ENVIRONMENT
& HEALTH

Procedures for Making Visibility Projections and Adjusting Glidepaths using the WRAP-WAQS 2014 Modeling Platform

final draft – Revised March 1, 2021 – final draft

RECOMMENDATION

Based on the technical analysis presented in this document, and Regional Haze planning goals in rule and guidance, of the three visibility projection methods presented, tested, and analyzed, the EPA without fire contribution (EPAwoF) visibility projection method described below is recommended for consistent 2028 Class I area visibility projections for Reasonable Progress Goals across the contiguous WESTAR-WRAP region. It will be implemented as the default setting on the WRAP Technical Support System (TSS[1]) visibility projection tools, while the other two methods (EPA and ModMID) will also be accessible on TSS.

Several methods were evaluated for adjusting the URP Glidepath to account for the presence of international anthropogenic emissions and/or wildland prescribed (Rx) fire. Methods A and B that use the relative change in, respectively, international emissions alone or international emissions plus Rx fire, combined with ambient natural conditions are recommended and are implemented on the WRAP TSS.

INTRODUCTION

The Western Regional Air Partnership (WRAP)[2] and the Western Air Quality Study (WAQS) Cooperators[3] have developed a 2014 Photochemical Grid Model (PGM) modeling platform that is being used to support the development of western states' Regional Haze Rule (RHR) State Implementation Plans (SIPs) due July 2021. In the RHR SIPs, individual states will set 2028 Reasonable Progress Goals in deciviews for each Class I area (CIA) in their jurisdiction. One important use of the WRAP-WAQS 2014 PGM modeling platform is to make 2028 visibility projections for comparison with the Uniform Rate of Progress (URP) Glidepath. The URP Glidepath is a straight line of visibility impairment (in deciview) from the observed 2000-2004 baseline period visibility conditions average for the IMPROVE 20 percent Most Impaired Days (MID) to progress toward better visibility and estimated natural conditions in 2064 at IMPROVE monitoring sites that represent CIAs. The 2028 visibility projection is compared against the URP Glidepath at 2028 to see whether a projected visibility condition estimate at the CIA will be on, above, or below the Glidepath to judge how well the modeled trend in visibility is tracking the straight-line rate of progress to the estimated natural conditions in 2064.

The EPA method for identifying the IMPROVE MID uses a statistical procedure that is designed to identify the days at IMPROVE monitoring sites that are likely most impaired by anthropogenic emissions, primarily relying on measured ammonium sulfate and ammonium nitrate species quantities as proxies for manmade emissions. Using the IMPROVE sampling record from 2000-2014, the IMPROVE MID statistical procedure estimates the contributions of routine natural haze and natural haze due to episodic events (i.e., fires and windblown dust) using measured carbon and geogenic species as proxies to measured daily light extinction with the remainder extinction assumed to be mainly anthropogenic in

[1] https://views.cira.colostate.edu/tssv2/
[2] http://www.wrapair2.org/
[3] https://views.cira.colostate.edu/iwdw/About/Default.aspx#agencies

origin. The IMPROVE Most Impaired Days (MID) visibility metric is obtained for each year as the 20% highest days with anthropogenic visibility impairment after the statistical procedures have removed days with high estimated fire and dust contributions from carbon and geogenic filter mass measurements. The IMPROVE MID is the metric required in the RHR January 2017 changes by EPA to evaluate progress for the 2028 planning milestone toward reaching the distant long-term goal of achieving estimated natural conditions at CIAs by 2064. To help assess whether a CIA is on a path toward this RHR long-term goal, the trends in the IMPROVE MID visibility impairment are compared against the URP Glidepath. As part of an RHR SIP, future year visibility projections are made at IMPROVE sites representing CIAs with PGM results for comparison against the URP Glidepath with the current (second) round of RHR SIPs to estimate whether a CIA is progressing reasonably by the 2028 milestone planning year toward estimated natural conditions in 2064.

Purpose

This document discusses the approaches being used for making 2028 future year visibility projections for the MID using current and future year emission scenario simulations and the WRAP-WAQS 2014 CAMx PGM modeling platform. It also discusses how the visibility projection methods will be evaluated using the 2002 Dynamic Evaluation simulation. Finally, the methods that will be evaluated for adjusting the URP Glidepath to account for international anthropogenic emissions and emissions from wildland prescribed fires are also discussed.

Example URP Glidepath Calculations

The WRAP version 2 of the TSS includes numerous tools and products based on analysis of air quality, emissions and modeling data that western states can use as the technical basis for their RHR SIPs. With more than 100 CIAs in the WESTAR-WRAP region, a regional technical decision support system is necessary since most, if not all, CIAs have notable amounts of international, natural, and interstate transport impacts on visibility, in addition to the host state's sources impacting their CIAs. One such TSS product is the Glidepath Tool that includes the URP Glidepath and 2028 visibility projections using CAMx modeling results from the WRAP-WAQS 2014 photochemical modeling platform.

Figure 1 displays a URP Glidepath and 2028 visibility projections for Yellowstone (YELL) CIA that was obtained from the WRAP TSS Glidepath Tool (i.e., Chart 4 of the WRAP TSS Modeling Express Tools). The upper part of Figure 1 is the URP Glidepath for the IMPROVE MID where the goal is to achieve estimated natural conditions by 2064, and the bottom part of the Glidepath is the IMPROVE Clearest 20% days (cleanest 20% of measured days for total light extinction) where the goal is no worsening in visibility from the 2000-2004 Baseline. The MID URP Glidepath starts with the observed IMPROVE MID 2000-2004 5-year Baseline average (green line, 8.4 dv) and the Glidepath is a straight trend line (red) in deciview (dv) to an estimate of natural conditions of 4 dv in 2064. The annual IMPROVE MID observations are shown by the dots connected by the red line. The three diamond symbols at 2028 are the projected 2028 visibility MID using the RepBase2/2028OTBa2 CAMx modeling results and three visibility projections methods (EPA, EPAwoF and ModMID), which are described in detail below. The orange line at 7.5 dv is the measured 2014-2018 IMPROVE MID that is the starting point for the 2028 visibility projections. In this case for YELL, the 2028 visibility projections are above the URP Glidepath so are above the trend line toward estimated natural conditions in 2064.

The lower part of Figure 1 is information on the clearest days where the RHR goal is no degradation in visibility from the 2000-2004 Baseline. The green line is the 20% clearest days IMPROVE 2000-2004 Baseline (2.6 dv) and since the goal is no degradation, the line extended to 2064 in grey is flat. In this case, both the observed clearest day visibility and the 2028 visibility projections for the 20% clearest days are showing visibility improvements over the Baseline so there is no degradation in visibility for the clearest days. For the clearest days, just the EPA default projection method is shown as the biggest difference in the three methods is how modeled fires are treated and the clearest days tend to not have any fire impacts so the three methods give essential the same 2028 projection for the clearest days.

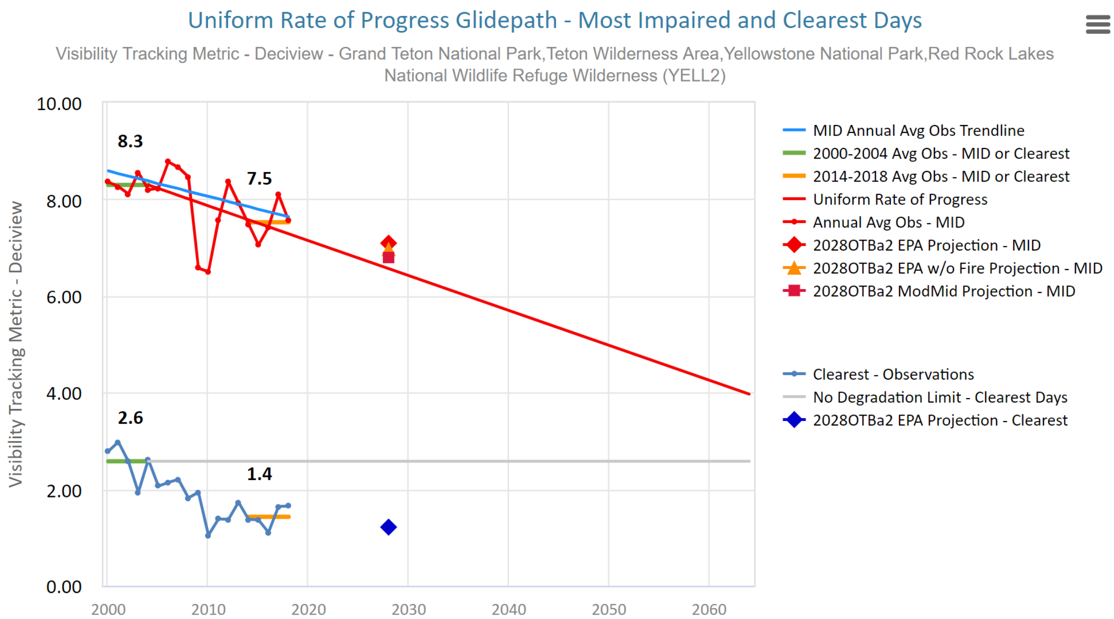

Figure 1. Example URP Glidepath and 2028 visibility projections for Yellowstone National Park, Wyoming from the WRAP TSS Modeling Express Tools Chart 4 (accessed February 4, 2021).

WRAP-WAQS 2014 Modeling Platform Modeling Results

WRAP and WAQS have jointly developed a 2014 PGM modeling platform using 36-km grid resolution continental U.S. (36US1) and 12-km grid resolution western U.S. (12WUS2) modeling domains, as shown in Figure 2. Sensitivity modeling and an initial 2014v1[4] base case simulations and model performance evaluation (MPE) were conducted using the CAMx and CMAQ PGMs. Improvements were made and a second 2014v2 base case was conducted using just the CAMx PGM with the results available on the 2014v2 MPE webpage.[5]

A Representative Baseline (RepBase2) CAMx simulation was also conducted that used anthropogenic emissions representative of the 2014-2018 5-year planning period, natural emissions and Boundary Conditions (BCs) the same as the 2014v2 simulation and Representative Baseline fire emissions developed by the WRAP Fire and Smoke Work Group (FSWG[6]). Two 2028 on-the-book (OTB) future year emission scenarios were conducted where anthropogenic emissions were projected to 2028 and natural emissions and BCs were held constant at 2014v2 levels. The two 2028 emission scenarios differ in that 2028OTBa uses the RepBase fires and 2028OTBb uses the 2014v2 actual fires.

The RepBase and 2028OTBa emission scenarios used a mixture of emissions from the 2014NEI, WRAP-WAQS 2014 updates to historic data and projections, and EPA-processed data from the National Emission Inventory Collaborative (NEIC)[7] 2016v1 emissions modeling platform. After the completion of the CAMx RepBase and 2028OTBa CAMx simulations, duplicate sources were found in the NEIC 2016v1 platform emissions that were used for some source sectors. Thus, WRAP-WAQS and the western states removed the duplicate sources, updated the emissions, and removed the incorrect results for RepBase and 2028OTBa from the TSS displays. New RepBase2 and 2028OTBa2 emissions were developed and CAMx simulations conducted. Details on the emissions used in the RepBase2 and 2028OTBa2 are given

[4] http://views.cira.colostate.edu/iwdw/docs/waqs_2014v1_shakeout_study.aspx
[5] https://views.cira.colostate.edu/iwdw/docs/WRAP_WAQS_2014v2_MPE.aspx
[6] https://www.wrapair2.org/FSWG.aspx
[7] Inventory Collaborative Wiki (colostate.edu)

in their Run Specification Sheet.[8] Methods for the RepBase2 and 2028OTBa2 High-Level (H-L) Source Apportionment (SA) CAMx simulations are detailed in a separate Run Specification Sheet.[9]

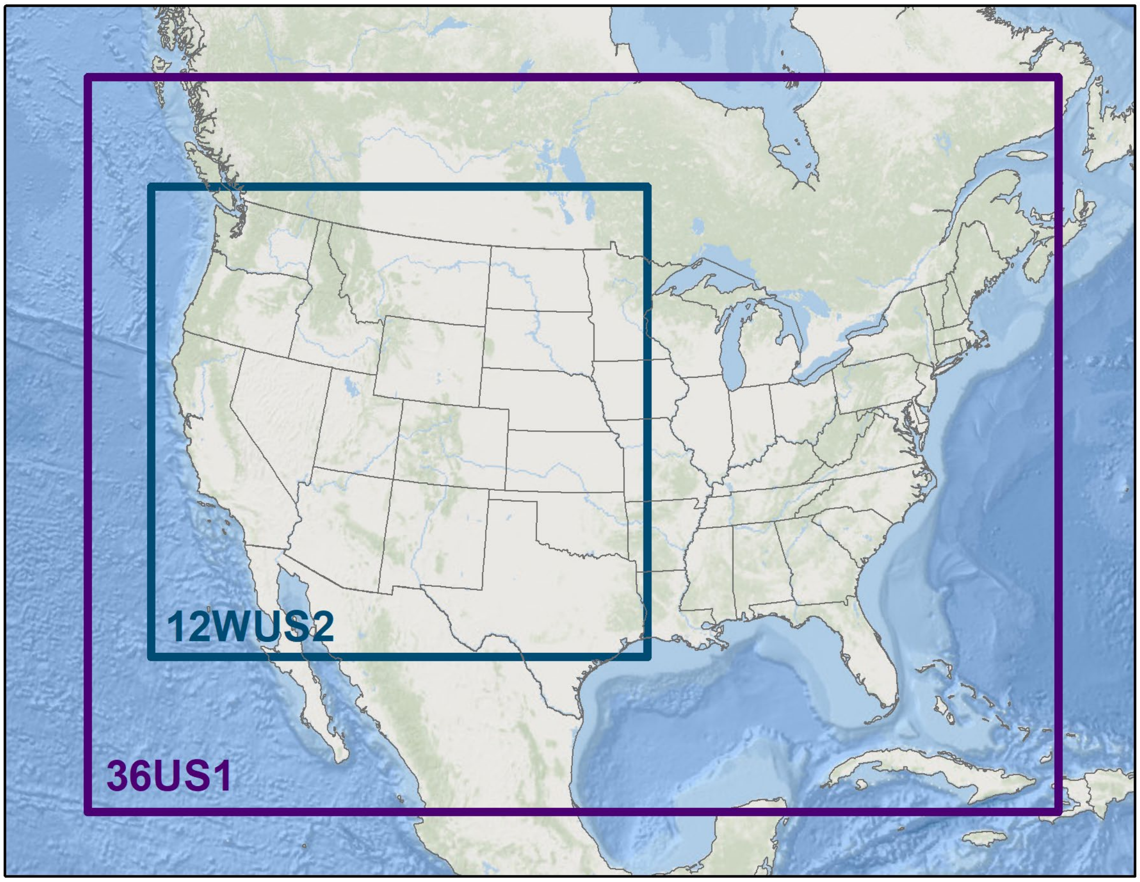

Figure 2. WRAP-WAQS 36/12-km 36US1/12WUS2 modeling domains used in the WRAP-WAQS 2014 modeling platform current (2014v2 and RepBase2) and future (2028OTBa2) year CAMx simulations.

[8] https://views.cira.colostate.edu/docs/iwdw/platformdocs/WRAP_2014/EmissionsSpecifications_WRAP_RepBase2_and_2028OTBa2_RegionalHazeModelingScenarios_Sept30_2020.pdf

[9] https://views.cira.colostate.edu/docs/iwdw/platformdocs/WRAP_2014/SourceApportionmentSpecifications_WRAP_RepBase2_and_2028OTBa2_High-LevelPMandO3_and_Low-Level_PM_andOptionalO3_Sept29_2020.pdf

VISIBILITY PROJECTION APPROACHES USING THE WRAP-WAQS 2014 PLATFORM

Three visibility projection approaches were used with the WRAP-WAQS 2014 modeling platform CAMx current year (e.g., RepBase2) and 2028 future year (e.g., 2028OTBa2) modeling results to project the 2014-2018 observed IMPROVE MID visibility to the 2028 future year. The EPA recommended visibility projection procedures are outlined in Section 5.3 of their ozone, $PM_{2.5}$ and regional haze modeling guidance (EPA, 2018[10]). The projection procedure uses the CAMx RepBase2 and 2028OTBa2 modeling results in a relative fashion to scale the observed IMPROVE concentrations from the 2014-2018 MID to obtain 2028 future year MID concentrations. The model derived scaling factors are called Relative Response Factors (RRFs) and are obtained as the ratio of the CAMx future (2028OTBa2) to current (RepBase2) year modeling results averaged across several days, where the EPA default projection approach uses days from the base year IMPROVE MID. For example, the equation for SO4 concentrations from the 2014-2018 IMPROVE MID are as follows:

$$RRF_{SO4} = \sum 2028OTBa2_{SO4} / \sum RepBase2_{SO4}$$

$$Projected\_SO4_{2028} = IMPROVE\_SO4_{2014\text{-}2018} \times RRF_{SO4}$$

The daily projected 2028 species concentrations for each day from the 2014-2018 IMPROVE MID are converted to extinction using the second IMPROVE extinction equation and then into deciview to obtain the 2028 visibility projection.

Three separate visibility projection procedures are being used with the WRAP modeling results that differ in how days with modeled fire impacts are treated and which days are used to develop the RRFs. The three visibility projection procedures are as follows:

EPA: The EPA default projection approach follows the procedures in EPA's guidance (EPA, 2018) to project the observed 2014-2018 IMPROVE MID using RRFs based on average modeled concentrations across the 2014 IMPROVE MID.

EPAwoF: Even though the observed IMPROVE MID are obtained using a statistical procedure to limit the influence of fires on the MID, modeled fire impacts can still occur on the observed 2014 IMPROVE MID. The EPA without fire (EPAwoF) method uses the RepBase2 and 2028OTBa2 Source Apportionment (SA) results to remove the contributions of emissions from U.S. wildfires (WF), U.S. wildland prescribed (Rx) burns, and non-U.S. (Mexico and Canada) fires[11] in the RepBase2 and 2028OTBa2 modeling results used in the RRFs. Thus, the EPAwoF method RRFs are based on the same days in the observed 2014 IMPROVE MID as used by the EPA default method, only the contributions from U.S. WF and Rx and Mex/Can fires have been removed in the RRFs.

ModMID: The third method uses the modeled most impaired days (ModMID) to calculate the RRFs, but still applies the RRFs to the observed 2014-2018 IMPROVE MID. The days in the ModMID are defined as the 20% days with the highest fraction of impairment due to U.S. anthropogenic emissions (i.e., 20% highest $Bext_{USAnthro}/Bext_{Total}$ days). As in EPAwoF, the RRFs are

[10] https://www3.epa.gov/ttn/scram/guidance/guide/O3-PM-RH-Modeling_Guidance-2018.pdf

[11] The WRAP-WAQS RepBase2 and 2028OTBa2 modeling has four types of open land fires: wildfires (WF), wildland prescribed (Rx) burns and agricultural (Ag) burning in the U.S. and other (Mexico/Canada) open land fires outside of the U.S. Ag burning in the western states, while anthropogenic, is a small fraction of the total fire and is retained in the RRFs in the EPAwoF and ModMID projection methods. Although wildland Rx burns are considered anthropogenic in state and tribal smoke management programs and for air quality planning purposes, they are performed to address land management and ecosystem health objectives and for the purposes of visibility projections are treated like WF. The Mex/Can fires are not separated into WF, Rx and Ag categories and are dominated by WF so are treated as such and are also removed when calculating the RRFs for the EPAwoF and ModMID visibility projection methods.

calculated without the WF, Rx and Mex/Can fire contributions but using concentrations averaged across days in the ModMID instead of days in the observed 2014 IMPROVE MID.

EPA Recommended Default Visibility Projection Procedure (EPA)

EPA's recommended procedure for projecting IMPROVE measured PM species concentrations from the observed 2014-2018 IMPROVE MID to the 2028 future year uses RRFs based on modeled concentrations from the base year IMPROVE MID, which is 2014 in this case. The EPA recommended procedures are described in EPA's 2018 regional haze, ozone and $PM_{2.5}$ modeling guidance and codified in the Software for the Modeled Attainment Test (SMAT[12]) tool; the code and any updates for SMAT is controlled by EPA.[13] The application of these procedures for the RepBase2 and 2028OTBa2 CAMx modeling results involves the following steps.

1. For each aerosol species (SO4, NO3, EC, OMC, Soil and CM),
    a. Calculate Relative Response Factor (RRF) using modeled aerosol concentration:
        i. Use modeling results for the same days from the observed 2014 IMPROVE MID in the CAMx RepBase2 and 2028OTBa2 modeling results.
        ii. Calculate average model species concentrations on days in the 2014 IMPROVE MID for CAMx RepBase2 and 2028OTBa2 scenarios.
        iii. Calculate RRF for each species using the ratio of the average species concentrations averaged across the 2014 IMPROVE MID from the RepBase2 and 2028OTBa2 CAMx modeling results.
    b. Apply the species-specific RRF to each aerosol concentration for every IMPROVE MID in 5-year period 2014-2018 to obtained 5-years of 2028 daily species concentrations.
    c. Convert daily species concentrations to extinction using the second IMPROVE extinction equation and sum the species daily extinction to obtained daily 2028 extinction values for each day from the 2014-2018 IMPROVE MID.
2. Convert daily total extinction to 5-year average of annual deciview
    a. For each day from 2014-2018 MID, convert projected 2028 daily extinction to deciview.
    b. Average daily deciview across MID for each of the 5 years.
    c. Average annual deciview MID across 5 years to obtain the 2028 MID visibility projection.
3. Compare 2028 MID visibility projection to the 2028 point on URP Glidepath.

The EPA-recommended visibility projection approach was used to make the 2028 visibility projections using the WRAP RepBase2/2028OTBa2 current/future year CAMx modeling results, with an example for Yellowstone shown in Figure 1. Additional examples are available on the WRAP TSS Glidepath Tool discussed previously.

<u>Discussion of EPA's Recommended Visibility Projection Approach</u>

EPA's recommended visibility projection approach using RRFs based on modeling results from specific days in a specific modeling year (i.e., days in the 2014 IMPROVE MID) could theoretically be appropriate for making 2028 visibility projections using WRAP's 2014v2/2028OTBb CAMx modeling results that use 2014 actual fire emissions. The RepBase2 and 2028OTBa2 modeling scenarios used the same wildland prescribed and agricultural fire activity times, locations, and emissions rates as were used in the 2014v2 scenario (i.e., they were unchanged).[14] In contrast, the inter-annual variation in time, space, and levels of wildfire activity in the WESTAR-WRAP region make the choice of a particular year to project future air quality problematic. As wildfire is among the largest pollution sources affecting Regional Haze, the Representative Baseline wildfire emission inventory was prepared, used, and held constant in the

[12] SMAT-CE v1.6 released October 28, 2019: https://www.epa.gov/scram/photochemical-modeling-tools

[13] The SMAT tool source code is not publicly available nor has it received independent quality assurance. EPA controls the SMAT tool and how it works. It requires input files of monitoring data and model results.

[14] fswg_rhp_fire-ei_final_report_20200519_FINAL (wrapair2.org), page 14.

RepBase2 and 2028OTBa2 modeling scenarios. However, it may be inappropriate for use with the RepBase2/2028OTBa2 CAMx modeling results that use RepBase fires because the RepBase wildfires are not specific to the 2014 calendar year so modeled fire concentration impacts could occur on the observed 2014 IMPROVE MID. Wildfire emissions are routinely transported great distances and their impacts broadly affect all western Class I areas to varying degrees, and the MID selection process for a given Class I area is a statistical sorting to remove the higher carbon and geogenic samples from the MIDs for a given year. Figures 3 and 4 compare acres of actual 2014 wildfire activity to those used in the RepBase wildfire activity. There are differences at the state level in terms of wildfire acres, between 2014 estimates of actual wildfire and RepBase wildfire acres as shown in Figure 3. Figure 4 shows the same data comparison in acres at the county level for the WESTAR-WRAP contiguous region; the vast majority of counties are very similar (±30,000 acres) especially given the uncertainties in tracking of actual 2014 wildfire activity. RepBase wildfire activity is more representative of typical recent years and is then constant in space, time, and associated emissions rates in the 2028OTBa2 scenario to limit the effect of wildfire on Regional Haze progress assessment, and are not very different for the purpose of assessing the MIDs with regional modeling than 2014 wildfire inventory activity data.

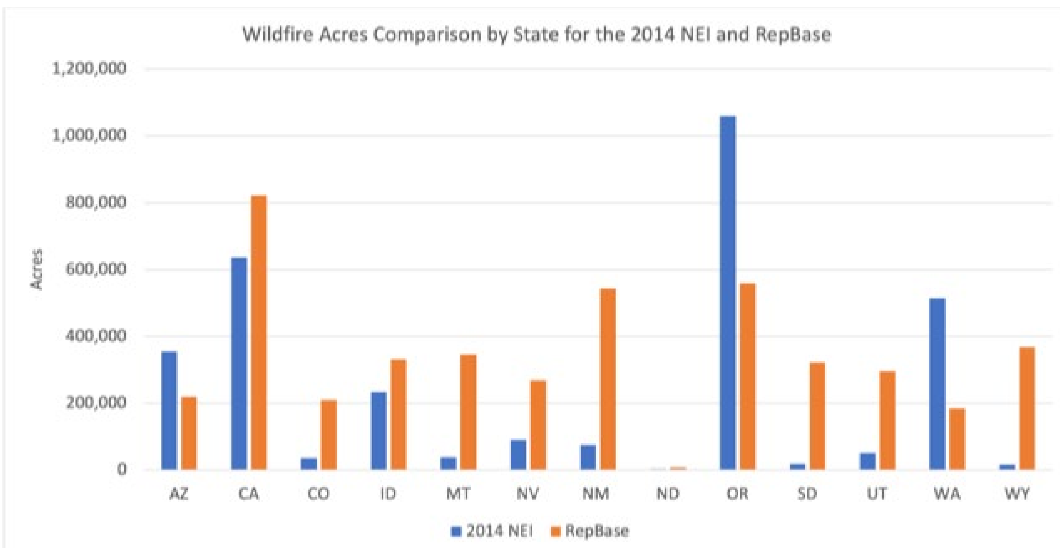

Figure 3. Comparison of 2014 NEI (used in 2014v2 modeling scenario) vs. RepBase (used in RepBase2 and 2028OTBa2 modeling scenarios) wildfire activity in acres by state in the WESTAR-WRAP contiguous region.

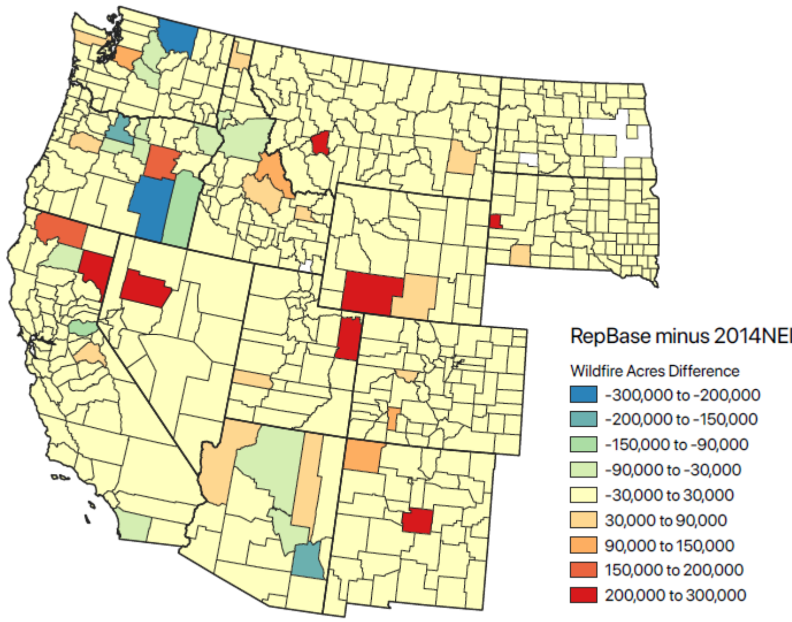

Figure 4. Map of county-level differences in 2014 NEI vs. RepBase wildfire activity. Warm colors represent more activity in RepBase; cool colors show more activity in 2014 NEI

As the RRFs are supposed to represent changes in concentrations on the IMPROVE MID and the MID were calculated to reduce effects of large measured PM carbon events on the MIDs and account to some degree for routine PM carbon influences as proxies for fire impacts, the EPA projection method may cause the presence of fires in the RRF numerator and denominator to be exaggerated and could make the RRFs stiff at any of the 100+ Class I areas in the contiguous WESTAR-WRAP region on specific MIDs (i.e., less responsive to controllable anthropogenic emissions changes); they could underestimate the actual improvement in 2028 MID visibility. Next, we evaluate those effects.

The issue of potential RepBase modeled fire impacts on the use of RepBse2 CAMx concentration estimates on days from the 2014 IMPROVE MID in the RRF projection factors as required in EPA guidance was examined by comparing observed and modeled 2014v2 and RepBase2 daily PM species light extinction on the 2014 IMPROVE MID with examples given in Figures 5 and 6. The top panel in Figure 5 shows the observed, 2014v2 and RepBase2 visibility extinction by species for the 2014 IMPROVE MID at the Canyonlands (CANY1) IMPROVE monitoring site. There are no readily apparent fire impacts as represented by PM carbon in either the observed or modeled extinction at CANY1 on the 2014 IMPROVE MID, which are indicated by large extinction values due to organic matter carbon [OMC, also called organic aerosol (OA) and organic carbon (OC)] and elemental carbon [EC, also called light absorbing carbon (LAC)]. Thus, the EPA recommended visibility projection approach would be appropriate for CANY1 using both the 2014v2 and RepBase2 modeling results[15]. The lower panel in Figure 5 shows the 2014 IMPROVE MID observed, 2014v2 and RepBase2 extinction bar charts for Mount Rainier (MORA1). At MORA1, there are days in the 2014 IMPROVE MID in August that have elevated carbon (OMC and EC) in the RepBase2 scenario that can reasonably be hypothesized to be due to fires, but the high OMC and EC extinction are not apparent in the observations or the 2014v2 scenario. The EPA projection approach would be not appropriate for MORA1 using the RepBase2/2028OTBa2 modeling

[15] Note that the large windblown dust contribution at Canyonlands on 11/1/2014 indicates strong winds that could be associated with atypically large transport of sulfate from Mexico. The model RRF will be insensitive to U.S. emissions reductions if days are included that have large international transport contributions to impairment, and an alternate method to address this concern is to identify the MID based on the days with the largest U.S. contribution to impairment.

results as the RRFs for OMC and EC would be very stiff (i.e., near 1.0). Although fires are most pronounced in the OMC and EC concentrations/extinctions, fires also emit SOx and NOx species so would also reduce the effect of any response to reductions in U.S. anthropogenic emissions contributing to AmmSO4 or AmmNO3.

The top panel in Figure 6 shows the stacked extinction bar charts on the 2014 IMPROVE MID at Point Reyes (PORE1) IMPROVE site. At PORE1, the 2014v2 CAMx simulations has elevated OMC (attributed to fire) on IMPROVE MID on September 11 and 14, 2014 that are not seen in the observed or RepBase2 modeling results. Thus, the EPA recommended approach may not even be appropriate to make projections using the 2014v2/2028OTBb CAMx simulations using actual 2014 fires at PORE1. The bottom panel in Figure 6 show the stacked extinction bar charts on the 2014 IMPROVE MID for the Lassen Volcanic (LAVO1) site in northern California where the 2014v2 (August 3, 2014) and RepBase2 (August 24, 2014) CAMx simulations each have one day of elevated OMC and EC concentrations (attributed to fire) that would dominate the OMC and EC RRFs using the EPA recommended visibility projection approach.

Figures 5 and 6 confirm that using RepBase fires could result in RepBase2 modeled fire impacts on the 2014 IMPROVE MID that would result in too stiff RRFs using the EPA recommended visibility projection approach potentially resulting in understated visibility improvements in 2028. But they also raise concerns that even using 2014 actual fires in the projections there could be modeled fire impacts on the 2014 IMPROVE MID resulting in biased RRFs that understate projected 2028 visibility improvements on the MID. That said, numerous other important PGM source categories use the same emissions from RepBase2 and 2014v2 in the 2028 projection emissions, meaning the projected visibility change is based on assuming only the U.S. anthropogenic emissions would be changing by 2028. We know from numerous peer-reviewed studies, including EPA climate change assessments, that quasi-natural emissions such as fire, dust, and biogenic emissions that greatly affect Regional Haze are not constant into the future.

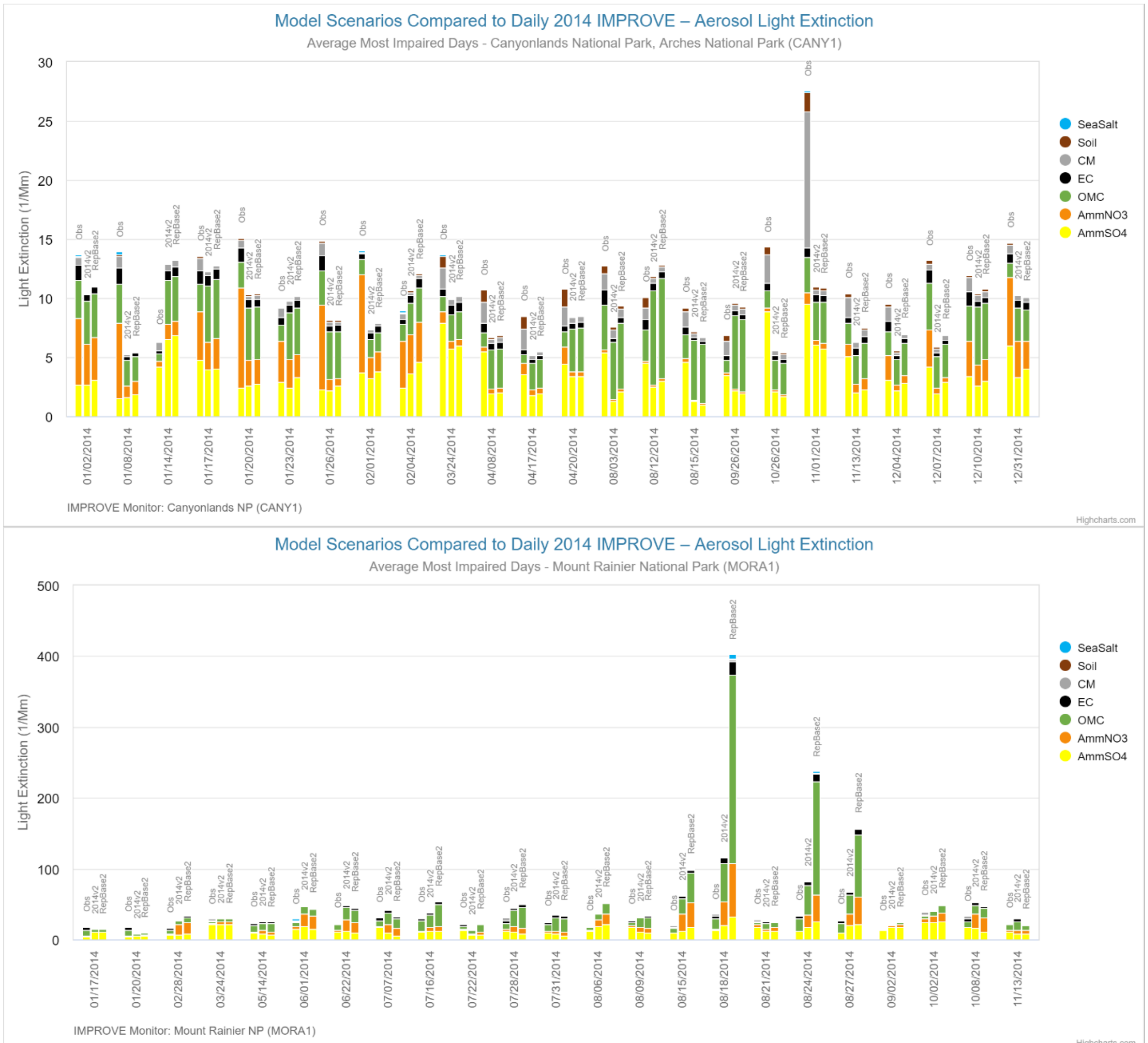

Figure 5. Visibility extinction stacked bar charts for Canyonlands UT (top) and Mount Rainer WA (bottom) IMPROVE sites on the 2014 IMPROVE MID for the observed (obs), and modeled 2014v2 actual base case and Representative Baseline (RepBase2) emission scenarios using the WRAP 2014 CAMx modeling platform. (Source: WRAP TSS Chart 2 accessed February 27, 2021).

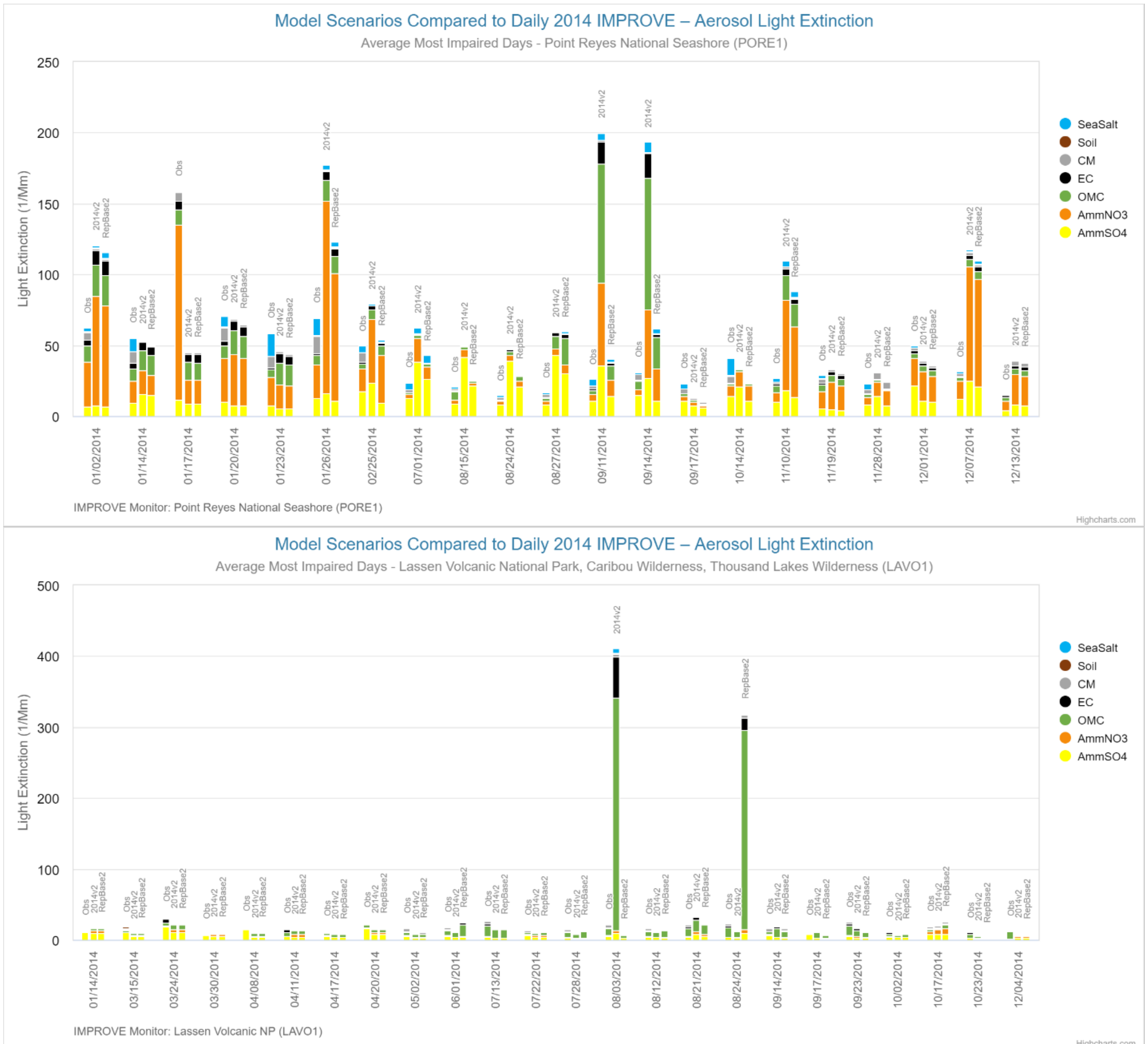

Figure 6. Visibility extinction stacked bar charts for Point Reyes CA (top) and Lassen Volcanic National Park CA (bottom) IMPROVE monitors on the 2014 IMPROVE MID for the observed (obs), and modeled 2014v2 actual base case and Representative Baseline (RepBase2) emission scenarios using the WRAP 2014 CAMx modeling platform. (Source: WRAP TSS Chart 2 accessed February 27, 2021).

EPA Recommended Visibility Projection Approach Without Fire Impacts (EPAwoF)

Several different approaches were examined to determine the best methodology for limiting the effects of fire contributions on RRFs based on the 2014 IMPROVE MID.[16] In the final EPA without fire (EPAwoF) approach, the CAMx RepBase2 and 2028OTBa2 concentrations for the days from the 2014 IMPROVE MID are used in the RRFs, as used in the EPA default projection approach, only the aerosol concentrations attributed to WF, Rx and other (Mex/Can) fires are excluded when the RRFs are calculated. The RepBase2 and 2028OTBa2 Source Apportionment results are used to remove the

[16] https://www.wrapair2.org/pdf/VisProj_Alt-EPAwoF-ModMID_RTOWG_2020-07-16v1.pptx

contributions of WF, Rx and Mex/Can fires from, respectively, the RepBase2 and 2028OTBa2 CAMx modeling results when calculating the EPAwoF RRFs.

For example, Figure 7 shows the RepBase2 SA contributions at the Crater Lake, Oregon IMPROVE site for the 2014 IMPROVE MID from all source categories (top) and for source categories with the contributions of WF, Rx and Mex/Can fires removed. That is, the top panel in Figure 7 show the source contributions on the 2014 IMPROVE MID that are used in the RRFs for the EPA default projection method, whereas the bottom panel shows the source contributions used in the RRFs for the EPAwoF alternative projection method. There are two days with large fire contributions, July 10 when WF fires (dark green) contribute almost 80% of the daily extinction and October 8 where WF (dark green) and Rx (light green) fires together contribute over 50% of the daily extinction (Figure 7, top panel); these high fire contributions are used in the EPA default method RRFs. Even with the removal of fires from the RRFs, as used in the EPAwoF method (Figure 7, bottom panel), the RepBase2 daily extinction on the 2014 MID (and other days) is still dominated by sources that are assumed to remain mostly unchanged between the current and future year, such as boundary conditions (BC) from international anthropogenic emissions (black), BC from natural sources (tan) and secondary organic aerosol from biogenic (SOAB) emissions (white).

Figure 8 is like Figure 7 only for the Sawtooth IMPROVE site in Idaho. WF contributions (dark green) can be seen in the top panel of Figure 8 in July through October, with Rx fire contributions (light green) also present in May and November. These fire contributions are used in the RRFs for the EPA default method. The bottom panel of Figure 8 shows the contributions without the WF, Rx and Mex/Can fires and represent the data used in the RRFs for the alternative EPAwoF projection method. Note that fires also emit VOCs some of which (e.g., terpenes) are precursors for secondary organic aerosol (SOA). Since the CAMx SA runs did not conduct source apportionment for SOA[17], we cannot remove fire influences from the SOA component of OA/OMC. The SOA contributions are divided between biogenic (SOAB) and anthropogenic (SOAA) based on their VOC precursors (e.g., terpenes vs. xylenes) with SOA formed from fire VOCs being lumped with the biogenic SOAB. Since fire VOC emissions are many times lower than fire primary OMC emissions, we believe the contribution of fires to SOAB is small. Although, many times we see higher SOAB contributions at the same time as high fire OA/OMC SA contributions (e.g., Figure 8 top panel). But this is due in part that fires tend to occur in the summer and fall when it is warm and there are elevated biogenic VOC emissions and faster conversation rates to SOA so higher SOAB concentrations are produced from biogenic VOC emissions.

[17] Although the CAMx PSAT source apportionment tool can track SOA source apportionment, because of the many species involved in SOA formation it would double the run times of the CAMx source apportionment simulations. So instead, we perform an operational mapping of SOA species to SOAB for those SOA compounds that are formed mainly from biogenic VOC species (e.g., terpene and isoprene) and to SOAA for those SOA compounds that are formed mainly from anthropogenic VOC species (e.g., xylene and toluene).

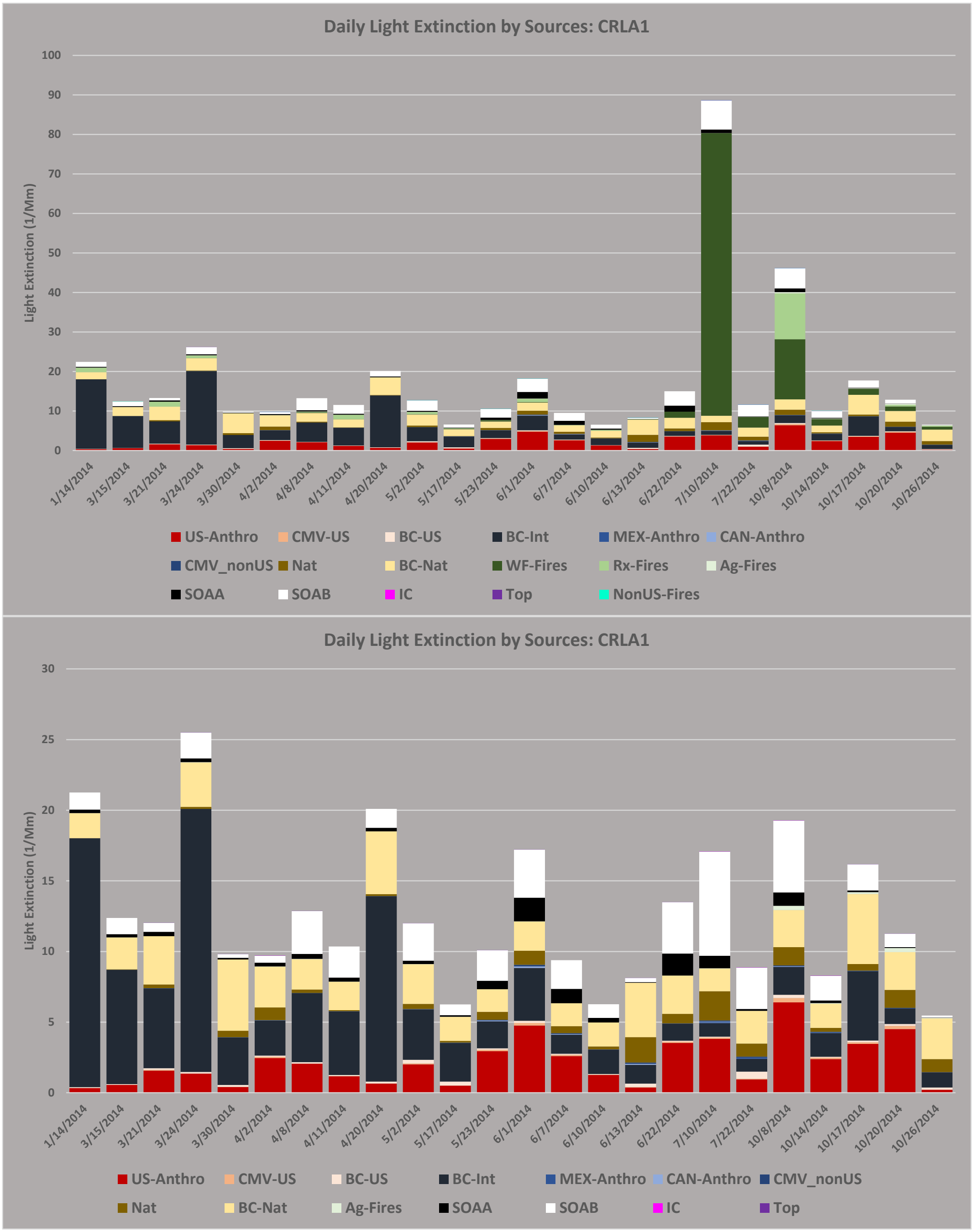

Figure 7. CAMx RepBase2 source apportionment results at Crater Lake (CRLA) Oregon for 2014 IMPROVE MID for all source categories (top) and with contributions of WF, Rx and Mex/Can fires removed (bottom).

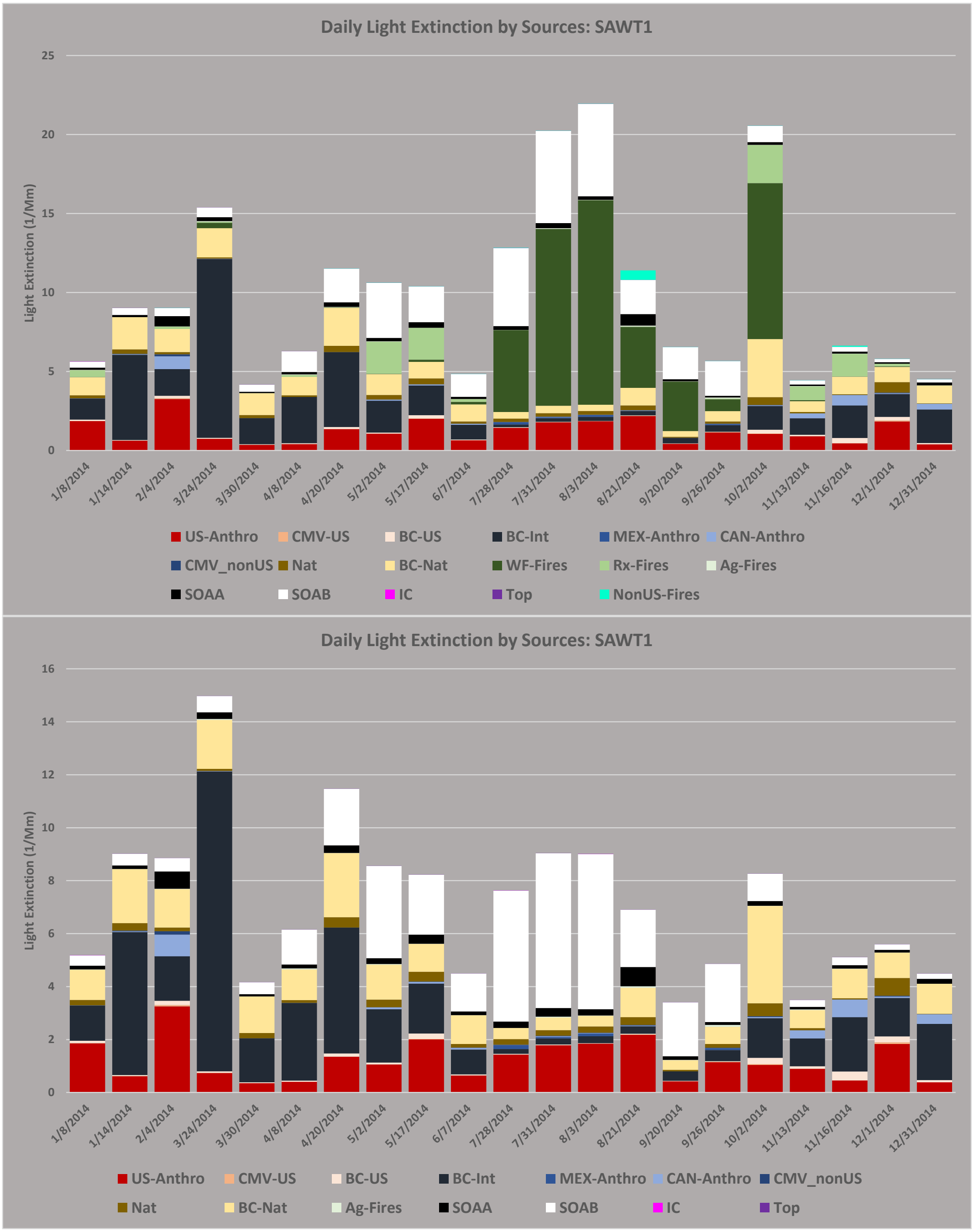

Figure 8. CAMx RepBase2 source apportionment results at Sawtooth (SAWT) Idaho for 2014 IMPROVE MID for all source categories (top) and with contributions of WF, Rx and Mex/Can fires removed (bottom).

Modeled MID (ModMID) Visibility Projection Approach

The third 2028 visibility projection approach (which also avoids days with modeled high fire impacts in the RRFs) is to base RRFs on the modeled Most Impaired Days (ModMID). PM source apportionment modeling is used to identify the 20% days in the CAMx RepBase2 H-L SA simulation that have the highest U.S. anthropogenic emissions impairment (i.e., 20% of the days with the highest fraction of extinction due to U.S. anthropogenic emissions to total extinction due to all sources).

The issue of modeled vs. IMPROVE days with the most anthropogenic impairment was studied in detail using the WAQS 2008 and 2011 modeling databases (e.g., Brewer et al., 2019[18]; Nopmongcol et al., 2016[19]; Morris et al., 2016a[20]; 2016b[21]). These analyses used results from PM source apportionment modeling to identify the most impaired days, which is discussed in detail on an IWDW website.[22] These analyses suggested that the modeled MID did not necessarily occur on the same days as the observed IMPROVE MID, and the observed IMPROVE MID still had fire influences, especially at sites and years with high fire impacts. Using source apportionment, the model can provide a very precise definition of the influences of anthropogenic, natural and fire contributions to the modeled visibility.

WRAP conducted CAMx Particulate Source Apportionment Technology (PSAT) simulation using the RepBase2 emissions (i.e., the CAMx RepBase2 H-L SA simulation) that provided separate visibility contributions due to fires, natural sources and U.S. and international anthropogenic emissions. Several different techniques for developing RRFs using the ModMID approach were evaluated[23] with the selected ModMID projection method described below.

For the ModMID projection approach, the RepBase2 and 2028OTBa2 H-L SA PM source apportionment simulation results were used to exclude the contributions of fires in the concentrations used for the RRFs (as in the EPAwoF approach). The RepBase2 H-L SA results were also used to identify the 20% of the 2014 IMPROVE sampled days during the year in which the CAMx RepBase2 has the highest impairment due to U.S. anthropogenic emissions. We also evaluated using the highest 20% U.S. anthropogenic emission contributions from all days of the year, but the results using just the IMPROVE sampling days were very similar. Thus the ModMID projection approach was based on the 2014 IMPROVE sampling days that had the 20% highest U.S. anthropogenic emissions impairment because it allows the evaluation of the model for the days used in the ModMID RRFs as well as have the ModMID projection RRFs based on a similar number of days as the EPA and EPAwoF projection approaches.

Figure 9 displays the RepBase2 source apportionment results at Crater Lake (CRLA) for days from the ModMID with (top) and without (bottom) including contributions from the WF, Rx and Mex/Can fires. There are 8 out of 24 days (33%) in the RepBase2 ModMID that overlap with the 2014 IMPROVE MID at CRLA. The selection of days for the ModMID doesn't eliminate all the occurrence of fires on those days, just assures that these are the days with the highest U.S. anthropogenic emissions contribution to total extinction. For example, there are several days in the ModMID at CRLA with Rx fire contributions (light green) and September 29, 2014 has a large (~8 Mm^{-1}) WF contribution (Figure 9, top). The fire contributions are then removed in the calculation of the RRFs used in the projections (i.e., Figure 9, bottom). Note that the inclusion of a day in the ModMID that has 20% highest U.S. anthropogenic impairment does not mean that it has a high absolute contribution of U.S. anthropogenic extinction. For example, on March 9, 2014 there is almost no modeled extinction from all sources at CRLA and it is probably also one of the modeled 20 percent cleanest days in addition to a day in the ModMID.

[18] https://www.tandfonline.com/doi/pdf/10.1080/10962247.2018.1537985?needAccess=true

[19] http://views.cira.colostate.edu/wiki/Attachments/Source%20Apportionment/Particulates_v6/C55_Nopmongcol_AWMA_vis_Sep2016.pptx

[20] http://views.cira.colostate.edu/wiki/Attachments/Source%20Apportionment/Particulates_v6/RMorris_WRAP_AWMA_Vis_n42_2016-09-29v3.pptx

[21] http://views.cira.colostate.edu/wiki/Attachments/Source%20Apportionment/Particulates_v6/RMorris_WRAP_AWMA_Vis_n116_2016-09-28v4.pptx

[22] http://views.cira.colostate.edu/wiki/wiki/9152/use-of-particulate-source-apportionment-modeling-to-identify-most-impaired-days

[23] https://www.wrapair2.org/pdf/VisProj_Alt-EPAwoF-ModMID_RTOWG_2020-07-16v1.pptx

Figure 10 shows similar results to Figure 9 only for the Mount Rainier (MORA) IMPROVE site in Washington. There are 6 days in the ModMID at MORA that overlap with the 2014 IMPROVE MID. Again, many days used in the ModMID RRFs at MORA have modest fire impacts (Figure 10, top). The elimination of fire contributions in the ModMID RRFs results in anthropogenic emissions being a larger relative contribution to the extinction in days used in the RRF (Figure 10, bottom). Note that CRLA and MORA IMPROVE sites were selected for illustration because they do have significant fire impacts on many days, including the observed 2014 IMPROVE MID. Using days from the ModMID in the RRFs eliminates days with the very high modeled fire impacts that are sometimes present in the observed 2014 IMPROVE MID.

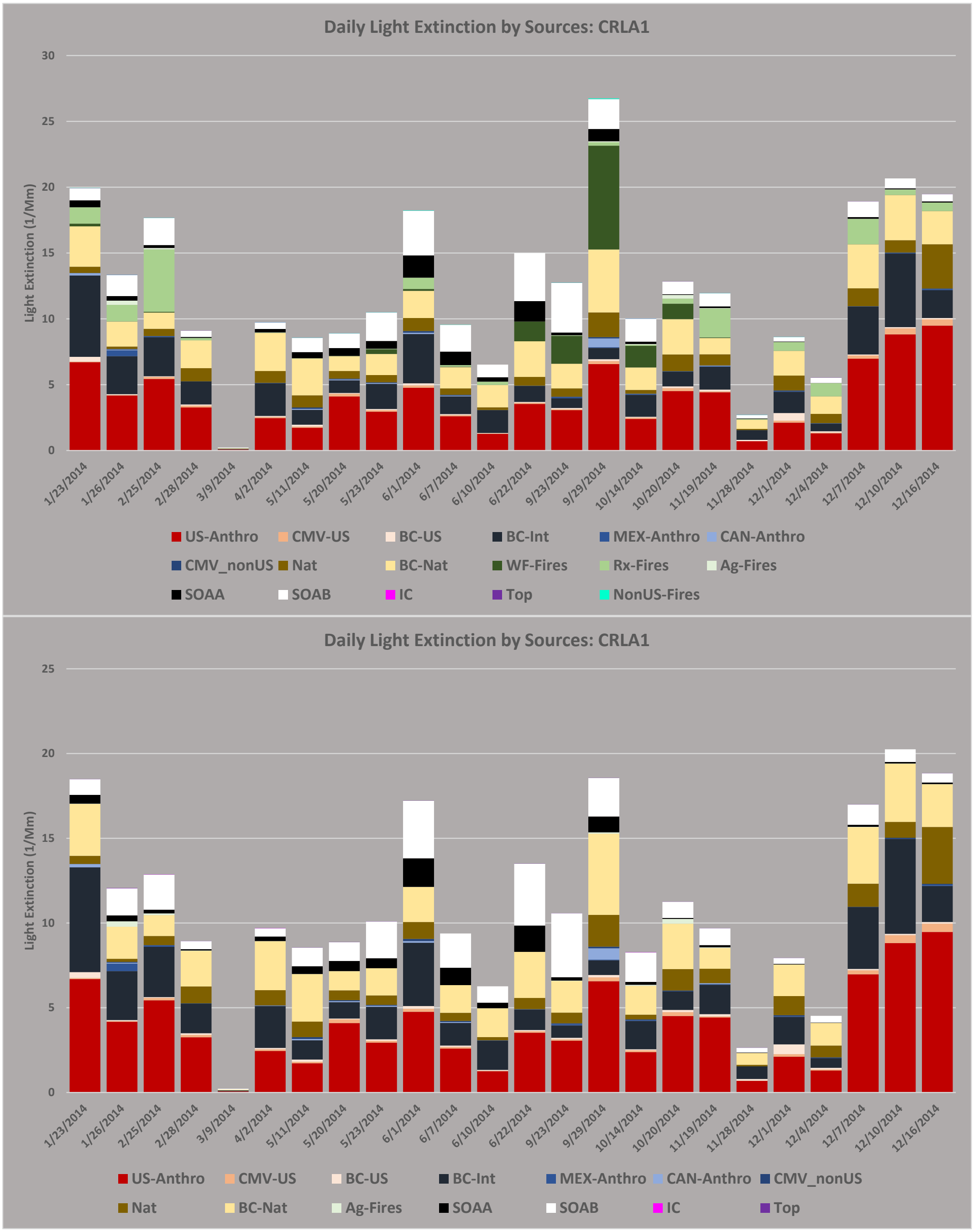

Figure 9. CAMx RepBase2 source apportionment results at Crater Lake (CRLA) Oregon for modeled most impaired days (ModMID) with all source categories contributions (top) and with contributions of WF, Rx and Mex/Can fires removed (bottom).

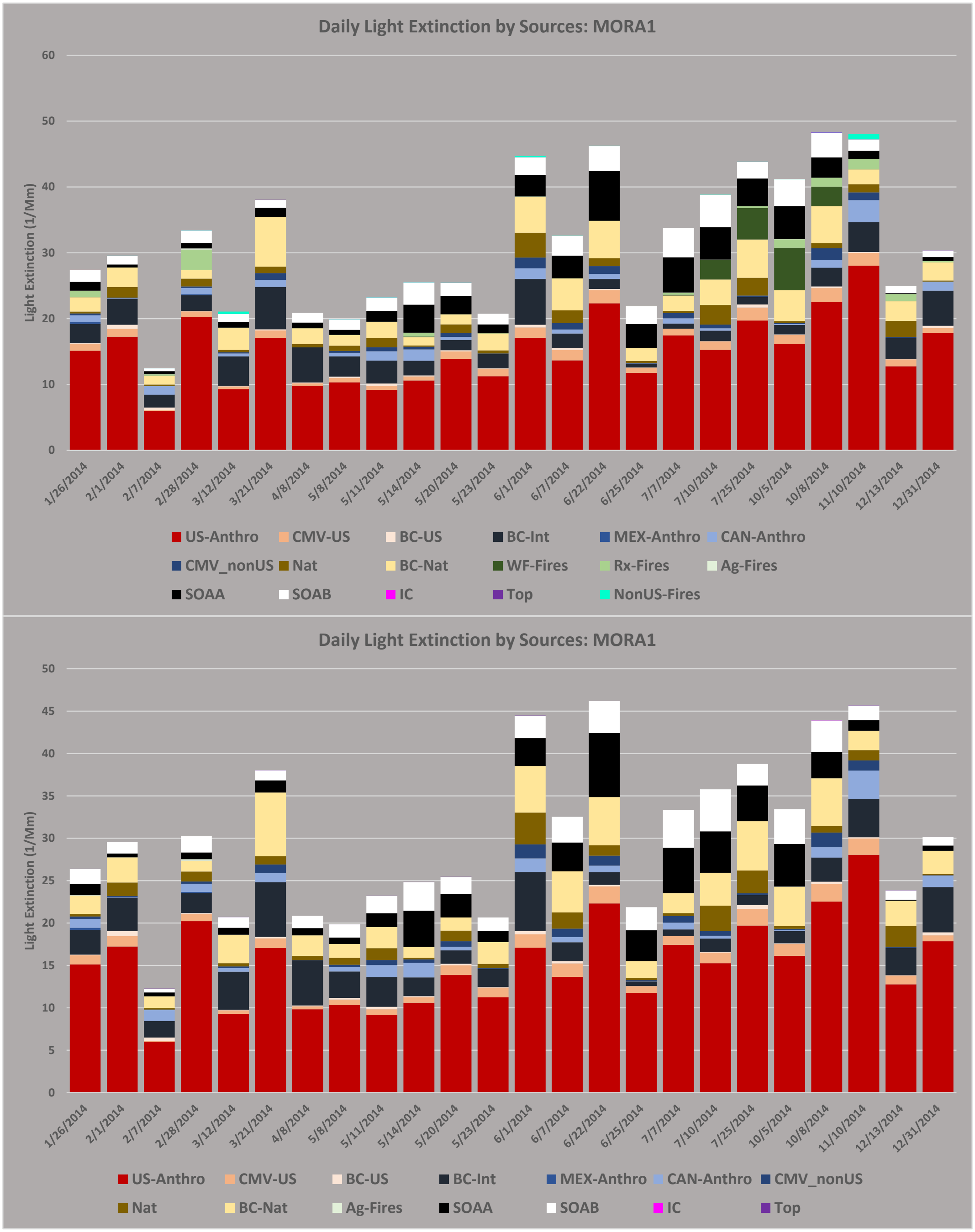

Figure 10. CAMx RepBase2 source apportionment results at Mount Rainier (MORA) Washington for modeled most impaired days (ModMID) with all source categories contributions (top) and with contributions of WF, Rx and Mex/Can fires removed (bottom).

Summary of 2028 Visibility Projection Approaches

Three 2028 visibility projection approaches have been developed that use the WRAP 2014 RepBase2 and 2028OTBa2 CAMx modeling results to project the observed 2014-2018 IMPROVE MID to the 2028 future year. These methods are:

EPA: Use RRFs based on modeled concentrations on the 2014 IMPROVE MID (i.e., EPA recommended approach that is codified in SMAT).

EPAwoF: RRFs based on same days from 2014 IMPROVE MID, only contributions of fires (WF, Rx, and Mex/Can) have been removed from the CAMx RepBase2 and 2028OTBa2 concentrations estimates using source apportionment in the RRFs (i.e., use SMAT with RepBase2 and 2028OTBa2 concentration outputs without WF, Rx and Mex/Can fire contributions).

ModMID: Use RRFs based on the modeled most impaired days (ModMID) that are defined as the 2014 IMPROVE sampling days that have the 20% highest U.S. anthropogenic emissions impairment. The ModMID RRFs are calculated without using contributions from WF, Rx and Mex/Can fires (like in EPAwoF).

Figures 11 and 12 display the average extinction across days used in the RRFs for the three projection methods at Crater Lake and Mount Rainer, respectively. The left panels in the two figures show the average modeled extinction by species for all source categories used in the RRFs, whereas the right panels show the source apportionment extinction results averaged across the days used in the RRFs for the three projection methods (e.g., no fire contributions in the EPAwoF and ModMID methods). The EPA and EPAwoF method source apportionment are the same except for EPAwoF eliminates the WF, Rx and Mex/Can fire contributions (top and middle panels).

For CRLA, the U.S. anthropogenic emissions contribution to total extinction averaged across the observed IMPROVE MID is approximately 12% for the EPA method and approximately 16% for the EPAwoF method that removes fire contributions in the RRFs. The CAMx RepBase2 modeling results for the average ModMID have more AmmNO3 and less AmmSO4 than the results for the days from the observed 2014 IMPROVE MID. The U.S. anthropogenic extinction averaged across the ModMID (~4.1 Mm^{-1}) is almost double than the 2014 IMPROVE MID (~2 Mm^{-1}). And the U.S. anthropogenic extinction contribution to the total extinction for the ModMID (~34%) is also higher than for the 2014 IMPROVE MID used in the EPA (~12%) and EPAwoF (~16%) projection methods.

For MORA, the U.S. anthropogenic extinction contribution averaged across the days used in the RRFs is approximately 26% for the EPA, 44% for the EPAwoF and 54% for the ModMID visibility projection methods. The higher fire contributions during the observed 2014 IMPROVE MID result in more differences in the EPA and EPAwoF methods.

Figure 11. Average species concentrations (left) and source apportionment of the extinction (right) averaged across days used in the RRFs at Crater Lake and for the EPA (top), EPAwoF (middle) and ModMID (bottom) visibility projection approaches.

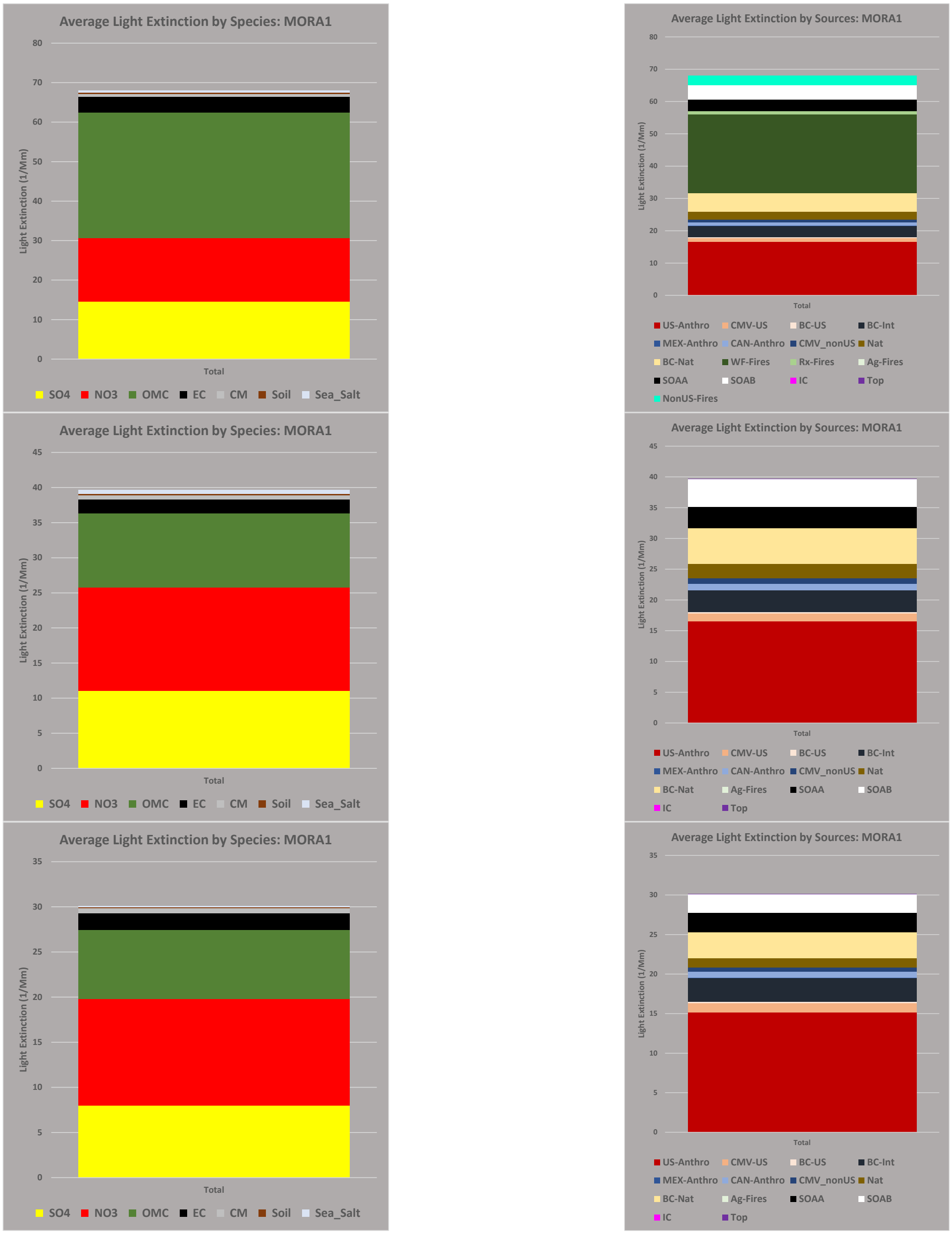

Figure 12. Average species concentrations (left) and source apportionment (right) of extinction for days used in the RRFs for Mount Rainier and the EPA (top), EPAwoF (middle) and ModMID (bottom) visibility projection approaches.

Species Held Constant in the Visibility Projection

Some measured visibility extinction species at an IMPROVE site may be dominated by natural sources that are not well simulated by the model so it may be appropriate to hold them constant between the current and future years (i.e., RRF = 1.0). For example, although the model simulates Sea Salt we would expect Sea Salt to remain unchanged between the current and future year, so EPA guidance and the SMAT projection tool holds the measured extinction due to Sea Salt constant. In Round 1 of the WRAP regional haze modeling, we assumed that Soil and Coarse Mass (CM) remained unchanged between the current and future years (i.e., set the Soil and CM RRFs = 1.0). When Soil and CM are large components of the daily visibility extinction, it is usually due to windblown dust (WBD) storms or localized dust impacts for CM, neither of which is well simulated by our current regional modeling systems due to difficulties in simulating emissions from WBD storms and subgrid-scale processes for localized CM impacts. For example, Figure 5 top panel shows very high CM and relatively high fine Soil observed extinction at Canyonlands on November 1, 2014 that is likely due to natural WBD that is not captured by the model.

An examination of the CAMx RepBase2 source apportionment results reveals that a vast majority of the modeled CM is of anthropogenic in origin. Thus, if there are large natural WBD storms causing high observed CM extinction at an IMPROVE site (e.g., the November 1, 2014 Canyonlands example given above), the changes in anthropogenic CM from the current to future will be used to adjust the natural WBD CM extinction, which would be inappropriate. Thus, for the current round of visibility SIPs we will also set the RRF for CM to 1.0 as was done in Round 1 (i.e., the extinction due to CM in 2028 is assumed to be the same as in the observed 2014-2018 IMPROVE MID).

Soil in the model is also mainly anthropogenic in origin, although it appears Mexico and Canada have larger contributions than the U.S. One update over the Round 1 regional haze modeling is that CAMx v7.1 being used that has explicit treatment of the same elemental species as used in the IMPROVE Soil extinction equation (i.e., Al, Si, Ti, Ca and Fe) so there is consistency between the observed and modeled Soil Species. Given that Soil is a small fraction of extinction for the current visibility projections and improvements in modeling Soil between Rounds 1 and 2 of the RHR SIP developments, the modeled Soil RRFs will be used in the current 2028 visibility projections.

Interpretation

The EPAwoF and ModMID alternative projection methods use RRFs that remove aerosol contributions assigned to fires by the CAMx particle source apportionment tool for days assigned as most impaired and modeled most U.S. anthropogenic impaired for the RepBase2 and 2028OTBa2 modeling scenarios. Removing fire contributions changes the relative response factors that are applied to the IMPROVE 2014-2018 most impaired days to calculate 2028 visibility projections. Note that fire contributions have not been removed from the IMPROVE 2014-2018 MID, nor the IMPROVE 2000-2004 baseline MID that determine the slope of the uniform rate of progress glidepath. Therefore adjustments to the glidepath to account for contributions from international emissions or wildland prescribed fire emissions as allowed in EPA guidance are independent and non-duplicative of the alternative projection methods.

Implementation of the Visibility Projection Procedures

WRAP has conducted the following CAMx Simulations:

- 2014v2: 2014 actual base case.
- 2028OTBb: 2028 On-the-Books implementation of both federal and state rules and permits (OTB) emissions with 2014 actual fires.
- RepBase2 H-L SA: Representative Baseline (2014-2018) emissions with RepBase fires High-Level (H-L) Source Apportionment (SA) simulation.
- 2028OTBa2 H-L SA: 2028 OTB emissions with RepBase fires High-Level Source Apportionment.
- PAC2: 2028 Potential Additional Controls with RepBase fires.

- 2002DE H-L SA: 2002 Dynamic Evaluation with RepBase fires High-Level Source Apportionment.
- FFS1: 2028 Future Fire Sensitivity (FFS) with climate-forced Wildfire (WF) activity estimates.
- FFS2: 2028 Future Fire Sensitivity (FFS) with "most likely" increased wildland Prescribed burns (Rx).

Summary of Future Fire Scenarios and changes by fire type[24]

Fire Type	Scenario 1: Future Wildfire	Scenario 2: Future Rx
Wildfire	Scaled from modeled future biomass burning	Unchanged from RB
Prescribed	Unchanged from RB	Scaled based on expert input
Agricultural	Unchanged from RB	Unchanged from RB

Three fire Source Groups are removed from CAMx output in the RRFs for the EPAwoF and ModMID visibility projection methods (Agricultural burning is retained as it is considered anthropogenic):

- U.S. Wildfires (WF)
- U.S. Wildland Prescribed Burns (Rx)
- Other Fires (Mex/Can)

Fires are held constant between the current year (CY) and future year (FY) CAMx simulations with 2014v2 and 2028OTBb using 2014 actual fires and all of the other CAMx simulations using Representative Baseline fires.

For the EPA projection method, SMAT is applied in the default mode to project the observed 2014-2018 IMPROVE MID using RRFs based on the days in the 2014 IMPROVE MID:

- Concentrations from the standard CAMx output file (AVRG) time-shifted to LST and 24-hour average SMAT-ready model input for both CY and FY.
- EPA is the only method used for 2014v2/2028OTBb; RepBase2/2028FFS1 and RepBase2/2028FFS2 projections.

For EPAwoF projection method, SMAT is applied as in the EPA method (2014-2018 IMPROVE MID projected to 2028 using RRFs based on modeling results from the 2014 IMPROVE MID) but the CAMx output input to SMAT has removed aerosol concentration contributions due to WF, Rx and Mex/Can fires.

For ModMID projections, SMAT is manipulated to make it use the days in the RepBase2 ModMID in the RRFs. This is done by adding a 2013 year to be projected (i.e., projecting 2013-2018 IMPROVE MID to 2028) that contains 2014 IMPROVE MID, removing the existing G90 flag in 2013 (2014) IMPROVE MID and adding G90 flag corresponding to days in the ModMID so that the RRFs are based on the days in the ModMID. SMAT is then run to project the 2013-2018 IMPROVE MID to 2028 using RRFs based on the 2013 G90 ModMID days. The SMAT 2028 output is post-processed for the 2014-2018 years (exclude auxiliary 2013 year from the 2028 projection calculations) to obtain 2028 visibility projection.

The fire source apportionment results from the RepBase2, 2028OTBa2 and 2002DE H-L SA simulations are used to remove fire contributions in EPAwoF and ModMID visibility projection methods:

- RepBase2 – [WF, Rx and Can/Mex from RepBase2]
- 2028OTBa2 – [WF, Rx and Can/Mex from 2028OTBa2]
- PAC2 – [WF, Rx and Can/Mex from 2028OTBa2]

[24] http://www.wrapair2.org/pdf/fswg_rhp_fire-ei_final_report_20200519_FINAL.PDF, page 17.

- 2002DE – [WF, Rx and Can/Mex from 2002DE]

The following visibility Projections are made for implementation on the WRAP TSS with CAMx CY/FY simulations used provided in parenthesis:

- **FFS1_EPA** (RepBase2/2028FFS1)
- **FFS2_EPA** (RepBase2/2028FFS2)
- **2028OTBa2_EPA** (RepBase2/2028OTBa2)
- **2028OTBa2_EPAwoF** (RepBase2/2028OTBa2: use SMAT-ready inputs without fires for both)
- **2028OTBa2_ModMID** (RepBase2/2028OTBa2: use SMAT-ready inputs without fires for both)
- **PAC2_EPA** (RepBase2/2028PAC2)
- **PAC2_EPAwoF** (RepBase2/2028PAC2: use SMAT-ready inputs without fires for both)
- **PAC2_ModMID** (RepBase2/2028PAC2: use SMAT-ready inputs without fires for both)

For the 2002 Dynamic Evaluation CAMx simulation, the three visibility projection methods are evaluated by doing backward and forward projections: (1) the observed 2014-2018 IMPROVE MID $PM_{2.5}$ species concentration are projected back to 2002 (RRF = 2002DE/RepBase2) and converted to extinction for comparison with the observed 2000-2004 IMPROVE MID average extinction; and (2) the observed 2000-2004 IMPROVE MID $PM_{2.5}$ species concentrations are projected forward to RepBase2 (representing 2014-2018; RRF = RepBase2/2002DE) and converted to extinction for comparison with the observed 2014-2018 IMPROVE MID average extinction..

- **2002DE_EPA** (RepBase2/2002DE)
- **2002DE_EPAwoF** (RepBase2/2002DE: use SMAT-ready inputs without fires for both)
- **2002DE_ModMID** (RepBase2/2002DE: use SMAT-ready inputs without fires for both)
- **RepBase2DE_EPA** (2002DE/RepBase2)
- **RepBase2DE_ EPAwoF** (2002DE/RepBase2: use SMAT-ready inputs without fires for both)
- **RepBase2DE_ModMID** (2002DE/RepBase2: use SMAT-ready inputs without fires for both)

For RepBase2DE_EPA and RepBase2DE_EPAwoF projections using SMAT, replace 2005 IMPROVE MID data with the 2014 IMPROVE data. Run SMAT to project observed 2000-2005 IMPROVE data using RRFs based on 2005 (2014) IMPROVE MID to obtain 6 years of RepBase2DE projections corresponding to 2000-2005 of MID data. Discard RepBase2DE projections for 2005 MID and average RepBase2DE projections for 2000-2004 MID to obtain RepBase2DE_EPA and RepBase2DE_EPAwoF projections.

For RepBase2DE_ModMID projections using SMAT, zero-out G90 flags in 2005 (2014) IMPROVE data in SMAT and add RepBase2 2014 ModMID G90 flags to 2005 (2014) IMPROVE data. Run SMAT (2000-2005 IMPROVE MID; 2005 base year for RRFs) and post-process RepBase2DE projections for 2000-2004 years (exclude auxiliary 2005 year from calculations).

The 2002DE visibility projections are compared against observed average 2000-2004 IMPROVE MID. The RepBase2DE projections are compared against the observed average 2014-2018 IMPROVE MID. The Dynamic Evaluation evaluates how well the model and projection technique simulates the observed change in visibility over time and is one of the four recommended model performance evaluation techniques in EPA's photochemical modeling guidance (Operational, Diagnostic, Dynamic and Probabilistic)[9].

GLIDEPATH ADJUSTMENTS

The Regional Haze Rule allows adjustments to be made to the URP Glidepath to account for contributions from international anthropogenic emissions ("international emissions") and wildland prescribed fires ("Rx fire"). Estimates of the contributions of international emissions and/or Rx fire are added to the 2064 natural conditions end-point to create an adjusted Glidepath.

EPA Guidance for Tracking Progress and Adjusting URP Glidepaths

In December 2018, building on the options specified in the January 2017 changes to the Regional Haze Rule, EPA released "Technical Guidance on Tracking Visibility Progress for the Second Implementation Period of the Regional Haze Program" (EPA, 2018[25]) that, among other things, provided recommendations for adjusting the URP Glidepath to account for international emissions and/or Rx fire contributions. The URP Glidepath adjustment is made by adding the contribution of international emissions (and/or Rx fire) to the estimated natural conditions end-point thereby decreasing the slope of the Glidepath. EPA guidance recommends using Chemical Transport Models (CTMs) to estimate the contributions of international emissions to visibility and makes recommendations on the year to be modeled and how to quantify the international emission contributions as follows (EPA, 2018, pp.18-22).

Year Selected for Estimating International Contribution: EPA postulates that modeling a current (e.g., base) year, implementation period end year (e.g., 2028) or 2064 end-point year could be used for estimating the contribution of international emissions. EPA notes that projecting international emissions to 2064 may be speculative and somewhat uncertain so believes modeling a more recent year is more appropriate: *"Therefore for the second implementation period, EPA recommends estimating international impacts in a recent year…"* and goes on to suggest that using recently developed modeling platforms for 2011, 2014 or 2016 would be appropriate (EPA, 2018, pp. 19). EPA also suggests that modeling the 2028 implementation period end year may also be appropriate if high-quality international emission projections are available. In the 2014-based WRAP Regional Haze modeling platform, the emissions from Canada, Mexico, and other international sources, and Rx fire, used in the 2028OTBa2 scenario are held constant at the emissions rates used in the RepBase2 scenario. Thus the international emissions and Rx fire contributions for 2028OTBa2 as determined from CAMx PSAT, which are added to the estimated natural conditions, are very similar to the RepBase2 international and Rx fire contributions.

Estimating Anthropogenic International Emissions Visibility Impacts: EPA guidance recommends two approaches for quantifying the contributions of international emissions to visibility impairment on the MID: (1) use of brute force international emissions zero-out simulations (ZROW, Zero-Out Rest of World); or (2) use of source apportionment to track the contributions of international emissions. Both approaches require coordinated modeling using both global and regional CTMs. EPA guidance recommends that the international emissions contribution modeling be consistent with the approach used to project 2028 MID for comparison against the URP Glidepath (i.e., use of the relative changes in modeling results to scale observed IMPROVE MID).

Whether using current (i.e., recent historic base year), or high quality 2028 milestone year projection modeling results, adjusting the 2064 end point requires adding results from current modeling results or 2028 projections to the 2064 estimated natural conditions. There is no connection in science between the statistically-estimated natural conditions estimates and modeling results for international anthropogenic and/or Rx fire contributions. Those modeled contributions are the relative amounts for the timeframe modeled and are unrelated to the statistically-estimated natural conditions.

[25] https://www.epa.gov/sites/production/files/2018-12/documents/technical_guidance_tracking_visibility_progress.pdf

EPA's Updated 2028 National Regional Haze Modeling

On September 19, 2019, EPA released updated 2028 national regional haze modeling (EPA, 2019[26]) that included 2016 base and 2028 future year CAMx 36/12-km modeling with 2028 visibility projections compared against the URP Glidepath. The Software for the Modeled Attainment Test (SMAT[27]) was used to project the observed IMPROVE MID data from 2014-2017 period to 2028 using the relative changes in the CAMx 2016 to 2028 modeling results following EPA's ozone, fine particulate, and regional haze SIP modeling guidance (EPA, 2018[28]).

EPA's updated regional haze modeling also included adjustments to the URP Glidepath to account for the contributions of international emissions. EPA's default adjusted URP Glidepaths only accounted for the contributions of international emissions and did not include the effects of Rx fire. EPA was concerned about the uncertainties with the representation of Rx fire based on only one year of modeling and that the contribution from Rx fire may be double counted as they may also be included in the natural conditions used as the Glidepath 2064 end-point, although there is no explicit term for Rx fire contributions in the 2064 end-point. EPA also noted that the contributions of Rx fire (~0 to 5 Mm^{-1}) were relatively small compared to the international emission impacts (~3 to 19 Mm^{-1}).

EPA conducted 2028 CAMx PM source apportionment modeling that obtained separate contributions of international emissions for several Source Groups, including:

- BC_{Intl} = International anthropogenic emissions contributions through the lateral boundaries of the CAMx modeling domain that was based on two Hemispheric CMAQ 2016 simulations, a base case and a no international emissions case (Zero-out Rest of World; ZROW).
- Mex = anthropogenic emissions from Mexico.
- Can = anthropogenic emissions from Canada.
- CMV_{200} = emissions from Commercial Marine Vessels more than 200 nautical miles from the U.S. coast and off the coast of non-U.S. countries.

The 2016 contributions of international anthropogenic emissions from outside of the CAMx modeling domain (i.e., BC_{Intl}) were held constant in the 2028 future projection for the historic timeframe they represented, as well as not being the same time period as the U.S. emissions inventory used in the EPA modeling. WRAP modeling has the same limitations. As U.S. anthropogenic emissions decline in the future, the 2028 milestone year, the constant emissions have a greater proportional impact on future visibility.

EPA developed a default contribution of international emissions that was consistent with their 2018 guidance:

- Use the CAMx modeling results in a relative sense using SMAT to project 2028 visibility base case conditions and 2028 conditions without contributions of international emissions [i.e., 2028 CAMx minus the source apportionment contributions from the BC_{Intl}, Mex, Can and CMV_{200} Source Groups] and take the difference between the two 2028 MID visibility projections to obtain the international emissions contribution.
- Use of ambient air quality based default Natural Conditions for the 2064 end-point.

EPA notes that there are inconsistencies in combining the relative modeling results of international emissions with the ambient based Natural Conditions in 2064 that produces results that are "obviously incorrect" at some sites. Thus, EPA calculated the adjusted URP Glidepath with an adjusted 2064 end-

[26] https://www.epa.gov/sites/production/files/2019-10/documents/updated_2028_regional_haze_modeling-tsd-2019_0.pdf
[27] https://www.epa.gov/scram/photochemical-modeling-tools
[28] https://www3.epa.gov/ttn/scram/guidance/guide/O3-PM-RH-Modeling_Guidance-2018.pdf

point five different ways using relative (i.e., using SMAT to project 2028 visibility for the MID) and absolute (i.e., CAMx concentration estimates on the IMPROVE MID) contributions of international emissions as well as the ambient data derived Natural Conditions and modeled natural conditions as the 2064 end-point:

1. [**Default**] Relative international anthropogenic model contributions + ambient natural conditions.
2. Absolute international anthropogenic model contributions + ambient natural conditions.
3. Relative international anthropogenic and prescribed fire model contributions + relative modeled natural conditions.
4. Absolute international anthropogenic and prescribed fire model contributions + absolute modeled natural conditions.
5. Relative international anthropogenic and prescribed fire model contributions + ambient natural conditions

In EPA's documentation, the adjusted URP Glidepath was presented as a shaded range of the five methods given above with the default approach presented as a dotted line. Figure 13 below shows an example of EPA's URP Glidepath for Canyonlands IMPROVE site with the shaded range of adjusted URP Glidepaths.

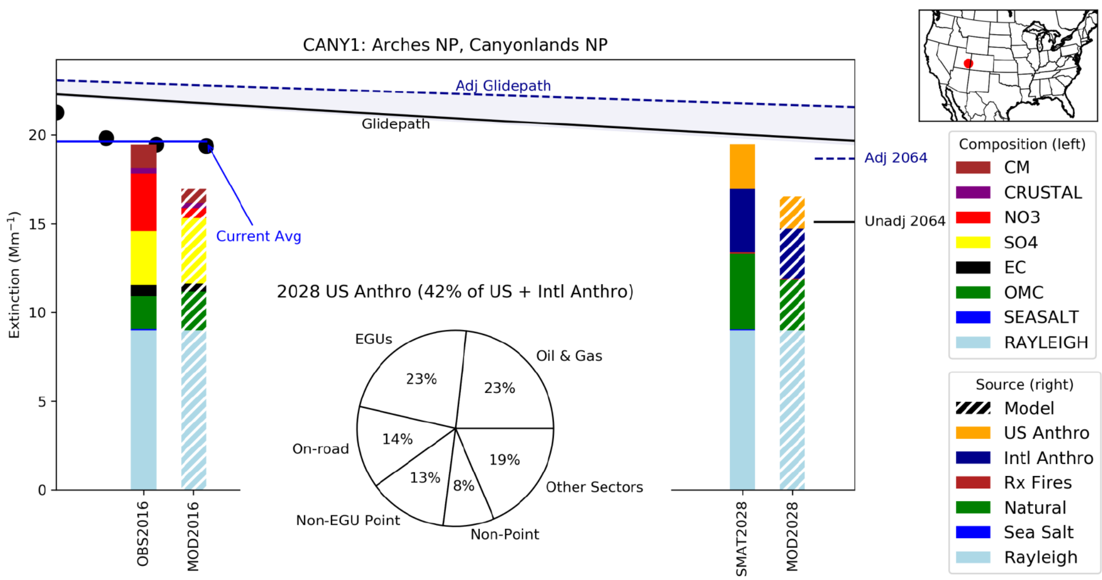

Figure 17: 2014-2017 IMPROVE observations, 2016 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at CANY1. Used for Class I areas: Arches NP, Canyonlands NP.

Figure 13. Example of EPA's URP Glidepath for Canyonlands showing range of adjusted Glidepath using the five methods as well as default adjusted Glidepath (Source, EPA, 2019).

Adjusted Glidepaths using the WRAP 2014 Modeling Platform

There are several ways WRAP could obtain the contributions of international emissions and Rx fire:

- WRAP has conducted RepBase2 and 2028OTBa2 CAMx High-Level (H-L) Source Apportionment (SA) modeling and, like EPA's 2028 CAMx SA modeling, obtained separate contributions of BC_{Intl}, Mex, Can, CMV_{200} and Rx fire. The RepBase2 or 2028OTBa2 H-L SA run can be processed in a relative sense (i.e., using SMAT to scale the 2014-2018 IMPROVE MID data) or in an absolute fashion (e.g., use 2014 IMPROVE MID data or modeled MID) to get the current year (i.e., RepBase -- 2014-2018) or 2028 future year contributions of international emissions and Rx fire to impairment on the MID.

- WRAP also conducted linked GEOS-Chem/CAMx international anthropogenic emissions zero-out (ZROW) modeling that could also be used to obtain the international emission contributions. The GEOS-Chem ZROW modeling was used for the CAMx RepBase2 and 2028OTBa2 H-L SA BC inputs to allow the separate tracking of BC_{Intl}.

Recommended Data Source for Glidepath Adjustments: We recommend the use of the results from the CAMx 2028OTBa2 H-L SA run to obtain international emissions and Rx fire contributions, so they are calculated in an internally consistent fashion to the 2028 projections. This is in contrast to the linked 2014 GEOS-Chem/CAMx ZROW sensitivity modeling that could only be used for international emissions and not Rx fire Glideslope adjustments.

Potential sources for the natural conditions 2064 endpoint are as follows:

- The recommended Natural Conditions based on 2000 through 2014 ambient data used as the default 2064 end-point (NCII or NC_Amb).[29]
- The RepBase and/or 2028OTBa2 H-L SA runs could be used to obtain the modeled natural conditions contribution using either the relative (NC_Rel) or absolute (NC_Abs) modeling results. The natural conditions SA Source Group includes biogenic VOC and NOx, lightning NOx (LNOx), oceanic sea spray aerosol (SSA) and dimethyl sulfide (DMS), and windblown dust (WBD) emissions. It can be combined with the natural component of the BCs ($BC_{Natural}$).
    - Note that biogenic soil NOx does include some anthropogenic components from fertilizer application and atmospheric deposition of nitrogen of anthropogenic origin.
- WRAP also conducted a zero-out all anthropogenic emissions GEOS-Chem/CAMx natural (NAT) simulation that could also be used to obtain to obtain an estimate of Natural Conditions.
    - One advantage of using the WRAP NAT zero-out run is that its biogenic NOx emissions eliminated the contributions of soil NOx emissions due to fertilizer application and nitrogen deposition.
    - A big disadvantage of using the WRAP RepBase NAT zero-out run is that it includes wildfire (WF) emissions that will greatly affect the natural conditions 2064 end-point at some sites.

Recommended Data Source for Natural Conditions: We recommend that natural conditions based on ambient data (NCII/NC_Amb) and relative (SMAT) and absolute modeling results from the 2028 H-L SA simulation be evaluated for use as the natural conditions 2064 end-point in the Glidepath.

Relative versus Absolute Modeling Results

EPA's 2028 national regional haze modeling used five techniques to develop adjusted URP Glidepaths that used both relative and absolute modeling results. The EPA default visibility projection approach is to use EPA's relative approach that involves running SMAT for the 2028 scenario and the 2028 scenario with the international emissions contribution removed using source apportionment.

Recommended Approach for Adjusting the URP Glidepath

Like EPA's national regional haze modeling, it is difficult to tell a priori which approach for adjusting the URP Glidepath to account for contributions of international emissions (IE) and Rx fire will work best in all cases. As reported in EPA's regional haze modeling technical support document (EPA, 2019), EPA's

[29] https://www.epa.gov/sites/production/files/2018-12/documents/technical_guidance_tracking_visibility_progress.pdf

default guidance (EPA, 2018) approach produced results for some sites that EPA found were "obviously incorrect."

Table 1 below lists five candidate approaches that WRAP evaluated for developing contributions of international emissions and Rx fire as well as the 2064 end-point natural conditions that can be used to adjust the URP Glidepaths in the WRAP regional haze modeling.

A. The first method is the EPA guidance (EPA, 2018) approach (called Default in EPA's national modeling). SMAT is run twice to project the observed 2014-2018 IMPROVE MID to 2028 using RepBase current year and two future year emission scenarios: 2028OTBa and 2028OTBa with the contributions of international emissions removed using the 2028OTBa source apportionment results. The difference in the two 2028 SMAT projections are the relative contributions of international emissions that are added to the ambient natural conditions (NC_Amb).
B. The second method is like the first only accounting for international emissions and Rx fire. EPA was concerned that the Rx fire may also be present in the Natural Conditions so did not include Rx fire in their adjusted Glidepaths to avoid double counting.
C. The third method uses internally consistent SA absolute modeling results for both international emission and Rx fire Source Groups as well as the natural Source Group for the 2064 natural conditions.
D. The fourth method uses the relative approach to represent international emissions and Rx fire (as in method 2). And uses the relative approach for the 2064 natural conditions as well (i.e., running SMAT with natural sources removed from the 2028OTBa2 results).
E. The fifth method uses the absolute modeling results for international emissions and Rx fire combined with the ambient natural conditions.

Table 1. Potential methods using WRAP modeling results for developing adjusted URP Glidepaths to account for international emissions, international emissions and Rx fire and alternative natural conditions.

Method	Intl Emiss/Rx Fire	2064 Nat Cond	Comment
A	Relative SA IE	NC_Amb	EPA default ambient natural conditions
B	Relative SA IE+Rx	NC_Amb	EPA default ambient natural conditions
C	Absolute SA IE+Rx	Absolute SA Nat	Absolute modeled view of world
D	Relative SA IE+Rx	Relative SA Nat	Relative modeled view of world
E	Absolute SA IE+Rx	NC_Amb	Absolute international and Rx w/ NC_Amb

Procedures for Calculating the Glidepath Adjustments

Below we present the procedures for developing the five sets of Glidepath Adjustments listed in Table 1 above using the 2028OTBa2 High-Level Source Apportionment modeling results. Table 2 lists the Source Groups used in the 2028OTBa2 H-L SA simulation that obtained separate contributions of SO4, NO3, POA, PEC, Soil and CM. Note that PM source apportionment was not obtained for Secondary Organic Aerosol (SOA), but we were able to use the standard model output and split it between anthropogenic (SOAA) and biogenic (SOAB) source categories.

Table 2. Source Groups used in the RepBase2 and 2028OTBa2 High-Level Source Apportionment simulation.

No.	RepBase2	2028OTBa2	Description
1	$BC_{Natural}$	$BC_{Natural}$	Natural sources BC
2	BC_{Intl}	BC_{Intl}	International Anthropogenic Emissions BC
3	BC_{US}	BC_{US}	U.S. Anthropogenic Emissions BC
4	TopCon BC	TopCon BC	BCs from above top of the model (50 mb, ~19 km MSL)
5	IC	IC	Initial Concentrations

6	Natural	Natural	Biogenic, LNOx, oceanic [SSA and DMS] and WBD
7	WF	WF	U.S. Wildfires (WF)
8	Rx Fires	Rx Fires	U.S. Prescribed Burns (Rx)
9	Ag Burning	Ag Burning	U.S. Agricultural Burning Fires (Ag)
10	Can/Mex Fires	Can/Mex Fires	Fires from Canada and Mexico (WF+Rx+Ag)
11	CMV_{200}	CMV_{200}	Commercial Marine Vessel (CMV) within 200 nautical miles (nmi) of the U.S. coast (i.e., the ECA zone of the coast of the U.S.)
12	CMV_{Intl}	CMV_{Intl}	CMV greater than 200 nmi off of the U.S. coast or off of the coast of Mexico or Canada
13	Mex Anthro	Mex Anthro	Mexico anthropogenic emissions
14	Can Anthro	Can Anthro	Canada anthropogenic emissions
15	U.S. Anthro	WRAP Anthro	RepBase2: All U.S. anthropogenic emissions 2028OTBa2: 13 WRAP state anthropogenic emissions
16		Non-WRAP Anthro	RepBase2: Not Applicable 2028OTBa2: Non-WRAP state U.S. anthropogenic emissions

Relative Contributions

The Relative (Rel) contributions were obtained using just the EPA 2028 visibility projection approach. The 2028 projections of the three methods (EPA, EPAwoF, and ModMID) are similar. In addition to the over complicating the Glidepath adjustment analysis by analyzing three relative visibility projection approaches, there are also conceptual issues and the potential for getting negative concentrations in the EPAwoF and ModMID methods because Rx fire is removed twice. The Rel contributions are obtained by running SMAT two times using the EPA visibility projection approach with the RepBase2 base year and with future years being 2028OTBa2 results and 2028OTBa2 results with the SA contribution of the Natural Conditions, IE or IE+Rx removed. The difference of the two SMAT simulations is obtained in extinction (Bext) and that is used to define the parameter deciview.

- NC_Bext (Mm^{-1}) = SMAT[2028OTBa2] – SMAT[2028OTBa2 – ($BC_{Natural}$ + Natural + SOAB)]
- NC_Rel (dv) = 10 ln[NC_Bext + Rayleigh)/10]

- IE_Bext (Mm^{-1}) = SMAT[2028OTBa2] – SMAT[2028OTBa2 – (BC_{Intl} + CMV_{Intl} + Mex Anthro + Can Anthro)]
- IE_Rel (dv) = 10 ln[(NC_Bext + IE_Bext + Rayleigh)/10]
- IE_Rel_Amb (dv) = 10 ln[(NC_Amb + IE_Bext + Ray)/10]

- IERx_Bext (Mm^{-1}) = SMAT[2028OTBa2] – SMAT[2028OTBa2 – (BC_{Intl} + CMV_{Intl} + Mex Anthro + Can Anthro + Rx Fires)]
- IERx_Rel (dv) = 10 ln[(NC_Bext + IERx_Bext + Rayleigh)/10]
- IERx_Rel_Amb (dv) = 10 ln[(NC_Amb + IERx_Bext + Rayleigh)/10]

Absolute Contribution

The Absolute (Abs) contributions are obtained by doing averages of the extinction in the CAMx 2028OTBa2 simulation across the days in the 2014 IMPROVE MID and then converting to deciview. The contributions of the NC, IE and IERx Source Groups are calculated as averages across all the days in the MID/ModMID from specific source apportionment groups:

$$NC\_Abs_{Bext} = \frac{1}{N}\sum_{i=1}^{N}\{BC_{Natural} + Natural + SOAB\}_i$$

$$IE\_Abs_{Bext} = \frac{1}{N}\sum_{i=1}^{N}\{BC_{Intl} + CMV_{Intl} + Mex.Ant + Can.Ant\}_i$$

$$IERx\_Abs_{Bext} = \frac{1}{N}\sum_{i=1}^{N}\{BC_{Intl} + CMV_{Intl} + Mex.Ant + Can.Ant + Rx\ fires\}_i$$

Where the sum (i) is across the N days in the 2014 IMPROVE MID.

And the corresponding deciview values for the unadjusted Glidepath end-point (NC_Abs_{dv}) and adjusted Glidepath end-point account for just IE (IE_Abs_{dv}) and accounting for IE and Rx ($IERx\_Abs_{dv}$):

$$NC\_Abs_{dv} = 10\ \ln\left(\frac{NC\_Abs_{Bext} + Rayleigh}{10}\right)$$

$$IE\_Abs_{dv} = 10\ \ln\left(\frac{NC\_Abs_{Bext} +\ IE\_Abs_{Bext} + Rayleigh}{10}\right)$$

$$IERx\_Abs_{dv} = 10\ \ln\left(\frac{NC\_Abs_{Bext} + IERx\_Abs_{Bext} + Rayleigh}{10}\right)$$

$$IERx\_Abs\_Amb_{dv} = 10\ \ln\left(\frac{NC\_Amb_{Bext} + IERx\_Abs_{Bext} + Rayleigh}{10}\right)$$

Table 3 lists the five methods to be examined for adjusting the URP Glidepath in Table 1 using the calculations above to define the 2064 end-point for the Glidepath.

Table 3. 20164 end-point used in five proposed approaches for analyzing alternative adjustments to the URP Glidepath.

Method	Intl Emiss/Rx Fire	2064 Nat Cond	2064 End-Point
A	Relative SA IE	NC_Amb	IE_Rel_Amb
B	Relative SA IE+Rx	NC_Amb	IERx_Rel_Amb
C	Absolute SA IE+Rx	Absolute SA Nat	$IERx\_Abs_{dv}$
D	Relative SA IE+Rx	Relative SA Nat	IERx_Rel
E	Absolute SA IE+Rx	NC_Amb	$IERx\_Abs\_Amb_{dv}$

Example Adjusted Glidepath Results

Figures 14 through 17 are copied from a developmental version of Chart 5[30] of the WRAP TSS Modeling Express Tools and show results of the 5 Glidepath adjustment approaches for four IMPROVE sites that represent Class I Areas (CIAs). For Mountain Rainier (MORA1) in Washington (Figure 14), approach A (IE_Rel_Amb) and B (IERx_Rel_Amb) are slightly above the standard Glidepath with approach C ($IERx\_Abs_{dv}$) and E ($IERx\_Abs\_Amb_{dv}$) above approaches A and B. However, the fully relative modeled IERx and natural conditions approach adjusted Glidepath (approach D) is below the standard unadjusted Glidepath.

At Lava Beds (LABE1) in northern California (Figure 15), approaches A and B are again slight above the standard unadjusted Glidepath, but approach E has near zero slope and approach C has a positive

[30] Note that the final version of the WRAP TSS Model Express Tools Chart 5 just includes the A and B Glidepath adjustment approaches.

slope. Like MORA1, approach D lies below the standard unadjusted Glidepath at LABE1 with a more negative slope.

Theodore Roosevelt (THRO1) in North Dakota (Figure 16) is near the Canadian border so has a larger international emissions contribution. All five approaches look reasonable with Glidepath adjustments than lessen the slope. Approaches A, B and D that use the relative IE are clustered together and have the least slope while the two approaches that use the absolute IE lie between them and the standard Glidepath.

The final example is for Canyonlands (CANY1) Utah that is shown in Figure 17. The three methods that use NC_Amb natural conditions (A, B and E) look reasonable and are clustered together above the standard Glidepath. However, the two approaches that use modeled natural conditions (C and D) have more negative slope and lie below the standard unadjusted Glidepath.

Recommendation for Glidepath Adjustments: Approaches A and B that use the relative change in IE and IE+Rx and ambient natural conditions are recommended for adjusting the Glidepath to account for, respectively, internal emissions alone and combined effects of international emissions and Rx fire. The other approaches either produce adjusted Glidepaths that lie below the standard unadjusted Glidepath or can produce Glidepaths with positive slope so don't appear consistent relative to the standard unadjusted Glidepath.

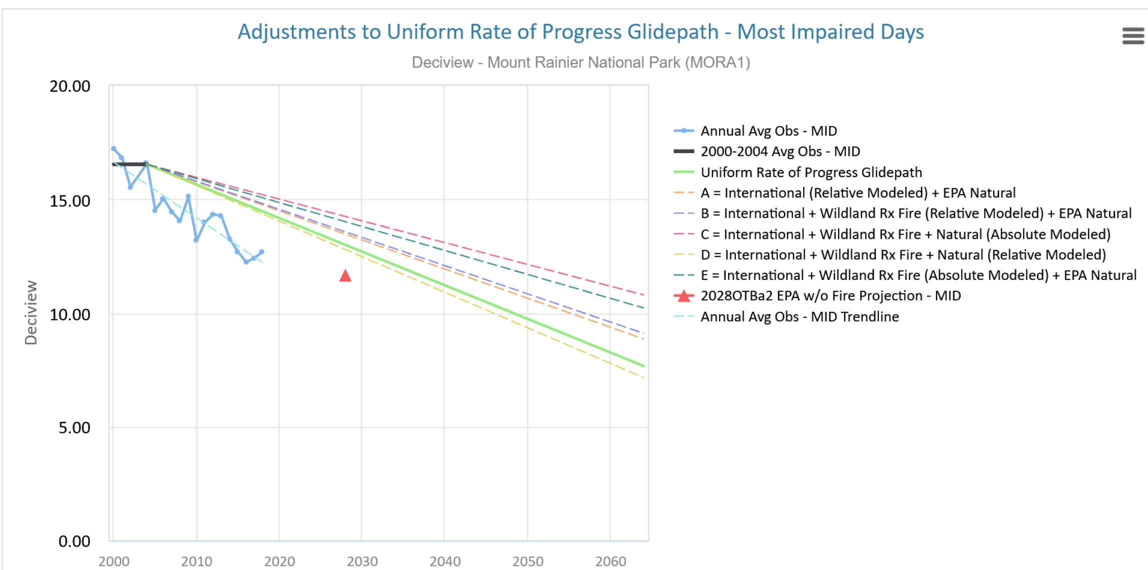

Figure 14. Example adjusted Glidepath results for Mountain Rainier (MORA1) CIA (from development version of the WRAP TSS Model Express Tools Chart 5, accessed February 12, 2021).

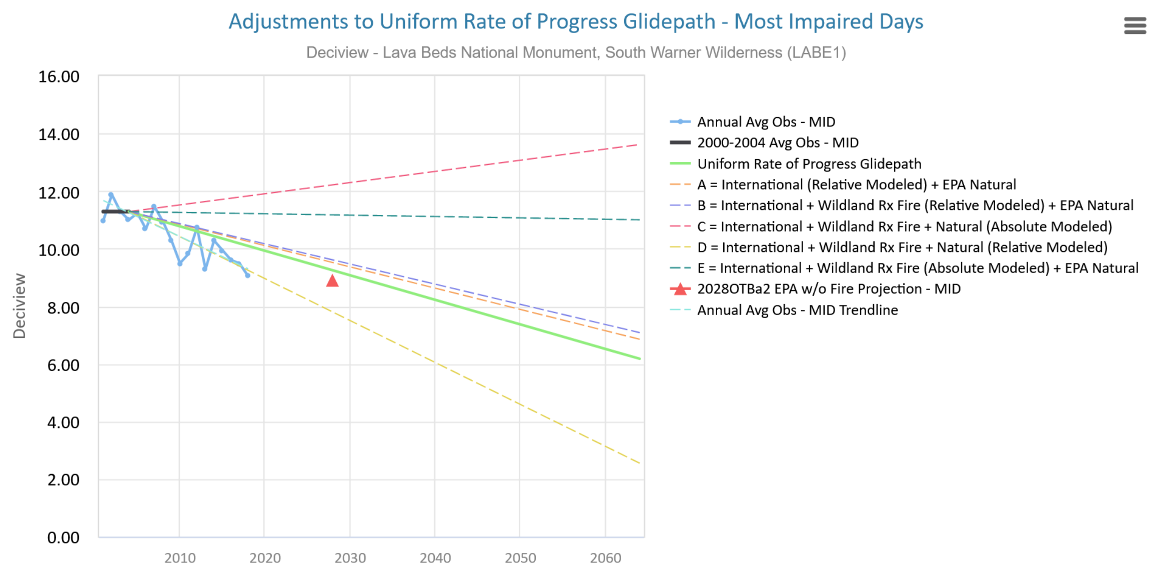

Figure 15. Example adjusted Glidepath results for Lava Beds (LABE1) CIA (from development version of the WRAP TSS Model Express Tools Chart 5, accessed February 12, 2021).

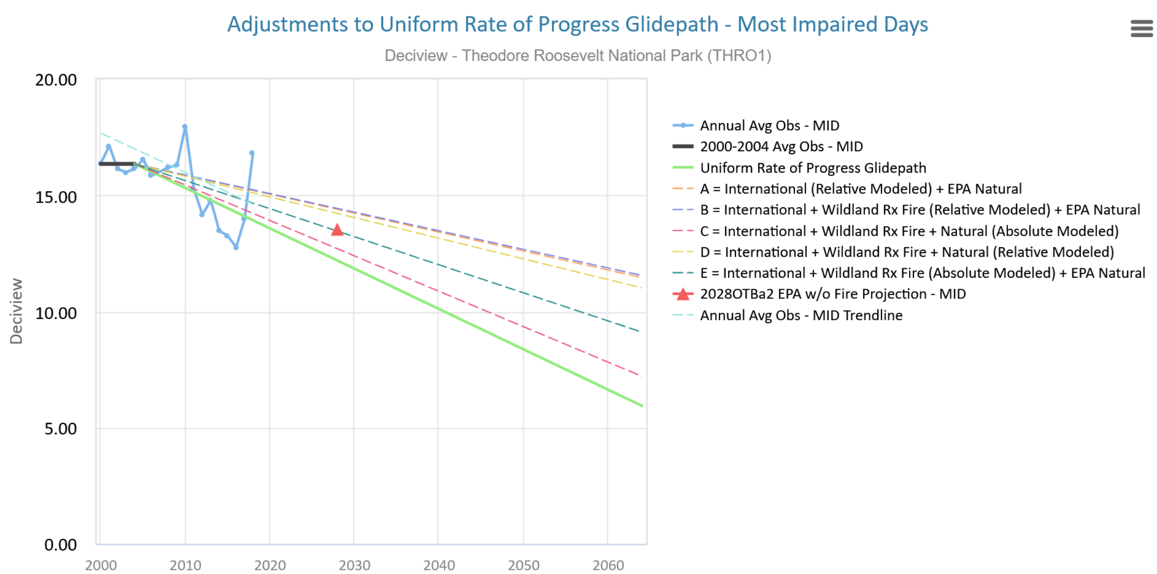

Figure 16. Example adjusted Glidepath results for Theodore Roosevelt (THRO1) CIA (from development version of the WRAP TSS Model Express Tools Chart 5, accessed February 12, 2021).

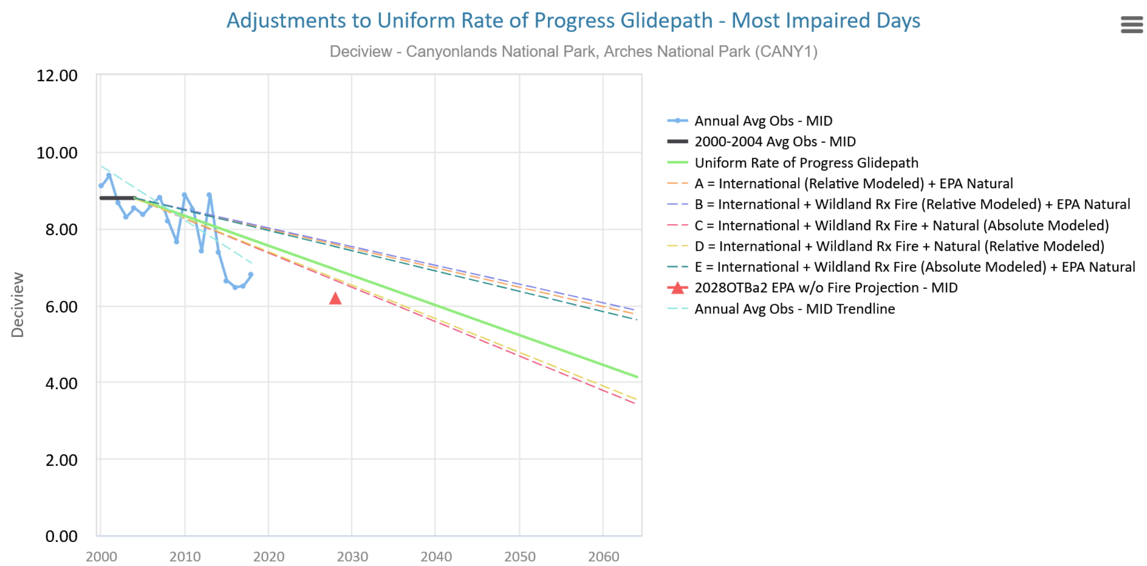

Figure 17. Example adjusted Glidepath results for Canyonlands (CANY1) CIA (from development version of the WRAP TSS Model Express Tools Chart 5, accessed February 12, 2021).