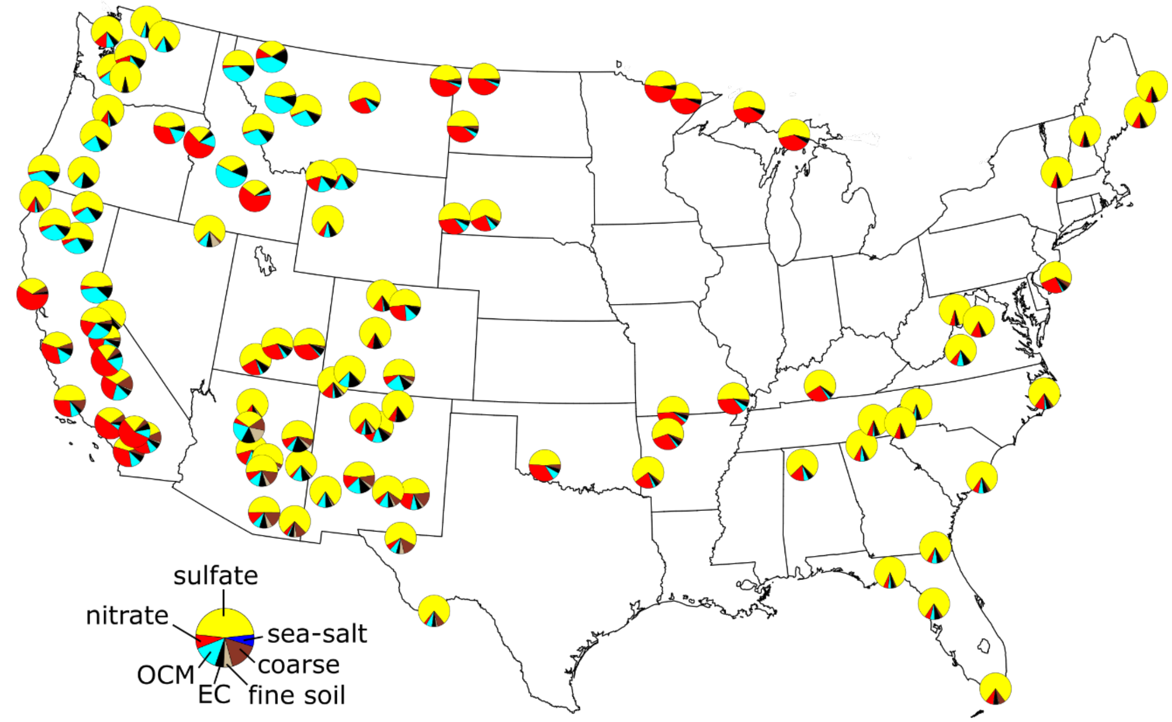

Figure 62. Average anthropogenic extinction budget on the 20% most impaired days in spring months (MAM), 2010-2014

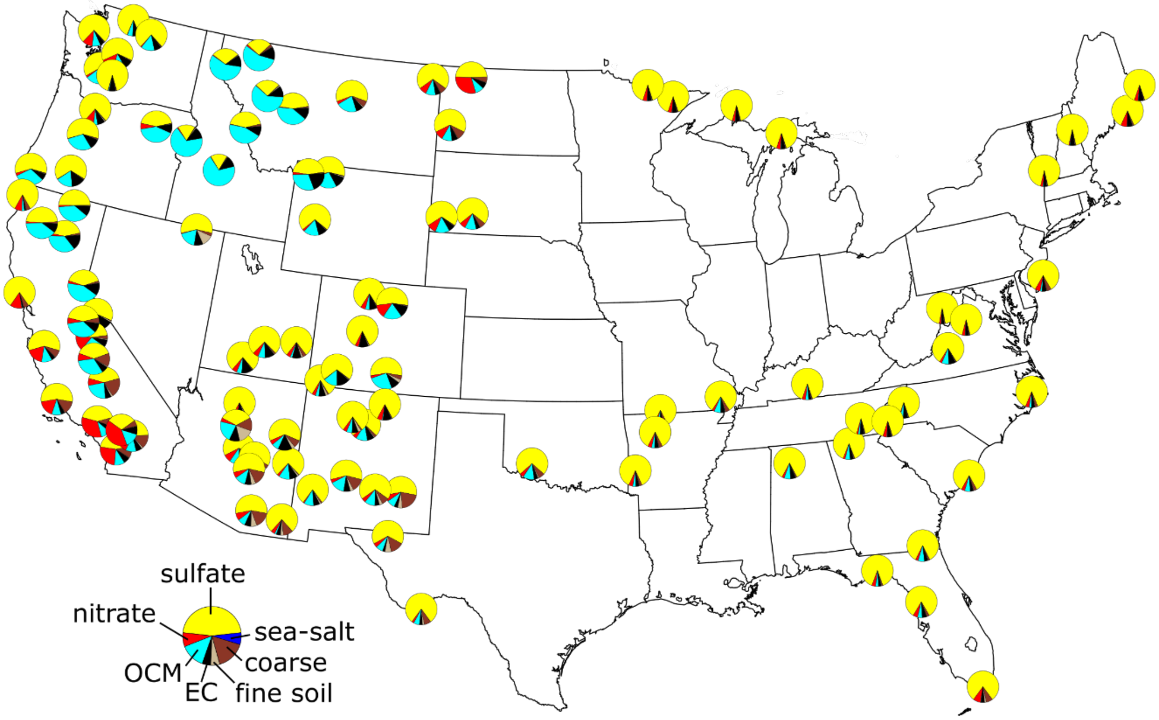

Figure 63. Average anthropogenic extinction budget on the 20% most impaired days in summer months (JJA), 2010-2014

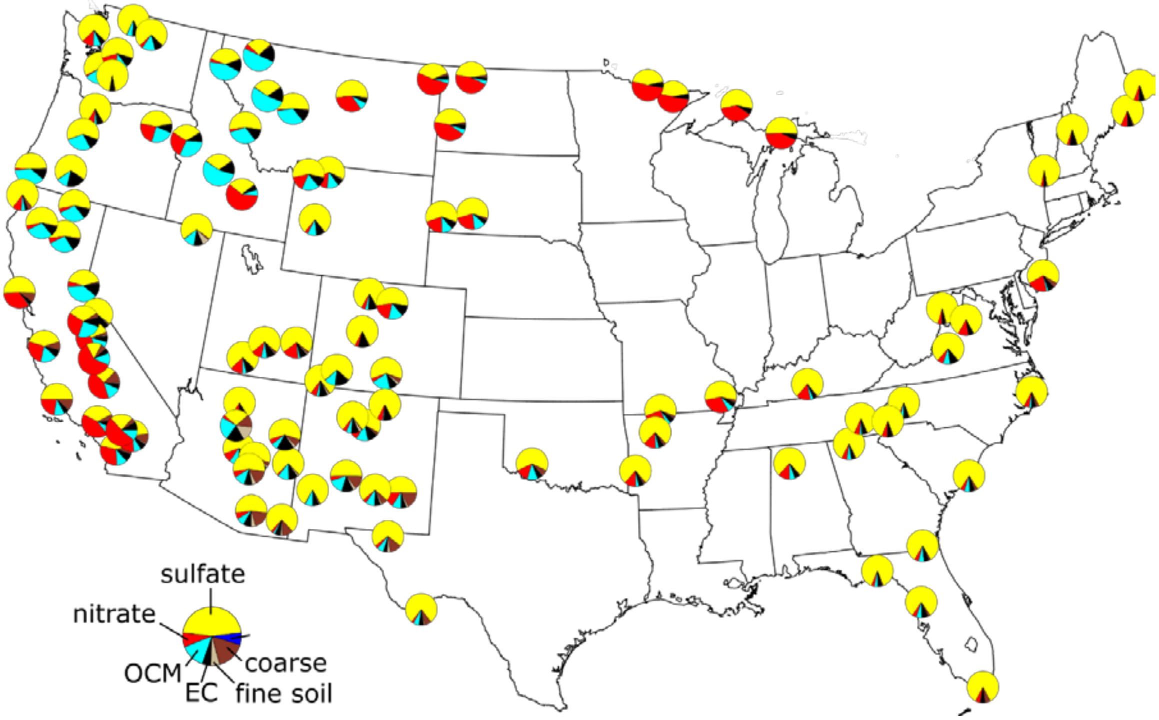

Figure 64. Average anthropogenic extinction budget on the 20% most impaired days in fall months (SON), 2010-2014

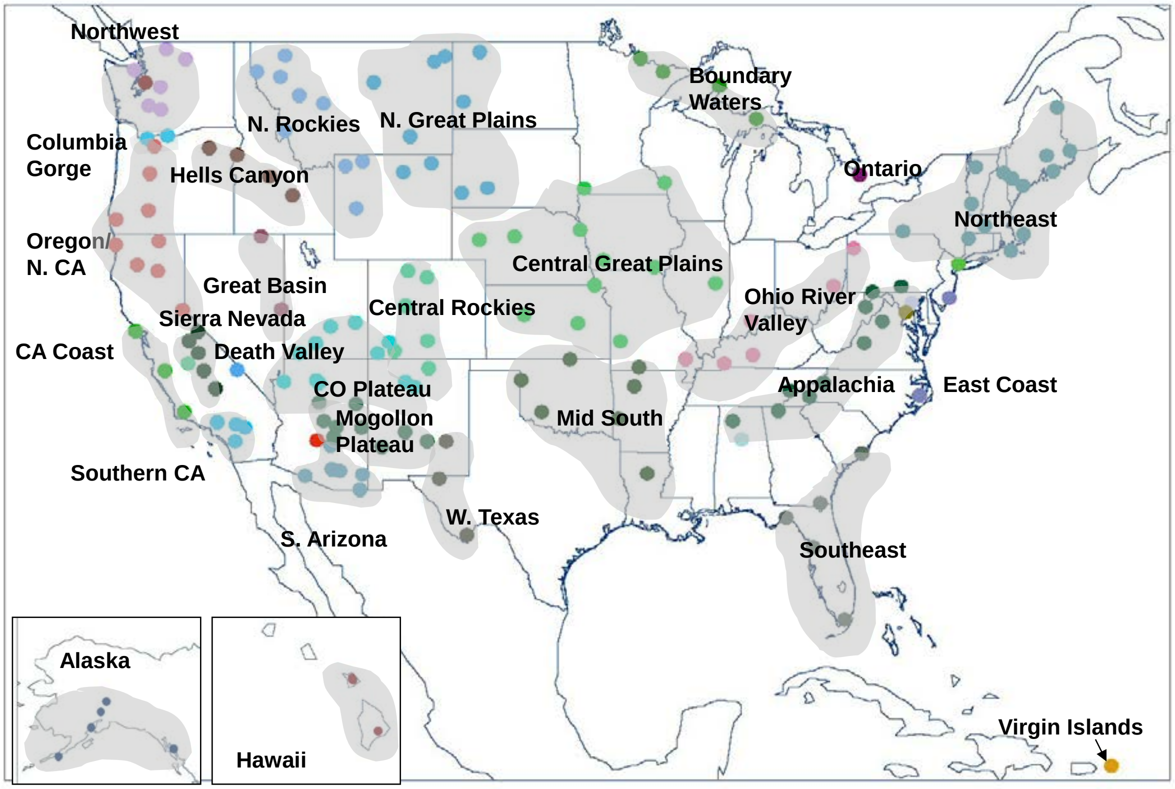

Figure 65. Twenty-five regional groupings of IMPROVE sites

Appendix G: Extinction and glidepath graphs for all sites

For each of the following sites, the top row represents graphs for the first implementation period’s approach and the bottom row represents graphs for the updated approach. The left column gives the total extinction budget for days classified as the 20% haziest (top) and 20% most impaired (bottom) in 2012 similar to Figure 6. The middle column gives the time series from 2000-2014 of the annual average total extinction budget for days classified as the 20% haziest (top) and 20% most impaired (bottom) similar to the bottom row of Figure 15.

(see supplemental information for Appendix G figures)

Appendix H: Seasonal anthropogenic extinction budgets for each site

Appendix H provides site-specific graphics which are organized according to 25 geographic groupings described in Figure 65. The graphics show the total extinction budget for the haziest days and the estimated anthropogenic portion of the average extinction budget for the most impaired days, by season, for 2010-2014. Included are the budgets for the most impaired days presented in two ways: based on the estimates of natural conditions described in Section 3 and using the alternative approach to estimate the natural contribution to OM described in Section 5. The average number of included days per season for each approach are shown by the gray line in the graphics for each site. Note that the scales are different for the total extinction and the anthropogenic portions. As previously shown in Section 3.1, there is a shift in the seasons which typically include the most impaired days compared to the haziest days for many regional grouping of sites, particularly in the Western U.S. The extinction budget charts show that estimated anthropogenic extinction for the most impaired days (with either approach to estimate natural contribution) has significantly less carbon or dust than the total extinction for the haziest days for most but not all regional groupings.

(see supplemental information for Appendix H figures)

Appendix I: Trends in clearest days and estimated natural conditions by site, 5-year average extinction budgets

(see supplemental information for Appendix I figures)

Appendix J: Seasonality in clearest days and estimated natural conditions by site, 5-year average extinction budgets (2010-2014)

(see supplemental information for Appendix J figures)