WRAP Technical Support System for Regional Haze Planning:

Modeling Methods, Results, and References

September 30, 2021 - Final

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1.0 Purpose:

The Western Regional Air Partnership and Western Air Quality Study (WRAP-WAQS) 2014 Regional Haze modeling platform is the latest of a series of regional modeling efforts supporting western U.S. air quality planning and management. The WRAP technical analyses follow the Environmental Protection Agency's (EPA) Modeling Guidance for Demonstrating Air Quality Goals for Ozone, PM2.5, and Regional Haze (November 2018) and the Technical Support Document for EPA's updated 2028 regional haze modeling (September 2019). The analyses fulfill the objectives of the WRAP 2018-2019 Workplan as updated and approved by the WRAP Board on April 3, 2019 and have been collectively designed, implemented, and reviewed by the WRAP Technical Steering Committee and its workgroups and subcommittees.

The Western Regional Air Partnership (WRAP) Technical Support System (TSS) hosts the visibility monitoring, emissions, and air quality modeling analyses that support the 15 western states in developing regional haze state implementation plans (SIPs). This reference document describes the WRAP emissions and modeling analyses and illustrates how the TSS products can be applied and interpreted to support the 2028 visibility progress demonstrations for western U.S. Class I areas.

2.0 Background:

The Regional Haze Rule requires states to demonstrate progress every ten years toward the Clean Air Act goal of no manmade visibility impairment. EPA guidance for tracking visibility progress (December 2018) defines a visibility impairment tracking metric (measured in deciview) using observations from the Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring network sites that represent Class I areas. EPA defined in the Regional Haze Rule and guidance a Uniform Rate of Progress glidepath for the 20% most impaired days as the straight line from the 2000-2004 IMPROVE 5-year average baseline to EPA estimates of future natural visibility conditions, plotted at 2064. In the first regional haze planning period, 2000-2018, EPA guidance interpreted most impaired days as those days with highest total haze. States were required to demonstrate visibility progress by 2018 compared to the Uniform Rate of Progress glidepath for the haziest days and no degradation of visibility on the clearest days from the 2000-2004 IMPROVE 5-year average baseline. Visibility on the clearest days improved between 2000 and 2018 across the Class I areas in the western U.S. However, smoke from wildfire and wildland prescribed fire events and dust events on the haziest days made tracking the visibility benefits due to reducing U.S. anthropogenic emissions more difficult.

For the second regional haze implementation period, 2018-2028, states are required to demonstrate visibility progress by 2028 for the most impaired days and no visibility degradation for the clearest days. EPA guidance (December 2018) defined most impaired days as those days with the highest fractional contribution to aerosol light extinction from anthropogenic sources. EPA statistical methods use IMPROVE measurements of carbon and crustal materials to separate contributions from episodic extreme natural events (e.g., wildfire or dust) from routine natural and anthropogenic contributions. Ammonium sulfate and ammonium nitrate are assigned primarily to anthropogenic emissions with smaller contributions from routine natural sources. This statistical approach does not separate contributions due to U.S. anthropogenic emissions from those of international anthropogenic emissions. Since states do not have authority to reduce international emissions, WRAP conducted source apportionment modeling analyses to evaluate U.S. anthropogenic contributions to haze and progress in reducing U.S. anthropogenic contributions to haze over time.

Table 1 summarizes the emissions and modeling scenarios, source apportionment runs, and alternative visibility progress analyses that were performed to support state regional haze planning.

Table 1. WESTAR-WRAP Emissions and Modeling Scenarios – update of January 18, 2021
Intermountain West Data Warehouse (IWDW) and Technical Support System (TSS) displays

Scenario Name	**Model Performance Evaluation** (2014v2 actual emissions / BCs and meteorology)	**Planning – Baseline** (mix of emissions inputs 2014-18 with 2014 meteorology)	**Planning – 2028 Projections** (2014 meteorology)	**Alternative Methods: 2028 Projections, Glidepath Endpoints, and Rate of Progress**	**Alternate Outcome Scenarios** (2014meteorology)
IWDW	Display emissions, model results, and site-level MPE results)	Display emissions and model results	Display emissions and model results		
TSS	Display emissions and model results	Display emissions and model results	Calculate and Display 2028 RPGs Display emissions and model results	Display alternative 2028 projections, glidepath endpoints, rate of progress	Calculate and Display 2028 RPGs. Display emissions and model results
Purpose	**Compare 2014v2 to RepBase2**	**Compare to RepBase2 to 2014v2, 2028OTBa2, 2028PAC2**	**Compare 2028OTBa2 to Repbase2, 2028PAC2, 2028FFS1, 2028FFS2**	**Focus on contributions of US anthropogenic emissions**	**Evaluate state source contributions and future fire scenarios**
CAMx Modeling Scenarios	**2014v2**	**RepBase2** Current Baseline (w/ RepFire). High-level CAMx PSAT source apportionment*	**2028OTBa2** (w/ RepFire) ** High-level PSAT source apportionment	**3 projection methods:** EPA default MID EPA MID w/o fires Modeled MID	**2028OTBa2 w/ SOxNOx PSAT** low-level (state by source sector contributions)
			2028PAC2 PotentialAddtlControls	Alternative 2064 glidepath endpoints	**2028FF1** Future Fire Sensitivity 1: Wildfire ****
			2028Adopted AddtlControls ***	U.S. Anthropogenic Modeled Rate of Visibility Progress ******	**2028FF2** Future Fire Sensitivity 2: WildlandRxFire *****

* 2014 International Anthro contribution adjustment option available from this modeling scenario (by difference)
** RepBase fires applied to 2028OTBa2
*** controls adopted by states in SIPs, this scenario is likely not possible until 2021 (*unfunded at present, not in Workplan*)
**** fire not paired in space or time with 2014 or RepFire activity, these sensitivity scenarios could give potential future wildfire contribution relative to 2028OTBa2
***** fire *is* paired in space *and* time with RepFire activity; this sensitivity scenario gives potential future Wildland Prescribed fire contribution relative to 2028OTBa2
******Dynamic Evaluation compare US anthropogenic contributions for 2002 Hindcast, RepBase2, and 2028OTBa2 to demonstrate alternative rate of visibility improvement

3.0 Emissions Scenarios:

The WRAP 2014v2 inventory was based on the 2014v2 National Emissions Inventory (NEI) plus updates provided by western states through WRAP Regional Haze workgroup's Emissions and Modeling Protocol subcommittee.

Table 2 defines the emissions data sources used for the WRAP 2014v2, Representative Baseline (RepBase2), and 2028 On the Books (2028OTBa2) emissions scenarios. Sector-specific data sources and assumptions are discussed in the companion TSS Emissions References document (September 2021). Future fire emissions sensitivities and 2002 hindcast emissions are also detailed in the TSS Emissions References document.

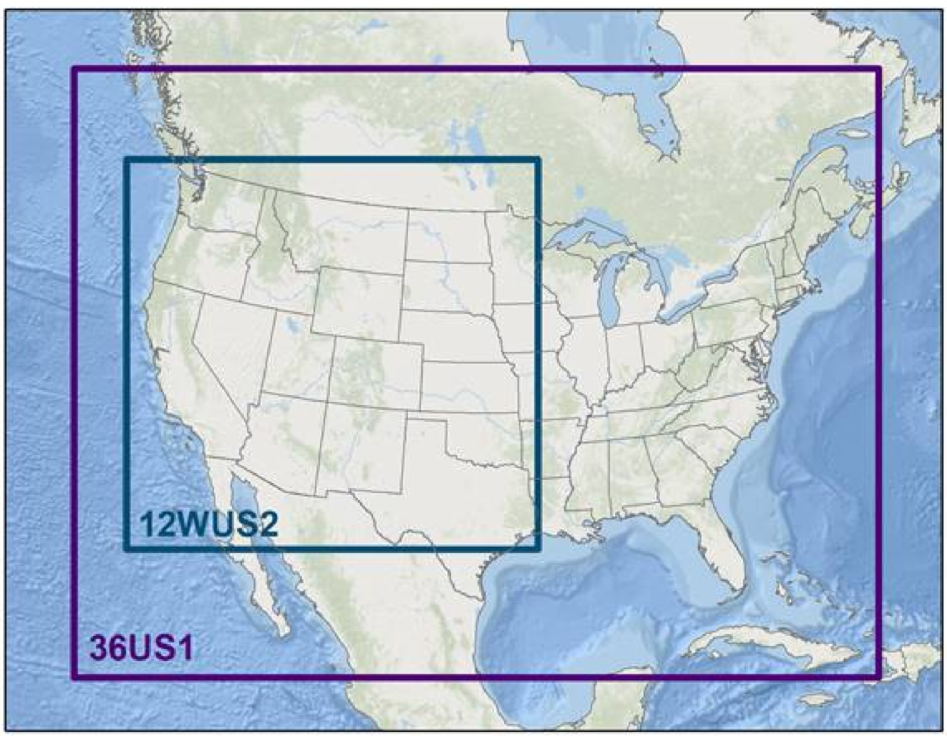
Table 2. Data sources for WRAP emissions sectors for the 12-km 12WUS2 and 36-km US domains for the 2014v2, Representative Baseline (RepBase2) and 2028 On the Books (2028OTBa2) scenarios.

Source Sector	**2014v2**	**RepBase2**	**2028OTBa2**
California All Sectors 12WUS2	CARB-2014v2	CARB-2014v2	CARB-2028
WRAP Fossil EGU w/ CEM	WRAP-2014v2	WRAP-RB-EGU [1]	WRAP-2028-EGU [1]
WRAP Fossil EGU w/o CEM	EPA-2014v2	WRAP-RB-EGU [1]	WRAP-2028-EGU [1]
WRAP Non-Fossil EGU	EPA-2014v2	EPA-2016v1	EPA-2028v1
Non-WRAP EGU	EPA-2014v2	EPA-2016v1	EPA-2028v1
O&G WRAP O&G States	WRAP-2014v2	WRAP-RB-O&G [2]	WRAP-2028-O&G [2]
O&G WRAP Other States	EPA-2014v2	EPA-2016v1	EPA-2016v1 [3]
O&G non-WRAP States	EPA-2014v2	EPA-2016v1	EPA-2016v1 [3]
WRAP Non-EGU Point	WRAP-2014v2	WRAP-2014v2 [4]	WRAP-2014v2 [4]
Non-WRAP non-EGU Point	EPA-2014v2	EPA-2016v1	EPA-2016v1
On-Road Mobile 12WUS2	WRAP-2014v2	WRAP-2014v2	WRAP-2028-Mobile [5]
On-Road Mobile 36US	EPA-2014v2	EPA-2016v1	EPA-2028v1
Non-Road 12WUS2	EPA-2014v2	EPA-2016v1	WRAP-2028-Mobile [5]
Non-Road non-WRAP 36US	EPA-2014v2	EPA-2016v1 [6]	EPA-2028v1 [6]
Other (Non-Point) 12WUS2	EPA-2014v2	EPA-2014v2 [7]	EPA-2014v2 [7]
Other (Non-Point) 36US	EPA-2014v2	EPA-2016v1	EPA-2016v1
Can/Mex/Offshore 12WUS2	EPA-2014v2	EPA-2016v1	EPA-2016v1
Fires (WF, Rx, Ag)	WRAP-2014-Fires	WRAP-RB-Fires [8]	WRAP-RB-Fires [8]
Natural (Bio, etc.)	WRAP-2014v2	WRAP-2014v2	WRAP-2014v2
Boundary Conditions (BCs)	WRAP-2014-GEOS	WRAP-2014-GEOS	WRAP-2014-GEOS

4.0 Model Development:

The WRAP-WAQS 2014 modeling platform was developed and performed by Ramboll, Inc., under contract to WESTAR-WRAP. The 2014 modeling platform used the Weather Research and Forecasting (WRF) meteorological model, the Sparse Matrix Operator Kernel Emissions (SMOKE) model and the Comprehensive Air Quality Model with Extensions (CAMx) to project air quality for the 2014 base year. The Goddard Earth Observing System global chemical model (GEOS-Chem) provided global boundary conditions for the regional CAMx model for the 2014 base year. The CAMx 2014v2 final model configuration is defined in Table 1 of the WRAP-WAQS 2014 modeling platform webpage. CAMx version 7beta 6 was used for the 2014v2 model performance run, while CAMx version 7.0 was used for the subsequent model scenarios. **Figure 1** below illustrates the CAMx 36-km modeling domain covering the Continental United States and the 12-km modeling domain covering the western states.

Figure 1. 36-km continental U.S. (36US1) and 12-km western U.S. (12US2) modeling domains used in the WRAP-WAQS 2014 modeling platform.



In addition to the 2014v2 model year, model runs were made using 2014 meteorology and with Representative Baseline (2014-2018, RepBase2), 2028 On the Books (2028OTBa2), 2028 Potential Additional Controls (2028PAC2), 2002 Hindcast, and Future Fire Sensitivities emission scenarios. Details are provided in model run specification sheets:

- Representative Baseline (RepBase2) and 2028 On the Books (2028OTBa2) CAMx simulations
- Dynamic Evaluation – 2002 Simulations
- Future Fire Sensitivity Simulations

5.0 WRAP-WAQS 2014v2 model performance

The WRAP-WAQS 2014v2 modeling platform webpage includes statistical model performance measures compared to EPA goals and criteria, spatial data plots and timeseries plots for the aerosol species listed below. For aerosol species concentrations, CAMx 2014v2 model outputs are compared to 2014 observations from the IMPROVE, Chemical Speciation Network (CSN) and Clean Air Status and Trends (CASTNET) monitoring network.

- Ozone model performance is reported on the Intermountain West Data Warehouse.

CAMx 2014v2 performance was evaluated using the EPA Atmospheric Model Evaluation tool (AMET) to compare model outputs to 2014 ambient air quality measurements (in μg/m3) for:

- Particulate matter less than 2.5 micrometers (PM2.5)
- Nitrate (NO3)
- Sulfate (SO4)
- Organic mass from carbon (OMC)
- Elemental carbon (EC)
- Fine soil (Soil)
- Coarse mass (particulate matter between 2.5 and 10 micrometers).
- Seasalt: performance is tracked separately for Sodium and Chloride

For example, **Figures 2a to 2d** are spatial plots of the Normalized Mean bias statistic for the winter months January - March and Summer months July – September, for Nitrate and Sulfate, respectively. IMPROVE sites are illustrated as circles, CSN sites as triangles, and CASTNET sites as squares. In Winter, Nitrate is overpredicted in the Pacific Northwest and CA and underpredicted in the northern plains. Performance is generally mixed in the Rocky Mountains and Southwestern interior. In Summer, Nitrate is overpredicted in the Pacific Northwest and under predicted in CA. Sulfate is generally overpredicted in the Pacific Northwest in winter and underpredicted in the Southwest in summer.

Figure 2a. Normalized mean bias for 2014v2 modeled Nitrate compared to the IMPROVE, CSN, and CASTNET monitoring networks for Winter (Jan – Mar). ([2014v2 MPE summary]())

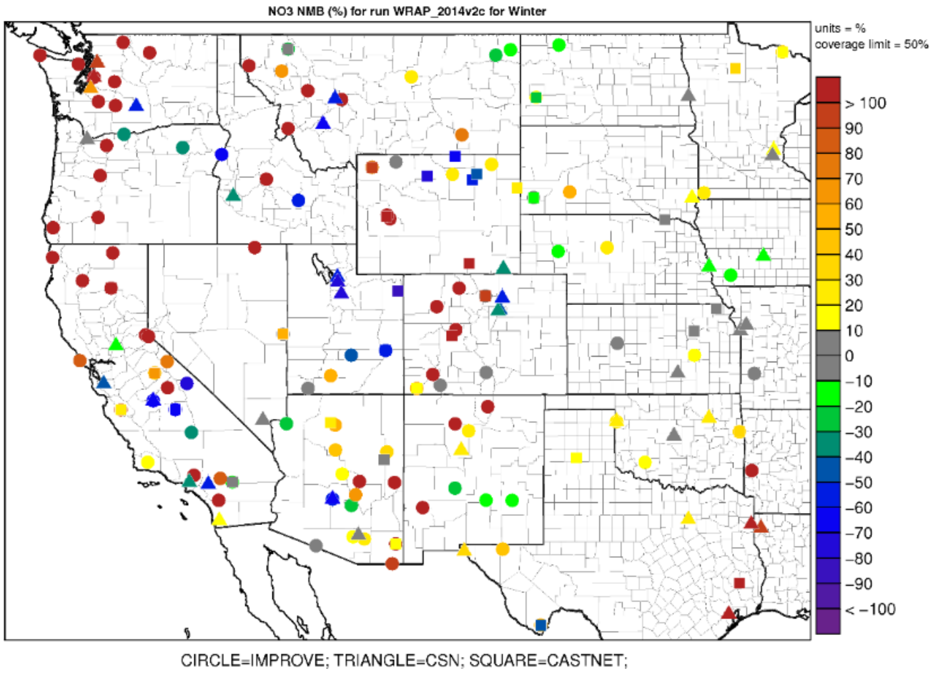


Figure 2b. Normalized mean bias for 2014v2 modeled Nitrate compared to the IMPROVE, CSN, and CASTNET monitoring networks for Summer (Jul – Sep). ([2014v2 MPE summary]())

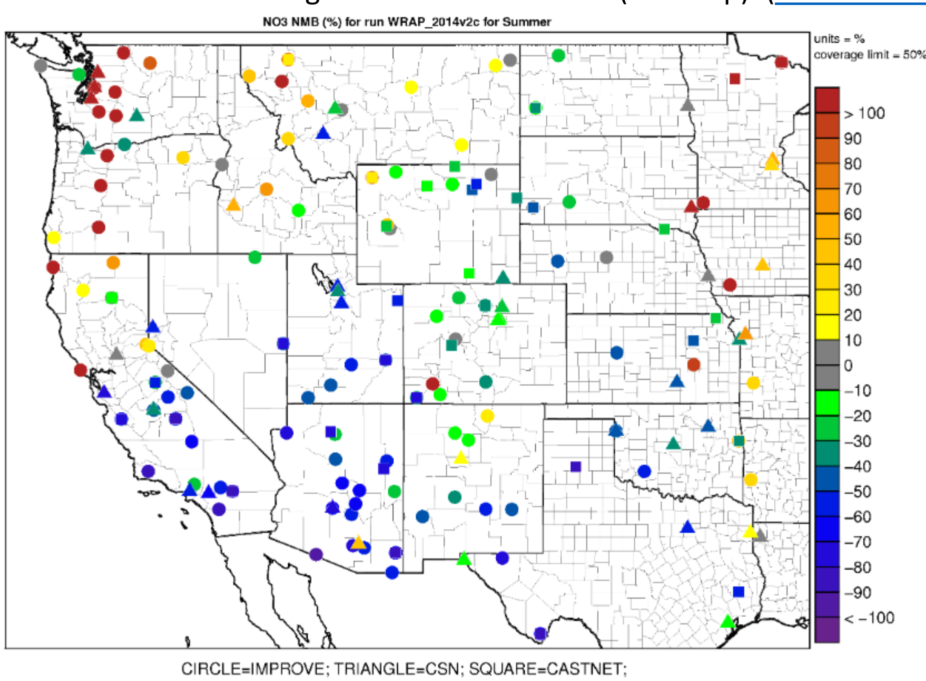


Figure 2c. Normalized mean bias for 2014v2 modeled Sulfate compared to the IMPROVE, CSN, and CASTNET monitoring networks for Winter (Jan – Mar). (2014v2 MPE summary)

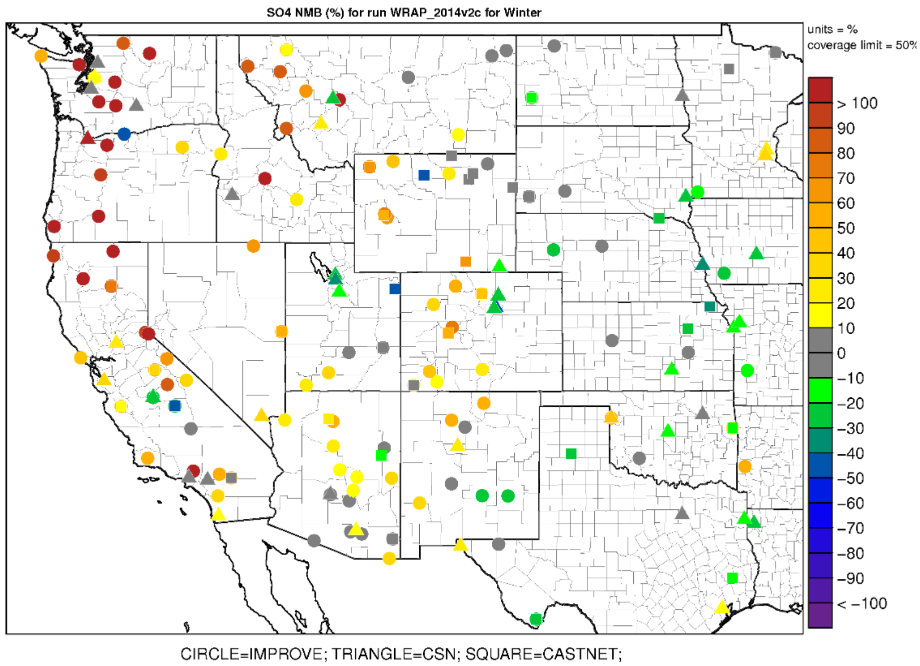
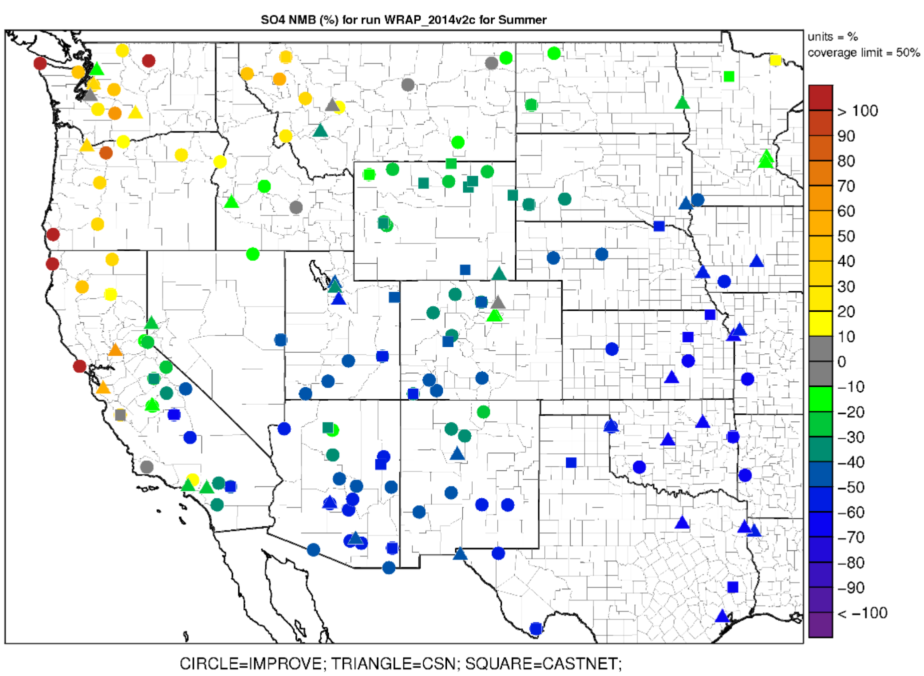


Figure 2d. Normalized mean bias for 2014v2 modeled Sulfate compared to the IMPROVE, CSN, and CASTNET monitoring networks for Summer (Jul – Sep). (2014v2 MPE summary)



CAMx 12-km gridded annual anthropogenic nitrogen oxide and anthropogenic sulfur dioxide emissions (tons per year) for 2028OTBa emissions (from the WRAP 2028 Weighted Emissions Potential analyses) are mapped in **Figures 3a and 3b**.

Figure 3a. 2028 On the Books CAMx gridded 12-km annual anthropogenic nitrogen oxide emissions (tons per year) (Weighted Emissions Potential)

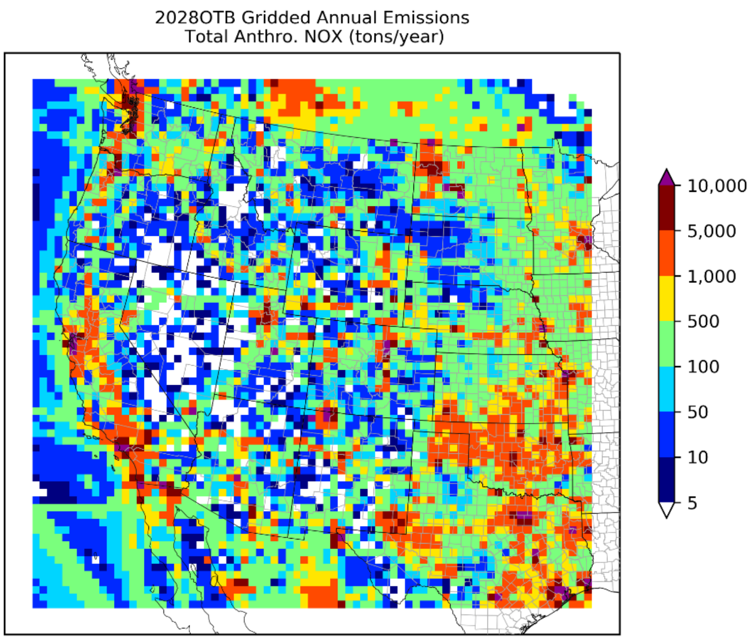
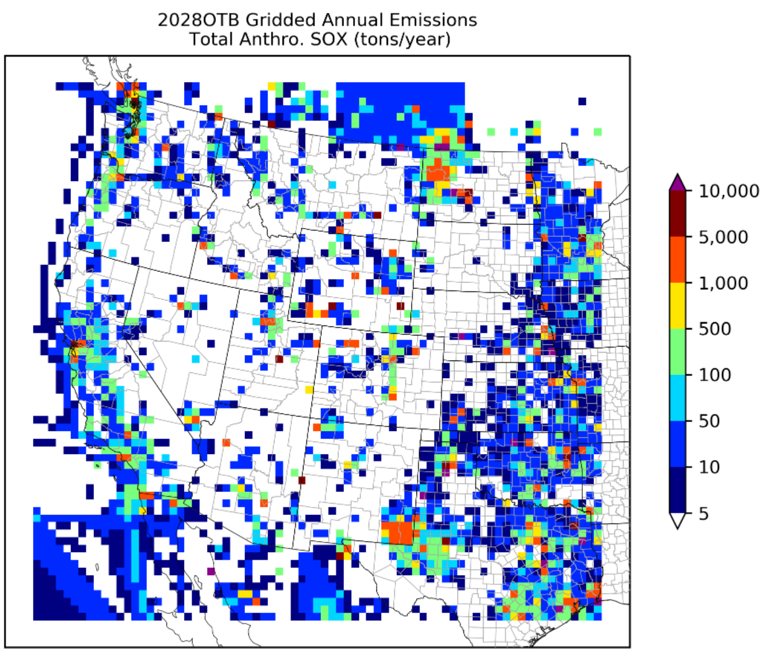


Figure 3b. 2028 On the Books CAMx gridded 12-km annual anthropogenic sulfur oxides emissions (tons per year) (Weighted Emissions Potential)



6.0 Model Comparisons to Observations

Yellowstone National Park, in a fire-dominated ecosystem in the northern Rocky Mountains, and Mesa Verde National Park, in a drier southwestern ecosystem, are used as example Class I areas to interpret WESTAR-WRAP 2014v2 model performance, source contributions to haze, and projected visibility progress by 2028.

Comparisons of 2014 IMPROVE observations to the 2014v2, RepBase2, and 2028OTBa2 model scenarios are illustrated in **Figures 7a through 7d** (TSS Modeling Express Chart #1) for IMPROVE monitors in Yellowstone (YELL2) and Mesa Verde (MEVE1) National Parks, respectively. The charts display speciated aerosol light extinction for the averages of the most impaired days or clearest days. These are absolute model results; the model outputs are not adjusted to IMPROVE data. Comparison of 2014 IMPROVE observations to 2014v2 model results illustrates the accuracy of the model performance on the selected days. Comparison of the 2014v2, RepBase2, and 2028OTBa2 model scenario results demonstrates the aerosol responses to changes in emissions across these scenarios. Natural, fire, and international emissions are held constant at RepBase2 levels in 2028OTBa2, so the only differences between the two scenarios are due to changes in U.S. anthropogenic emissions.

Interpretation: Comparing 2014 IMPROVE observations to 2014v2 model results on most impaired days (**Figures 7a and 7b**) at both YELL2 and MEVE1, ammonium sulfate, elemental carbon, and coarse mass are under predicted, while ammonium nitrate and organic carbon are over predicted. At both YELL2 and MEVE1 organic carbon is slightly higher in RepBase2 than 2014v2; this reflects changes for wildfire emissions in the RepBase2 scenario. At both YELL2 and MEVE1 ammonium nitrate shows small reductions between the RepBase2 and 2028OTBa2 scenarios, all other aerosol species show little change.

On the clearest days at both YELL2 and MEVE1 (**Figure 7c and 7d**) all aerosol species are overestimated, likely because aerosol concentrations are very low and small differences in light extinction are reflected as large percentage differences.

TSS Modeling Express charts for the clearest days are formatted the same as for the most impaired days and will not be displayed in this document forward.

Figure 4a. Model Scenarios Compared to 2014 IMPROVE Observations for Aerosol Light Extinction (Mm^{-1}) on the most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor. TSS Modeling Express Chart #1

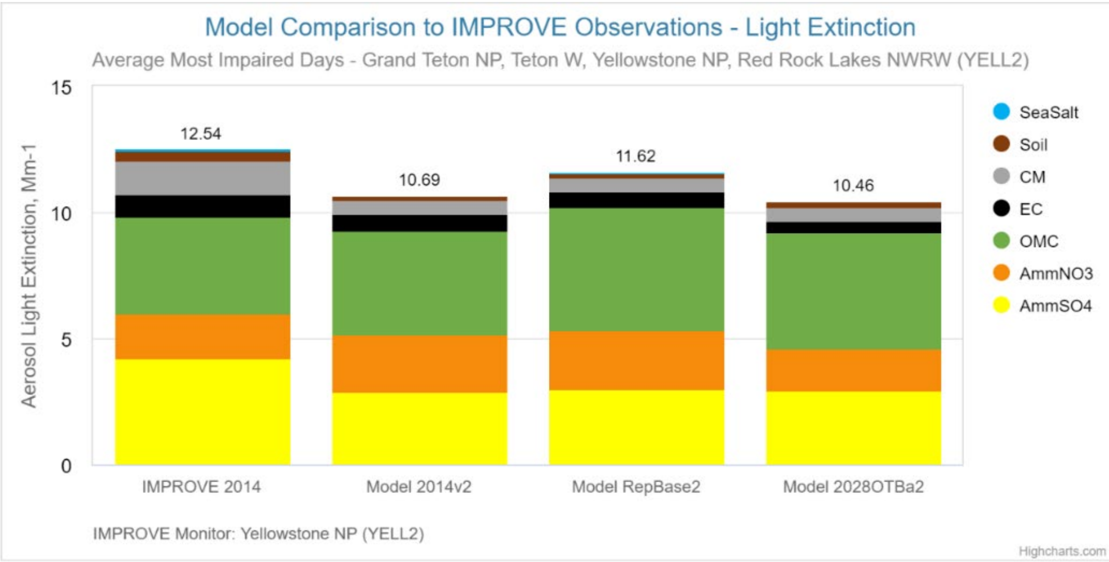


Figure 4b. Model Scenarios Compared to 2014 IMPROVE Observations for Aerosol Light Extinction (Mm^{-1}) on the most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor. TSS Modeling Express Chart #1

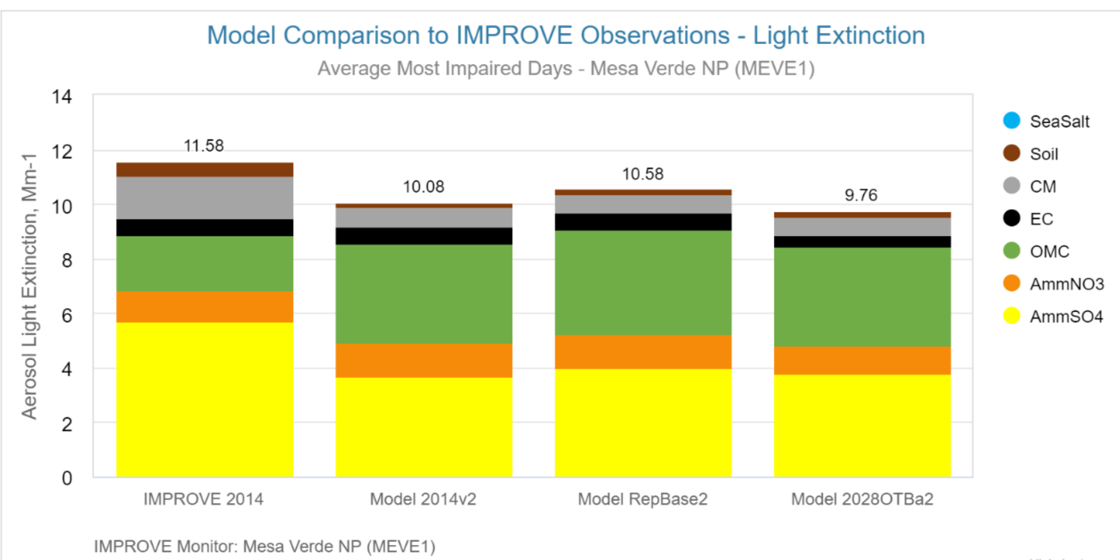


Figure 4c. Model Scenarios Compared to 2014 IMPROVE Observations for Aerosol Light Extinction (Mm^{-1}) on the clearest days at the Yellowstone National Park (YELL2) IMPROVE monitor. TSS Modeling Express Chart #1

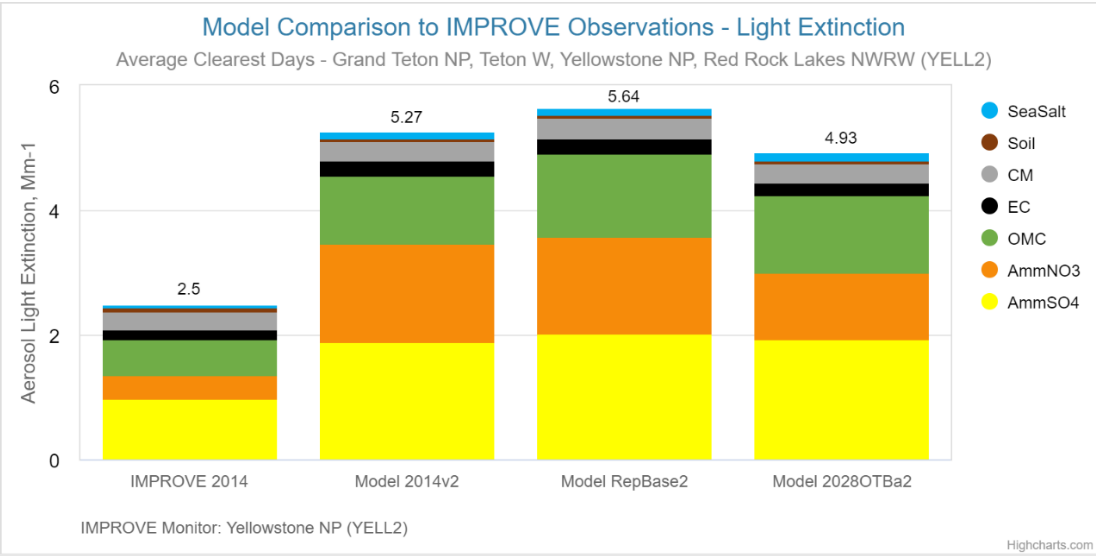
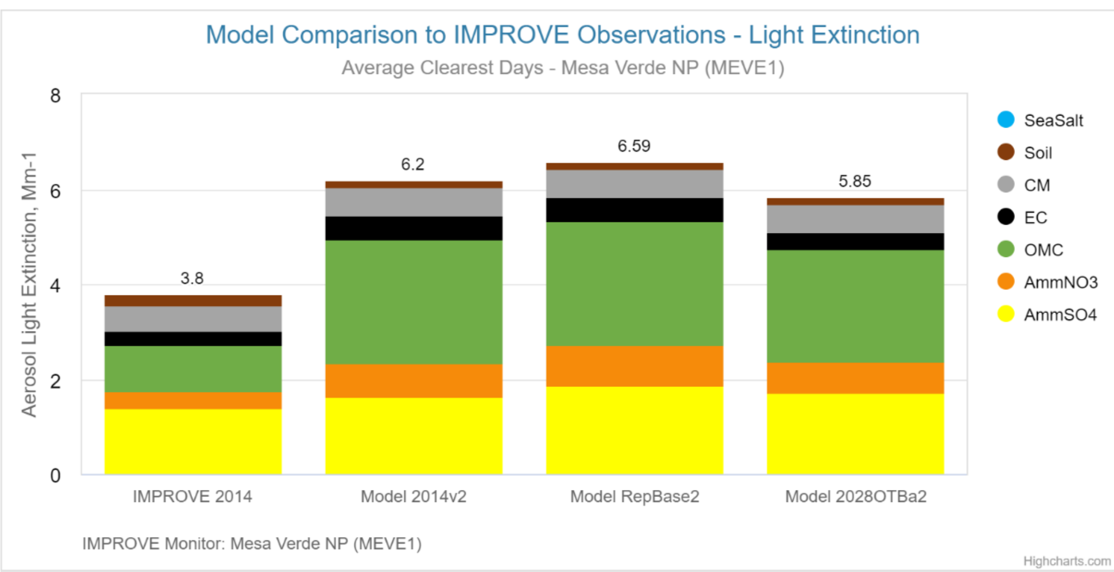


Figure 4d. Model Scenarios Compared to 2014 IMPROVE Observations for Aerosol Light Extinction (Mm^{-1}) on the clearest days at the Mesa Verde National Park (MEVE1) IMPROVE monitor. TSS Modeling Express Chart #1



Figures 5a and 5b display TSS Modeling Express Chart #2 for daily 2014 IMPROVE most impaired days at Yellowstone (YELL2) and Mesa Verde (MEVE1) National Parks, respectively, compared to the 2014v2, RepBase2, and 2028OTBa2 model scenarios.

Interpretation: Overall, comparing 2014 IMPROVE data to the 2014v2 modeled aerosol light extinction, CAMx showed credible skill for most impaired days at YELL2 and MEVE1. Maximum IMPROVE daily aerosol extinction on most impaired days is 24 Mm^{-1} at YELL2 and 20 Mm^{-1} at MEVE1. Daily ammonium nitrate (AmmNO3) is well represented on most impaired days at these two sites. On a few most impaired days at both YELL2 and MEVE1, 2014v2 modeled ammonium sulfate (AmmSO4) is more than 50% lower than IMPROVE observations. Under estimates of coarse mass are likely due to poor model skill in representing windblown dust. At both sites, organic carbon (OMC) is a large fraction of total aerosol extinction on several 2014 IMPROVE most impaired days. OMC is somewhat over predicted on several days. Differences in OMC on the most impaired days between the 2014v2 and RepBase2 scenarios are likely due to differences in wildfire activity assumptions for RepBase2 (covering the period the 2014 to 2018) compared to the single year 2014v2. Differences in total aerosol extinction between RepBase2 and 2028OTBa2 are small on all most impaired days, indicating little visibility progress.

Figure 5a. Model Scenarios Compared to 2014 IMPROVE Observations for Aerosol Light Extinction (Mm^{-1}) on most impaired days at the Yellowstone National Park (YELL1) IMPROVE monitor. TSS Modeling Express Chart #2

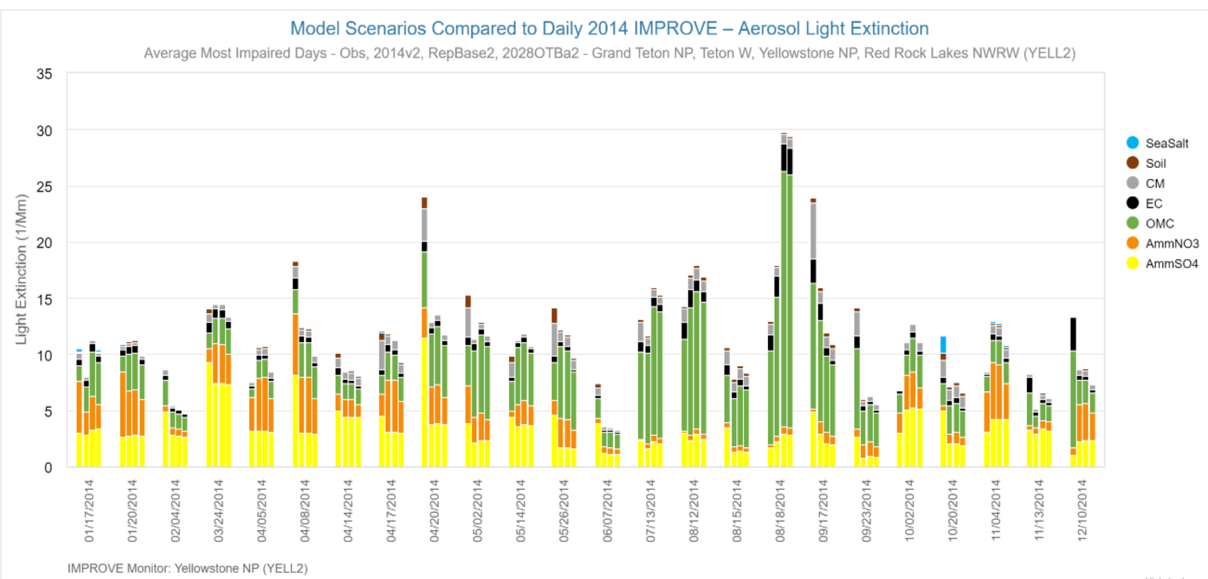
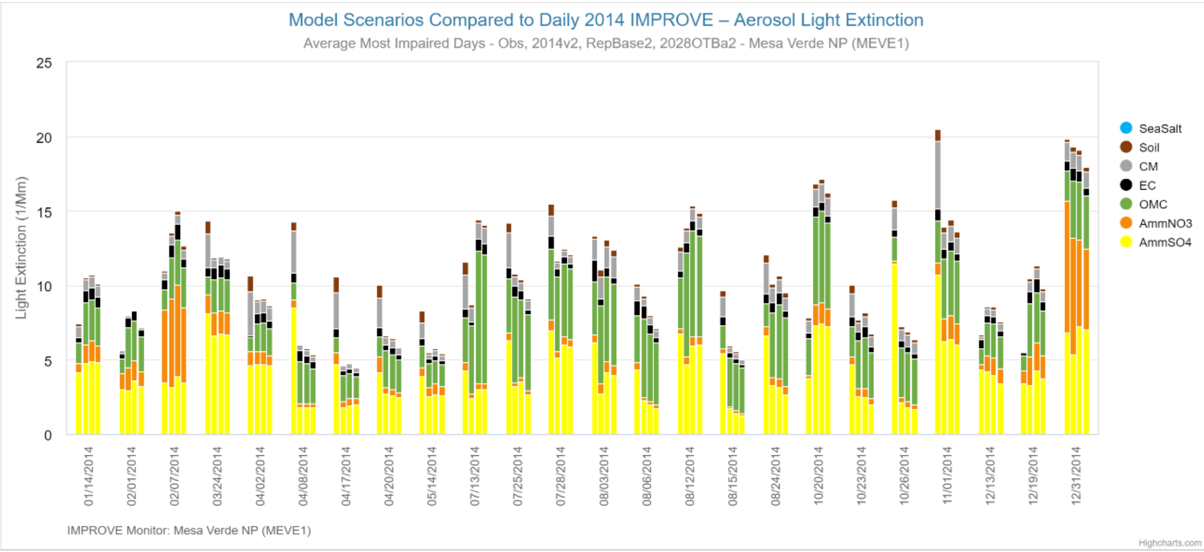


Figure 5b. Model Scenarios Compared to 2014 IMPROVE Observations for Aerosol Light Extinction (Mm^{-1}) on most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor. TSS Modeling Express Chart #2



7.0 2028 Visibility Projections

2028 visibility projections for the most impaired or clearest days are calculated following EPA guidance for ozone, PM2.5 and regional haze modeling (November 2018) using the EPA default projection method and using two WRAP alternative projection methods that are intended to reduce aerosol contributions from sources other than U.S. anthropogenic emissions on the most impaired days.

The EPA recommended projection procedures are used for all three WRAP projection methods (see WRAP Procedures for Making Visibility Projections and Adjusting Glidepaths, March 2021 final draft.) EPA's Software for the Model Attainment Test (SMAT) was used to perform the projection calculations. CAMx model results are used in a relative sense, meaning that the aerosol concentrations are scaled to the IMPROVE monitoring data for the 2014-2018 period. The fractional differences between the 2028OTBa2 and the RepBase2 modeled aerosol concentrations are used to define scaling factors, also called relative response factors (RRFs), that are calculated for each aerosol species on each 2014 IMPROVE most impaired day (or clearest day) and then averaged for all most impaired days (or clearest days). These average relative response factors are multiplied by the daily aerosol concentration on each most impaired day or clearest day for the IMPROVE 2014-2018 5-year period to define daily projected aerosol concentrations, as indicated by the equations below.

$$\text{Relative Response Factor, } RRF_{SO4} = \sum 2028OTBa2_{SO4} / \sum RepBase2_{SO4}$$

$$Projected\_SO4_{2028OTBa2} = IMPROVE\_SO4_{2014\text{-}2018} \times RRF_{SO4}$$

The daily projected 2028 aerosol concentrations for each of the 2014-2018 IMPROVE most impaired days (or clearest days) are converted to light extinction and then converted to deciview. The daily deciview values are averaged for each year and the annual averages are averaged for the 5-year period to define the 2028 visibility projections. The three WRAP projection methods:

- The **EPA default projection method** follows EPA guidance without deviation.
- The **EPA without fire projection method** uses the same 2014 IMPROVE most impaired days as the EPA default projection method. RepBase2 and 2028OTBa2 modeled source apportionment results are used to identify and remove modeled aerosol contributions from U.S. wildfire, U.S. wildland prescribed fire, and Non-U.S. (Canada and Mexico) fire on these days. After modeled fire contributions have been removed from the daily aerosol values, the EPA default projection procedures are used to calculate the relative response factors and 2028 visibility projections.
- The **Modeled MID projection method** selects the modeled RepBase2 days with the highest fraction of modeled U.S. anthropogenic contributions as the modeled most impaired days for both the RepBase2 and 2028OTBa2 scenarios. RepBase2 and 2028OTBa2 modeled source apportionment results are used to remove the fire contributions from the modeled most impaired days before calculating relative response factors and 2028 visibility projections.

In TSS Modeling Express Chart #3 users can choose to illustrate, for one, two, or three projection methods, for either the most impaired days or clearest days, the visibility projections for 2028 On the Books (2028OTBa2) or 2028 Potential Additional Controls (2028PAC2) in aerosol light extinction. These aerosol contributions are the basis for the 2028 visibility projections in deciview that define the regional haze tracking metric and are displayed in TSS TSS Modeling Express Chart #4 (see Section 8.0). Changes in aerosol species extinction across the 2028 projection scenarios and methods illustrate which aerosol species are responsible for the projected changes in the regional haze visibility tracking metric in deciviews.

Figures 6a and 6b illustrate the IMPROVE 2014-2018 aerosol contributions and the 2028OTBa2 visibility projections in aerosol light extinction using the 3 WRAP projection methods for Yellowstone and Mesa Verde National Parks, respectively.

Interpretation: For YELL2, AmmNO3, OMC, and EC are projected to decrease between the 2014-2018 IMPROVE observations and modeled 2028OTBa2 following the EPA default projection methods. The EPA without fire method has slight decreases in OMC and EC compared to the EPA default method, while the Modeled MID method, which selects different days as most impaired, has slight decreases in OMC, EC, and AmmSO4 (0.3 Mm^{-1}). At MEVE1, AmmNO3 and AmmSO4 are reduced slightly between 2014-2018 IMPROVE observations and

2028OTBa2 projections using EPA default methods. The EPA without fire and Modeled MID methods display slight changes to OMC and EC compared to the EPA default method. As will be illustrated under Section 10.0 Regional Source Apportionment, biogenic and anthropogenic sources of carbon are significant and unchanged fractions of OMC and EC at these two sites. Thus, for these two sites, removing fire contributions from most impaired days only changes a fraction of the total carbon and the EPA without fire projection method has only small changes in the 2028 visibility projection.

Nonetheless, WRAP recommended that EPA without fire projection method be the default 2028 visibility projection displayed because this method removes the contributions of fire on the most impaired days and most closely focuses on anthropogenic contributions to haze.

Figure 6a. 2028 Visibility Projections on most impaired days in Aerosol Light Extinction (Mm^{-1}) compared to 2014-2018 IMPROVE observations for Yellowstone National Park (YELL2). TSS Modeling Express Chart #3

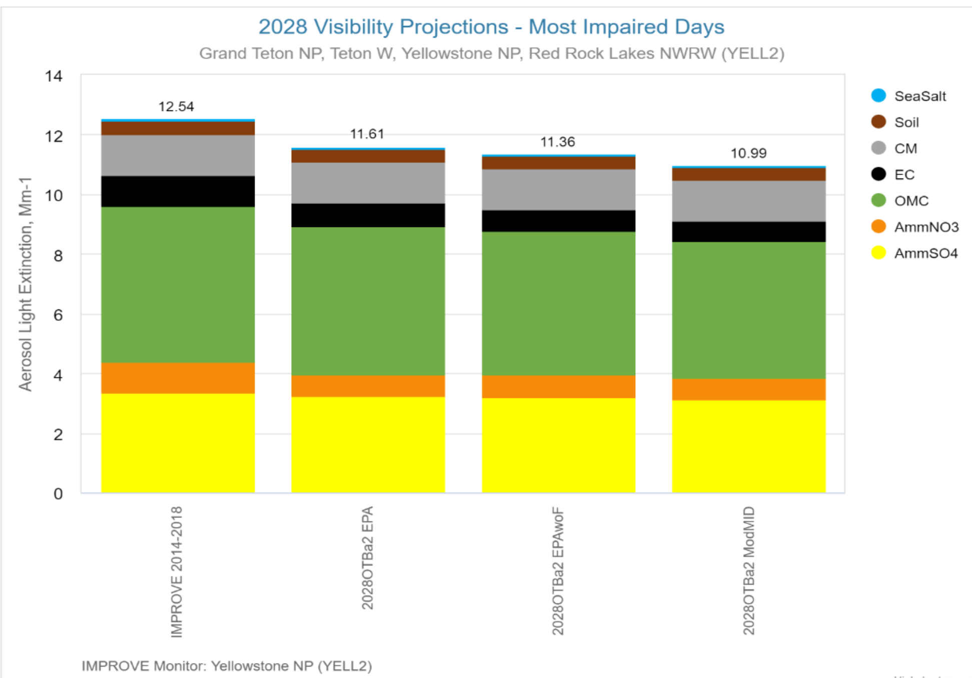
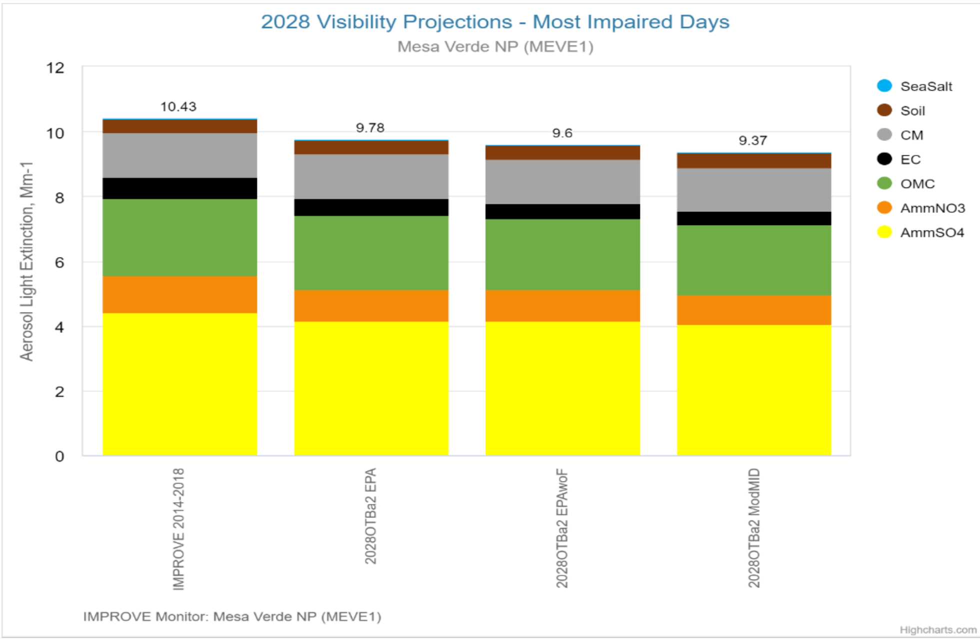


Figure 6b. 2028 Visibility Projections on most impaired days in Aerosol Light Extinction (Mm^{-1}) compared to 2014-2018 IMPROVE observations for Mesa Verde National Park (YELL2). TSS Modeling Express Chart #3



8.0 Visibility Projections compared to the Uniform Rate of Progress Glidepath

TSS Modeling Express Chart #4 displays 2028 visibility projections in deciview compared IMPROVE measurements for the period 2000-2018 and to the Uniform Rate of Progress (URP) glidepath as defined by EPA guidance (Dec 2018). The 2028 visibility projections in deciview are calculated from aerosol concentrations and extinction as described in Section 7. Users can also select to display chart data by aerosol light extinction for individual species or Total Light Extinction.

The URP glidepath is constructed (in deciviews) for the 20% most impaired days (MID) or clearest days using observations from the IMPROVE monitoring site representing a Class I area. The URP glidepath starts with the IMPROVE most impaired days for the 2000-2004 5-year baseline and draws a straight line to estimated natural conditions displayed for the year 2064. For clearest days, the goal is no degradation of visibility from the 2000-2004 5-year baseline, therefore the glidepath for clearest days is a straight line from the 2000-2004 baseline to 2064. In the second regional haze planning period, 2064 natural visibility condition estimates use the 15-year average of natural conditions on IMPROVE most impaired days in each year 2000-2014. IMPROVE annual average values are presented in this chart as points. IMPROVE 5-year average values are presented as solid lines covering the periods 2000-2004 and 2014-2018.

The 2028OTBa2 and 2028PAC2 visibility projections were processed using EPA's Software for the Model Attainment Test (SMAT) for the three WRAP projection methods described in Section 7 (see also WRAP Procedures for Making Visibility Projections and Adjusting Glidepaths, March 2021 final draft):

- EPA default projection method
- EPA without fire projection method
- Modeled MID projection method

2028 On the Books (2028OTBa2) and 2028 Potential Additional Controls (2028PAC2) visibility projections in deciview are illustrated as points that can be compared to the Uniform Rate of Progress glidepath. A state can select among the 2028 projection methods to define a 2028 Reasonable Progress Goal (RPG) for a Class I area for Regional Haze planning purposes.

The 2028 visibility projection is compared to the URP Glidepath at 2028 to determine whether visibility at the Class I areas is projected to be on, above, or below the URP Glidepath. Comparison of 2028 projections to the URP Glidepath defines how well the modeled trend in visibility tracks the straight-line uniform rate of progress to 2064. EPA guidance (August 2019) clarifies that the URP Glidepath is not a bright line test for reasonable visibility progress by 2028 and describes additional considerations for defining reasonable progress. Uncertainties in the glidepath assumptions are discussed in the U.S. Anthropogenic Emissions Rate of Progress (September 2021) document.

Figures 7a and 7b display TSS Modeling Express Chart #4 results for the 2028OTBa2 scenario for Yellowstone and Mesa Verde National Parks, respectively. Users could choose to also display results for the 2028PAC2 control scenario. Regional source apportionment data discussed in Section 10 will assist interpretation of 2028 visibility projections displayed in Chart #4.

Interpretation: For YELL2 (**Figure 7a**), the IMPROVE annual average deciview for the most impaired days varies widely between 2000 to 2018 and the 2000-2018 monitoring trend line (blue line) is above the URP Glidepath (red line). The IMPROVE 2014-2018 5-year average deciview for the most impaired days intersects the URP glidepath. The 2028OTBa2 visibility projections for all 3 WRAP methods are above the URP glidepath, although the EPA without fire and Modeled MID projection methods yield slightly lower 2028 projections than the EPA default projection. The IMPROVE annual average deciview for the clearest days show steady improvement between 2000 and 2018 and the 2028OTBa2 projection indicates further improvement on the clearest days.

At MEVE1 (**Figure 7b**) the IMPROVE annual average deciview for the most impaired days shows a consistent reduction between 2000 and 2018. The IMPROVE 2000-2018 monitoring trendline and the IMPROVE 2014-2018 5-year average deciview for the most impaired days are well below the URP glidepath. All 3 projection methods for 2028OTBa2 are also well below the URP glidepath. The clearest days at MEVE1 also show continuous improvement and the 2028OTBa2 projections are below the 2014-2018 5-year average deciview.

Figure 7a. 2028 Visibility Projections for clearest days and most impaired days, compared to the Uniform Rate of Progress Glidepath at the Yellowstone National Park (YELL2) IMPROVE monitor. TSS Modeling Express Chart #4

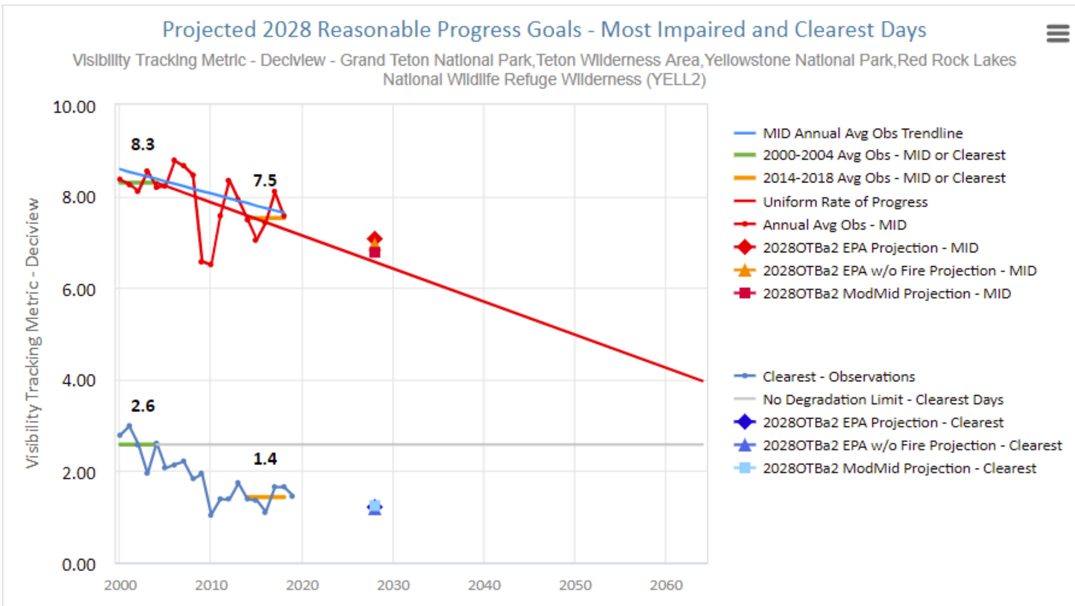
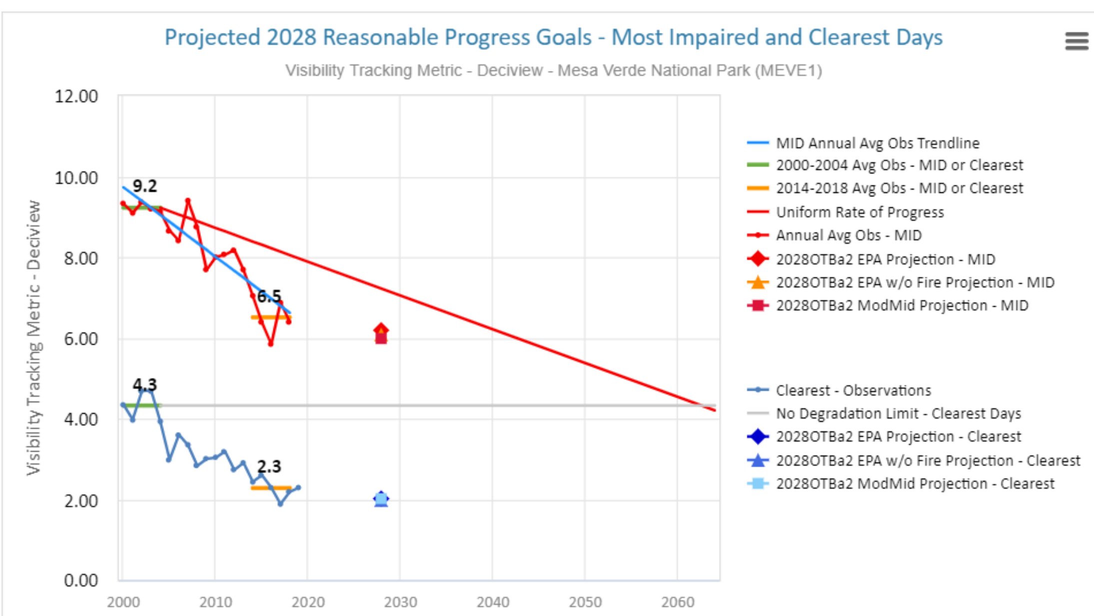


Figure 7b. 2028 Visibility Projections for clearest days and most impaired days, compared to the Uniform Rate of Progress Glidepath at the Mesa Verde National Park (MEVE1) IMPROVE monitor. TSS Modeling Express Chart #4



In general, western Class I areas near urban areas or major point sources demonstrate visibility improvement in the IMPROVE monitoring data between 2000 to 2018 and the 2028 visibility projections are below the URP glidepath. Ammonium nitrate and ammonium sulfate are major contributors on most impaired days at many of these sites, including Mesa Verde NP (see **Figure 6b**). Class I areas near oil and gas development do not display as much visibility improvement by 2028OTBa2 as more remote sites. Class I areas where carbon is a significant fraction of aerosol contributions on most impaired days, including Yellowstone NP (see **Figure 6a**) show more variable visibility progress in the IMPROVE monitoring data 2000-2018 and in the 2028 visibility projections.

Clearest days at all western Class I areas have improved between 2000 and 2018 and are projected to continue to improve by 2028 at almost all western Class I areas.

EPA Volcanic adjustment (August 2021) for IMPROVE monitors at Hawai'i Volcano (HAVO1) and Haleakalā (HALE1) National Parks:

EPA defined an adjustment to ammonium sulfate to account for episodic volcanic events at Hawai'i Volcano (HAVO1) and Haleakalā (HALE1) National Parks. EPA's adjustment follows the same methodology as defined in December 2018 guidance to account for episodic extreme fire or dust events using IMPROVE measurements of carbon or crustal materials. EPA's adjustment for volcanic contributions uses IMPROVE daily ammonium sulfate measurements for the years 2000-2014, defines the average 95th percentile value for each year, and selects the lowest annual value as the threshold to assign ammonium sulfate daily measurements above that threshold as episodic volcanic (natural) contributions. After accounting for episodic volcanic contributions to ammonium sulfate, impairment is calculated following EPA guidance. By assigning maximum ammonium sulfate values as natural rather than anthropogenic, the days that are defined as most impaired by anthropogenic contributions shift. Ammonium sulfate still dominates the most impaired days, suggesting that not all volcanic contributions are accounted for using a 95th percentile threshold.

In addition to the volcanic adjustment, to assure a complete IMPROVE data set for Haleakalā National Park, EPA also applied data substitution methods to merge data from two separate IMPROVE monitor locations that have represented the Haleakalā NP Class I area over the 2000-2018 period (HALE1 and Haleakala Crater, HACR1). The combined data set is referred to as HALE_RHTS.

EPA also provided 2028 visibility projections for the volcano adjusted data sets, HAVO1_VADJ and HALE_RHTS_VADJ, as described in EPA's Technical Support Document for Updated 2028 Regional Haze Modeling for Hawaii, Virgin Islands, and Alaska (August 2021). EPA 2028 visibility projections for HAVO1_VADJ and HALE_RHTS_VADJ are displayed in aerosol extinction in TSS Modeling Express Chart #20 (equivalent to TSS Modeling Chart #3). TSS Modeling Express Chart #21 (equivalent to TSS Modeling Chart #3) displays 2028 visibility projections in deciview for HAVO1_VADJ and HALE_RHTS_VADJ, the 2000-2018 volcano-adjusted monitoring data, estimated natural conditions in 2064, and the Uniform Rate of Progress for the volcano adjusted data for the most impaired days or clearest days at these two Class I areas.

TSS Modeling Express Tool #8 displays a table for each state listing all federal Class I areas in that state comparing the 2014-2018 5-year average IMPROVE observations to the 2028OTBa2 and 2028PAC2 visibility projections in deciview, calculated using the 3 WRAP projection methods. **Table 11** illustrates the 2028 visibility projection results for the state of Colorado. Note that Colorado did not define Potential Additional Controls for sources in Colorado for 2028PAC2, nonetheless, small changes in visibility were projected for 2028PAC2 due to PAC2 control assumptions in other WRAP states.

Table 11. 2028 Visibility Projections for the most impaired days at Class I areas in Colorado for the 2028 On the Books (2028OTBa2) and 2028 Potential Additional Controls (2028PAC2) model scenarios and 3 WRPA projection methods. TSS Modeling Express Tool #8

CO - 2028 Visibility Projections Summary

Most Impaired Days *(defined by EPA guidance [1])*

Class I Area IMPROVE Monitor	IMPROVE 2014-2018	2028 OTBa2 Model: EPA M.I.D.	2028 OTBa2 Model: EPA MID w/o Fire	2028 OTBa2: Modeled MID	2028 PAC2 Model: EPA M.I.D.	2028 PAC2 Model: EPA MID w/o Fire	2028 PAC2: Modeled MID
GRSA1	8.02 dv	7.55 dv	7.5 dv	7.33 dv	7.53 dv	7.49 dv	7.31 dv
MEVE1	6.51 dv	6.19 dv	6.1 dv	5.97 dv	6.18 dv	6.08 dv	5.94 dv
MOZI1	5.47 dv	4.96 dv	4.93 dv	4.94 dv	4.95 dv	4.92 dv	4.92 dv
ROMO1	8.41 dv	7.6 dv	7.56 dv	7.46 dv	7.59 dv	7.55 dv	7.44 dv
WEMI1	6.55 dv	6.12 dv	6.03 dv	5.89 dv	6.1 dv	6.02 dv	5.86 dv
WHRI1	4.98 dv	4.53 dv	4.49 dv	4.39 dv	4.52 dv	4.48 dv	4.37 dv

1) U.S. EPA. December 2018. Technical Guidance on Tracking Visibility Progress for the Second Implementation Period of the Regional Haze Program. EPA-454/R-18-010

9.0 Adjustments to the Uniform Rate of Progress Glidepath

EPA guidance (December 2018) allows a State to propose an adjustment to the URP glidepath to account for visibility contributions from anthropogenic emissions outside the U.S. or from emissions from wildland prescribed fires that meet specific land management objectives and apply basic smoke management practices. The EPA Administrator may approve proposed adjustments to the URP glidepath that follow "scientifically valid data and methods." EPA's regional haze modeling Technical Support Document (September 2019) demonstrates adjustments to the 2064 endpoint of the URP glidepath using source apportionment results for international anthropogenic or wildland prescribed fire emissions from the EPA 2028 model scenario.

WRAP methods to adjust the 2064 endpoints for the URP glidepath to account for international emissions or wildland prescribed fire emissions are described in detail in WRAP Procedures for Making Visibility Projections and Adjusting Glidepaths (March 2021). The WRAP adjustments to the URP glidepath are based on 2028OTBa2 source apportionment results for international anthropogenic and wildland prescribed fire. Consistent with the methods evaluated in the EPA Technical Support Document, WRAP evaluated five approaches using 2028OTBa2 source apportionment results to adjust the 2064 endpoints. 2028 source apportionment results were applied in a relative sense (model results normalized to 2028 visibility projections) or an absolute sense (unadjusted absolute model results). 2064 endpoints were defined using IMPROVE natural conditions estimated for 2000-2014 or using 2028 source apportionment results for natural source contributions.

After review of the initial glidepath adjustment results, WRAP recommended that adjustment of the URP glidepath for Class I areas in western states use 2028 source apportionment results in a relative sense and use EPA estimated natural conditions for the 2064 endpoint for one of two options:

- International anthropogenic contribution normalized to IMPROVE monitoring data and added to EPA estimated natural conditions (International).
- International anthropogenic plus Wildland Prescribed fire combined contributions normalized to IMPROVE monitoring data and added to EPA estimated natural conditions (International + wildland Rx fire)

Note that wildland prescribed fire events in the 2028 OTBa2model scenario reflect the same events as modeled for 2014v2. Wildland prescribed fire events may not occur on most impaired days in 2014v2. Location, timing, frequency, magnitude, and duration of wildland prescribed fire events vary geographically, seasonally, and year to year. Therefore, interpretation of wildland prescribed fire contributions on most impaired days for the 2028OTBa2 source apportionment results and for the 2064 adjustment to the URP glidepath is uncertain.

TSS Modeling Express Chart #5 illustrates the Regional Haze Uniform Rate of Progress (URP) Glidepath as defined by EPA guidance and the two WRAP alternative glidepath end point adjustments for 2064 (International, International + Wildland Prescribed Fire.)

The URP glidepath (in deciviews) for most impaired days and the optional glidepath adjustments all start from the 2000-2004 5-year baseline for most impaired days and draw a straight line to estimated natural conditions in 2064. All 2064 endpoints use EPA estimates of natural conditions based on 2000-2014 IMPROVE data. Annual average deciview for 2000 to

2018 most impaired days are illustrated as points. IMPROVE 2000-2004 and 2014-2018 5-year average deciview values are illustrated as solid lines. Users can choose to display 2028OTBa2 and/or 2028PAC2 visibility projections for 1-3 projection methods and to display 2064 endpoint without adjustment or adjustment for either international anthropogenic emissions or international anthropogenic plus wildland prescribed fire emissions. The 2028OTBa2 EPA without fire projection method is the default setting for purposes of comparing 2028 visibility projections to the adjustment glidepath.

Figures 8a and 8b illustrate examples of TSS Modeling Express Chart #5 for Yellowstone (YELL2) and Mesa Verde (MEVE1) National Parks.

Interpretation: At YELL2, the 2028OTBa2 EPA without fire projection is above the URP glidepath. Adding International anthropogenic contributions to the 2064 endpoint raises the adjusted glidepath in 2028 to be above the 2028OTBa2 EPA without fire projection value. The second adjustment to the 2064 endpoint (adding wildland prescribed fire contribution to the international anthropogenic contribution) slightly raises the slope of the glidepath compared to international emissions alone.

At MEVE1, the 2028 visibility projection is below the URP glidepath. Adjustment of the 2064 endpoint for the international anthropogenic contribution raises the slope of the glidepath; adjustment for wildland prescribed fire has a negligible change to the adjusted glidepath.

At most Class I areas in the western U.S., application of the recommended methods to adjust the 2064 endpoint raises the slope of the URP glidepath. Western states will independently determine whether or not to use the URP glidepath adjustments in their regional haze planning.

Figure 8a. 2028 Visibility Projections compared to adjustments to the Uniform Rate of Progress Glidepath for most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor. TSS Modeling Express Chart #5.

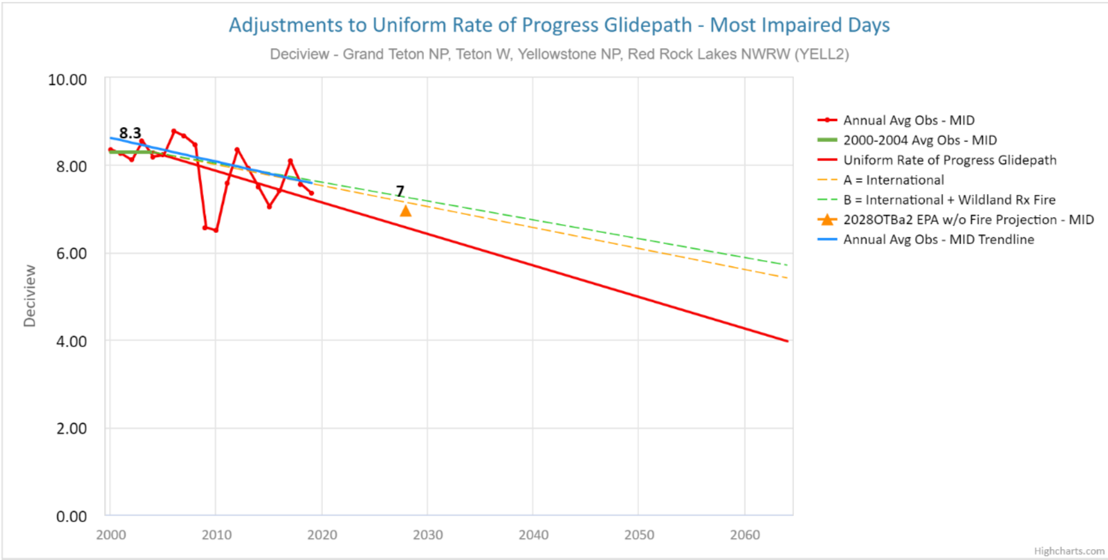
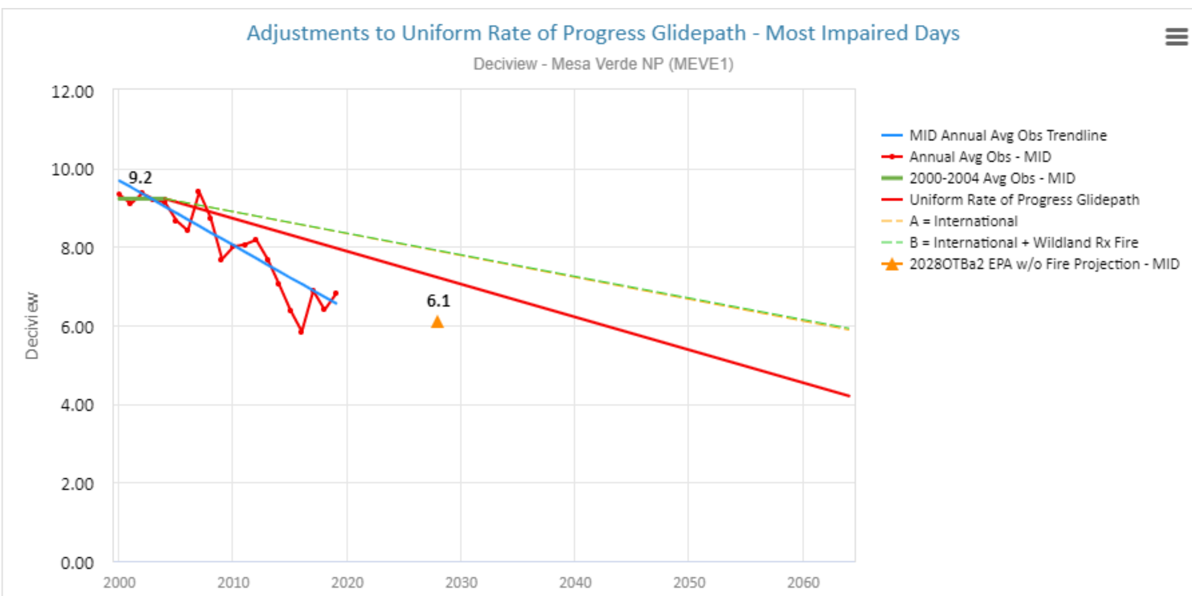


Figure 8b. 2028 Visibility Projections compared to adjustments to the Uniform Rate of Progress Glidepath for most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor. [TSS Modeling Express Chart](#) #5



10.0 Regional (High-level) Source Apportionment

WRAP Source Apportionment methods are described in the run specification sheet for High-Level and Low-Level Source Apportionment Modeling using the RepBase2 and 2028OTBa2 model scenarios (September 2020).

Purpose: Regional source apportionment results for U.S. anthropogenic, international anthropogenic, fire, and natural source contributions at each IMPROVE site representing western Class I areas were used as follows:

- Modeled most impaired days (ModMID) were defined based on RepBase2 source apportionment results. ModMID days were ranked by modeled U.S. anthropogenic contributions as a fraction of total aerosol light extinction. ModMID days are used as one of the WRAP alternative 2028 projection methods (see Section 7).
- 2028OTBa2 modeled international and U.S. wildland prescribed fire contributions were used as an option to adjust the 2064 endpoint of the URP glidepath for the most impaired days (see Section 9).
- Along with 2002 Hindcast scenario, RepBase2 and 2028OTBa2 regional source apportionment results for total aerosol light extinction were used to define a U.S. Anthropogenic Emissions Rate of Progress (see Section 12).

The CAMx photochemical model version 7.0 with the Particle Source Apportionment tool (PSAT) was applied at a regional level to separate U.S. anthropogenic contributions from those of fire, natural, and international anthropogenic contributions for the representative baseline period (2014-2018, RepBase2) and a future year, 2028OTBa2. CAMx with PSAT tracked gaseous and particle air emissions from sources through atmospheric dispersion, photochemical reactions, and transport to receptors (the 12-km modeling grid cell where the IMPROVE monitor is located), as defined in **Table 12**. Aerosol concentrations at the receptor include the direct products of primary gaseous and particle emissions and secondary aerosol formation.

Source contributions were defined for the following aerosols:

- Ammonium nitrate (AmmNO3)
- Ammonium sulfate (AmmSO4)
- Organic mass from carbon (OMC)
    - Primary Organic Aerosol (POA)
    - Secondary Organic Aerosols
        - Anthropogenic (SOAA)
        - Biogenic (SOAB)
- Primary Elemental Carbon (EC)
- Primary Fine Soil
- Primary Coarse Mass
- Seasalt

Table 12. PSAT emissions tracers mapped to IMPROVE aerosol species at the model receptor

PSAT Tracer Description	IMPROVE Species Name (TSS label)	Mapping between IMPROVE and PSAT species (concentration in µg/m3)	Notes
Particulate Sulfate (PS4)	Ammonium Sulfate (AmmSO4)	AmmSO4 = 1.375 * PS4	Factor 1.375 converts sulfate ion to fully neutralized ammonium sulfate
Particulate Nitrate (PN3)	Ammonium Nitrate (AmmNO3)	AmmNO3 = 1.29 * PN3	Factor 1.29 converts nitrate ion to fully neutralized ammonium nitrate
Primary Elemental Carbon (PEC)	Elemental Carbon (EC)	EC = PEC	
Primary Organic Aerosol (POA)	Organic Mass from Carbon (OMC)	OMC = POA +SOAA + SOAB	Secondary Organic Aerosols (SOA) are not explicitly tracked by source group. SOA are derived from AVRG concentration files and are operationally assigned to anthropogenic (SOAA) or biogenic (SOAB) source groups. All SOAA is assigned to U.S. anthropogenic source category and all SOAB is assigned to Natural source category.
Aluminum (PAL)	Fine Soil (Soil)	Soil = 2.2*PAL + 2.49*PSI + 1.63*PCA + 2.42*PFE + 1.94*PTI	Soil mapping is consistent with IMPROVE definition
Silicon (PSI)			
Calcium (PCA)			
Iron (PFE)			
Titanium (PTI)			
Coarse Crustal PM (PCC)	Coarse Mass (CM)	CM = PCC + PCS	
Other Coarse Particulate (PCS)			
Chloride (PCL)	Sea Salt	Sea Salt = 1.8 * PCL	Chloride is not tracked by Source Apportionment. It is obtained from the AVRG concentration files. All Chloride is assigned to sea salt. All sea salt is assigned to the "natural" source group. All other source group contributions to sea salt are 0.

Due to computational constraints, the secondary organic aerosols (SOA) family of reactive tracers were not used to track SOA at the receptor; rather SOA were operationally assigned to anthropogenic (SOAA) or biogenic (SOAB) contributions based on the chemical signatures (e.g., isoprene was assigned as biogenic in origin; benzene was assigned as anthropogenic in origin.) For purposes of compositing regional source categories, all SOAA were assigned to the U.S. anthropogenic source category and all SOAB were assigned to the Natural source category.

Regional source apportionment results for RepBase2 and 2028OTBa2 aerosol light extinction are displayed in TSS Modeling Express Tools # 10-16 for 15 source groups that are composited into 6 source categories as listed below. Abbreviations correspond to the source labels used in TSS Modeling Express Tools #10-16.

- U.S. Anthropogenic (USAnthro)
    - U.S. anthropogenic (AntUS)
    - U.S. agricultural fire (AgfireUS)
    - Secondary Organic Aerosol-Anthropogenic (SOAA)
    - Commercial Marine Vessels (CMVUS)
    - U.S. anthropogenic contributions from outside the CAMx 36-km domain boundary as defined by the GEOS-Chem global model. (BC-US)
- U.S. Wildfire (WFUS)
- U.S. Wildland Prescribed fire (RxUS)
- Canadian and Mexican fires (OthFr)
- Natural
    - Natural (Nat)
    - Secondary Organic Aerosol -Biogenic (SOAB)
    - Natural contributions from outside the CAMx 36-km domain boundary as defined by the GEOS-Chem global model. (BC-Nat)
- International Anthropogenic (IntlAnthro)
    - International Anthropogenic contributions from outside the CAMx 36-km domain boundary as defined by the GEOS-Chem global model. (BC-Int)
    - Canadian Anthropogenic (AntCAN)
    - Mexican Anthropogenic (AntMEX)
    - Commercial Marine vessels – International (beyond 200km from U.S. coast) (CMV_nonUS)

Users can choose to display source apportionment results in TSS Modeling Express Tools # 10-16 for most impaired days (EPA default 2014 IMPROVE days), modeled most impaired days, or clearest days. Charts in this document provide examples for 2014 IMPROVE most impaired days only.

Users can choose to display source apportionment results for total aerosol extinction or for individual aerosols species extinction.

Modeled source contributions to light extinction in [TSS Modeling Express Tools](#)# 10-16 are not normalized to IMPROVE monitoring data. Model performance should be considered when interpreting source apportionment results. Average and daily model performance for most impaired days as displayed in [TSS Modeling Express Tool](#) # 1 and 2 provide insight to confidence to place in source apportionment results for individual aerosol species.

[TSS Modeling Express Tool](#) # 10 defines in a single stacked barchart the light extinction contributions from 15 source groups for the RepBase2 or 2028OTBa2 model scenarios. **Figures 9a and 9b** illustrate regional source apportionment for 2028OTBa2 for Yellowstone NP (YELL2) and Mesa Verde NP (MEVE1), respectively.

Interpretation: At YELL2, U.S. anthropogenic emissions in 2028OTBa2 are projected to contribute less than 20% of total aerosol light extinction (left chart) and less than 30% of extinction due to AmmNO3 extinction (right chart). At MEVE1, U.S. anthropogenic emissions in 2028OTBa2 are projected to contribute less than 30% of total extinction (left) and 54% of AmmNO3 extinction (right).

Figure 9a. 2028OTBa2 Regional Source Apportionment for most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor for 15 source group contributions to total aerosol light extinction (Mm^{-1}) (left) or to Ammonium nitrate light extinction (right). [TSS Modeling Express Tool](#) # 10.

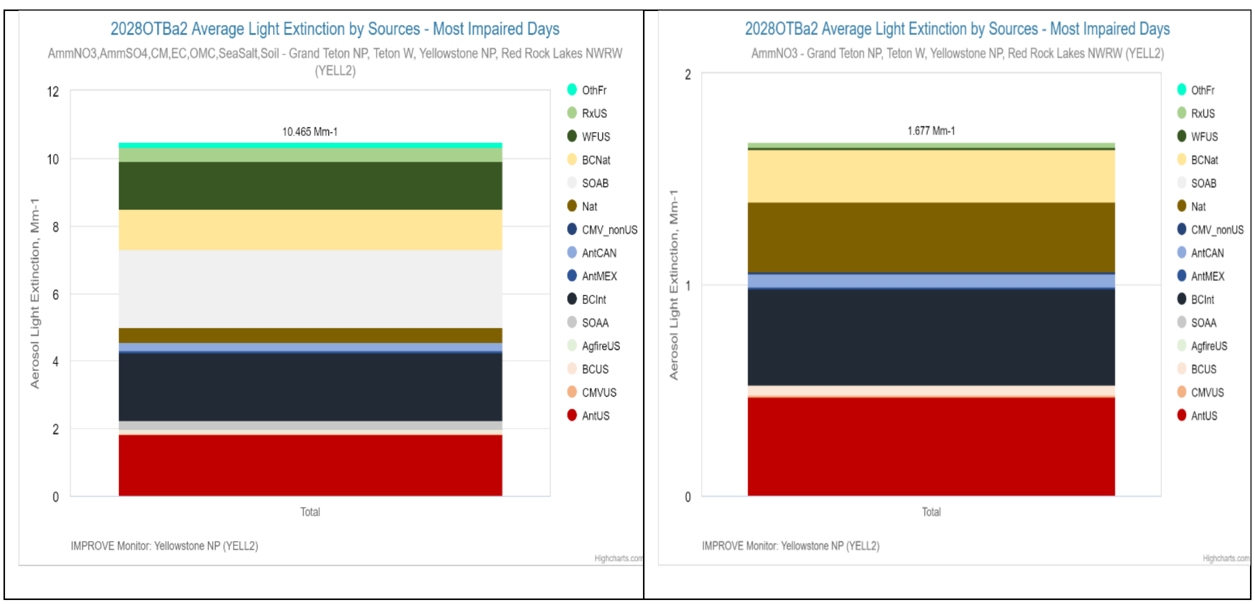
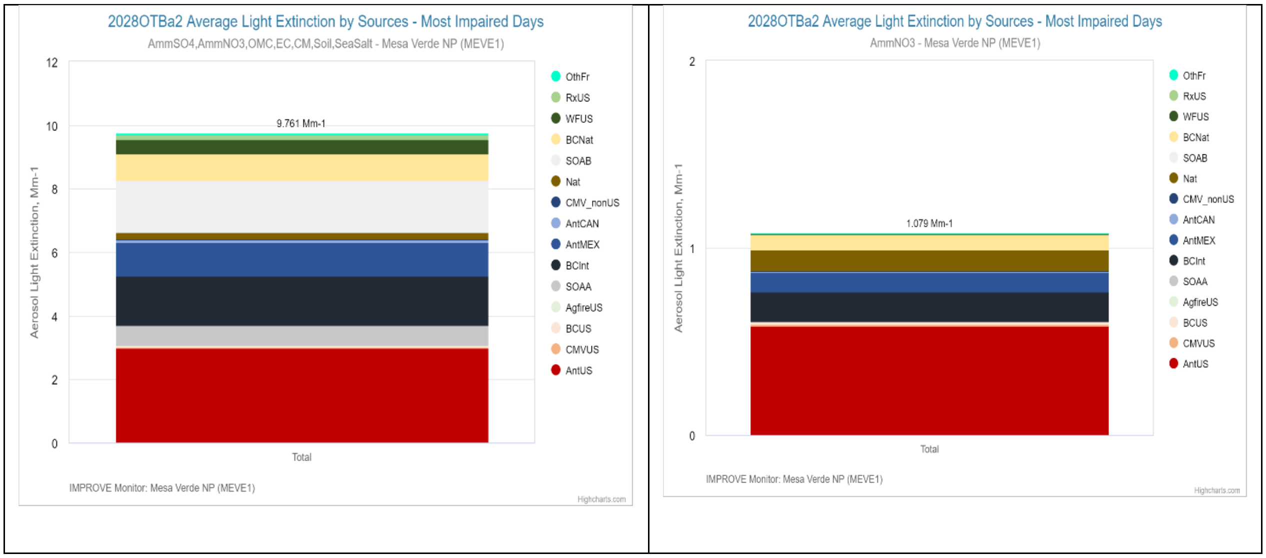


Figure 9b. 2028OTBa2 Regional Source Apportionment for most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor for 15 source group contributions to total aerosol light extinction (Mm^{-1}) (left) or to Ammonium nitrate light extinction (right). TSS Modeling Express Tool # 10.

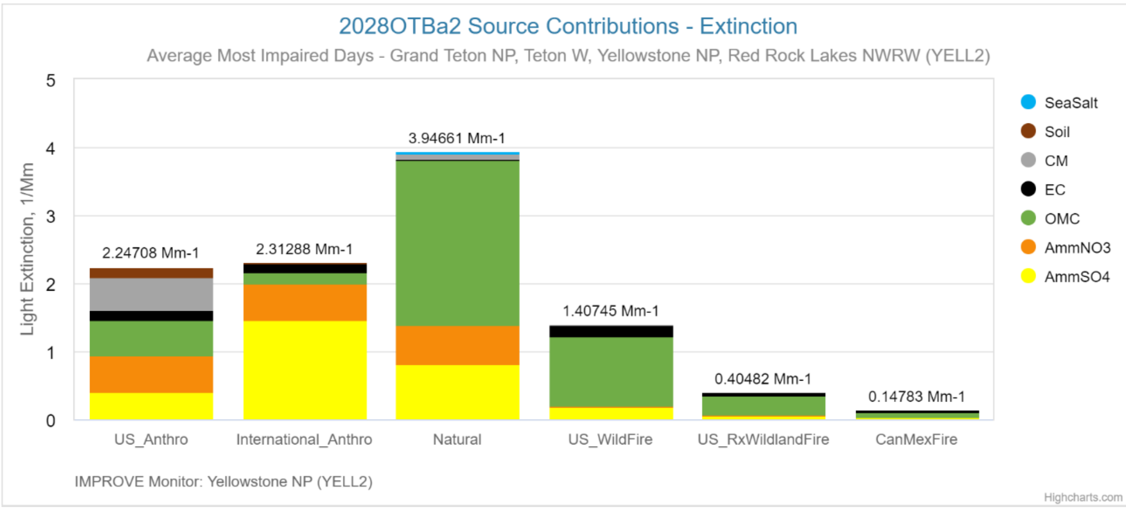


TSS Modeling Express Tool # 11, illustrated in **Figure 10a** for YELL2 and **Figure 10b** for MEVE1, displays speciated aerosol light extinction on most impaired days for RepBase2 or 2028OTBa2, by pollutant, for each of 6 source categories.

Interpretation: For YELL2, in 2028OTBa2, the natural source category is the largest source contribution, even on the most impaired days. Organic carbon dominates the natural and fire categories. International anthropogenic source contributions are equal to U.S. anthropogenic contributions and smaller than natural plus fire contributions. Ammonium sulfate and ammonium nitrate dominate the international anthropogenic category. For U.S. anthropogenic contributions, ammonium nitrate, ammonium sulfate, organic carbon, and coarse mass are projected to have similar contributions. U.S. wildland prescribed fire has very small contributions at YELL2.

The 2028OTBa2 visibility projections for YELL2 are projected to be above the URP glidepath (see **Figure 7a**, TSS Modeling Express Tool # 4) because U.S. anthropogenic sources are a smaller fraction of total aerosol extinction compared to natural, international, and fire contributions. Adding the 2028OTBa2 international contribution to the 2064 endpoint raises the URP glidepath above the 2028OTBa2 visibility projection for YELL2 (see **Figure 8a**, TSS Modeling Express Tool # 5). Adding 2028OTBa2 wildland prescribed fire to the 2064 endpoint has a very small impact on the slope of the URP glidepath because U.S. wildland prescribed fire has a small contribution to total aerosol extinction.

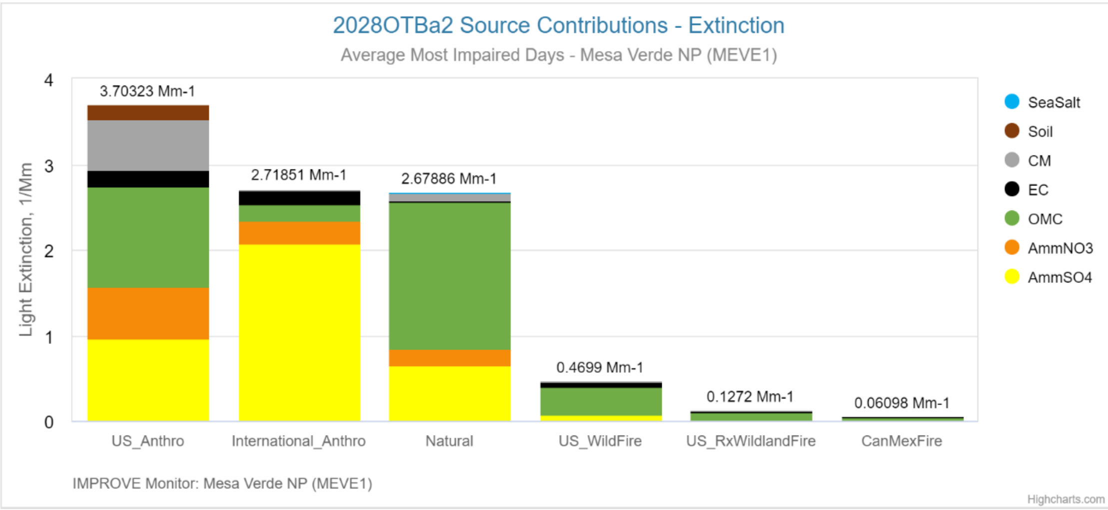
Figure 10a. 2028OTBa2 Regional Source Apportionment of Speciated Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor for U.S. Anthropogenic, International anthropogenic, Natural, and Fire source categories, with component species contributions. TSS Modeling Express Tool # 11.



Interpretation: For MEVE1, in 2028OTBa2, U.S. anthropogenic emissions have the largest contributions to total aerosol extinction, divided between ammonium sulfate, ammonium nitrate, organic carbon, and coarse mass (**Figure 10b**). International anthropogenic and natural sources have equivalent, somewhat smaller contributions than U.S. anthropogenic sources. International anthropogenic contributions are dominated by ammonium sulfate, while natural sources and fires are dominated by organic carbon. U.S. wildland prescribed fire has very small contributions at MEVE1.

The 2028OTBa2 visibility projections for MEVE1 are projected to be below the URP glidepath (see **Figure 10a**, TSS Modeling Express Tool # 4) because U.S. anthropogenic sources are a larger fraction of total aerosol extinction compared to natural, international, and fire contributions and changes in the U.S. anthropogenic emissions between RepBase2 and 2028OTBa2 are reflected in changes to 2028OTBa2 visibility projections. Adding the 2028OTBa2 international contribution to the 2064 endpoint raises the URP glidepath for MEVE1 (see **Figure 11a**, TSS Modeling Express Tool # 5). Adding 2028OTBa2 wildland prescribed fire to the 2064 endpoint has a very small impact on the slope of the URP glidepath because U.S. wildland prescribed fire has a small contribution to total aerosol extinction.

Figure 10b. 2028OTBa2 Regional Source Apportionment of Speciated Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor for U.S. Anthropogenic, International anthropogenic, Natural, and Fire source categories, with component species contributions. TSS Modeling Express Tool # 11.



TSS Modeling Express Tool # 12 illustrated in **Figure 11a** for Yellowstone NP, YELL2, and **Figure 11b** for Mesa Verde NP, MEVE1, displays speciated aerosol light extinction on most impaired days for RepBase2 or 2028OTBa2, by source category, for each of 7 pollutants.

Interpretation: At YELL2, in 2028OTBa2, on the most impaired days, organic carbon is the largest contributor to total aerosol extinction and natural and fire sources are the largest contributors to organic carbon. International anthropogenic emissions are the largest contributor to AmmSO4. Natural, international anthropogenic, and U.S. anthropogenic emissions have comparable contributions to AmmNO3.

At MEVE1, in 2028OTBa2, on most impaired days, AmmSO4 and organic carbon are the largest contributors to total aerosol extinction. International emissions are the largest contributor to AmmSO4 and natural emissions are the largest contributor to organic carbon. U.S. anthropogenic emissions are the second largest contributors to AmmSO4 and organic carbon.

Figure 11a. 2028OTBa2 Regional Source Apportionment of Speciated Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor for 7 pollutants, with component U.S. Anthropogenic, International anthropogenic, Natural, and Fire contributions to each pollutant. TSS Modeling Express Tool # 12.

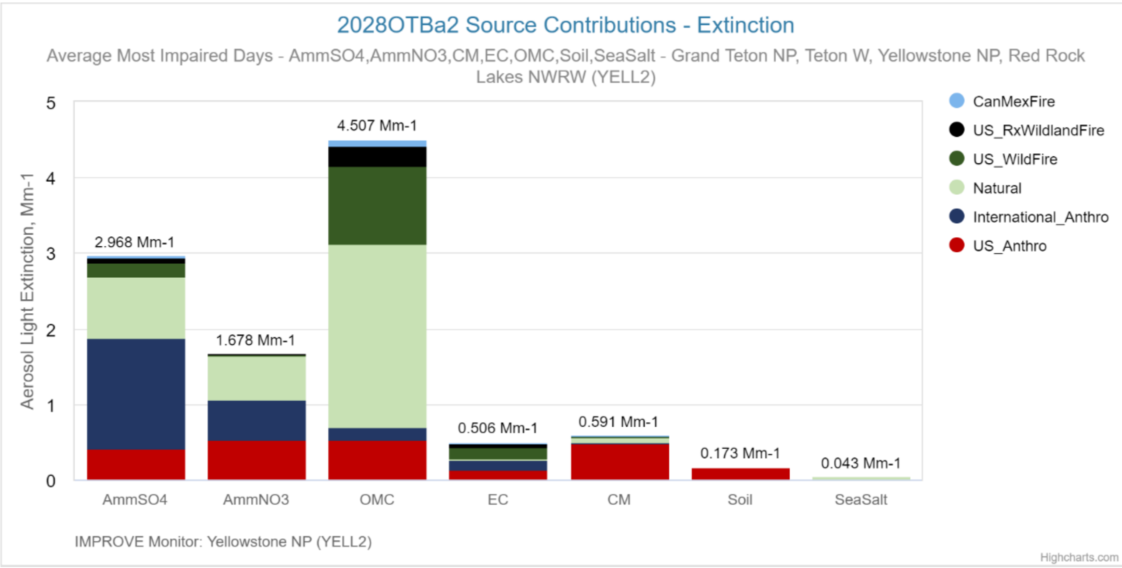
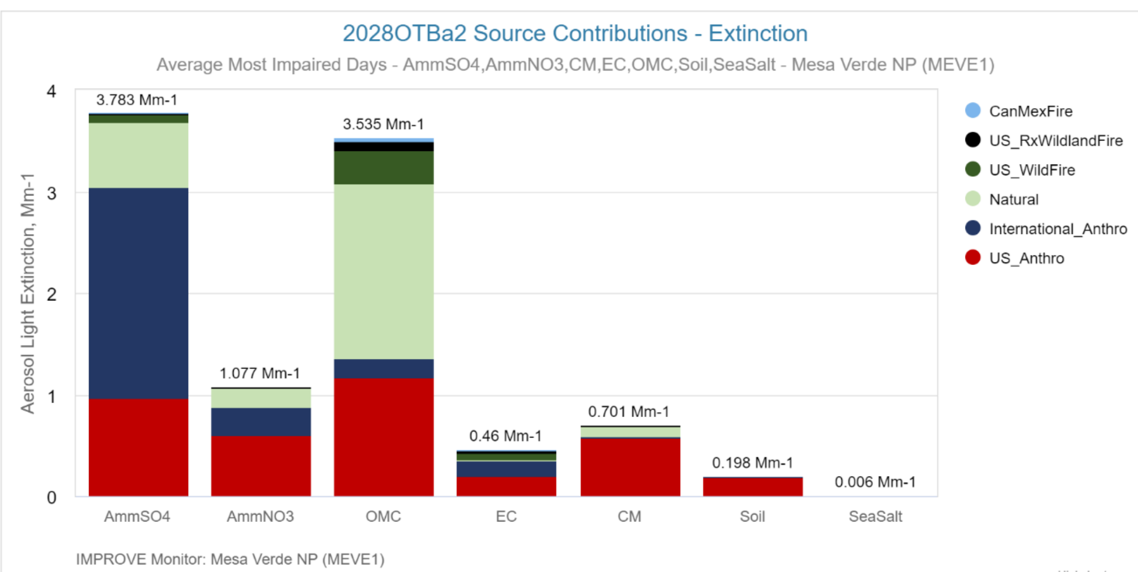


Figure 11b. 2028OTBa2 Regional Source Apportionment of Speciated Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor for 7 pollutants, with component U.S. Anthropogenic, International anthropogenic, Natural, and Fire contributions to each pollutant. TSS Modeling Express Tool # 12.



[TSS Modeling Express Tool] # 13 illustrated in **Figure 12a** for Yellowstone NP (YELL2) and **Figure 12b** for Mesa Verde NP (MEVE1), displays aerosol light extinction on individual 2014 IMPROVE most impaired days for RepBase2 or 2028OTBa2 source apportionment, by source category.

Interpretation: Comparing Figures 15a and 15b, U.S. anthropogenic contributions in 2028OTBa2 are a larger fraction of daily aerosol light extinction at Mesa Verde NP than at Yellowstone NP. U.S. anthropogenic contributions dominate on the two most impaired days with the highest total aerosol extinction at MEVE1. At YELL2, international anthropogenic and natural sources are equal or greater contributors to daily aerosol light extinction than U.S. anthropogenic sources. These source apportionment results are consistent with the 2028OTBa2 visibility projections for these two sites (see **Figure 7a**, TSS Modeling Express Tool # 4).

Figure 12a. 2028OTBa2 Regional Source Apportionment of Aerosol Light Extinction (Mm^{-1}) for 2014 IMPROVE daily most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor for U.S. Anthropogenic, International anthropogenic, Natural, and Fire emissions. TSS Modeling Express Tool # 13.

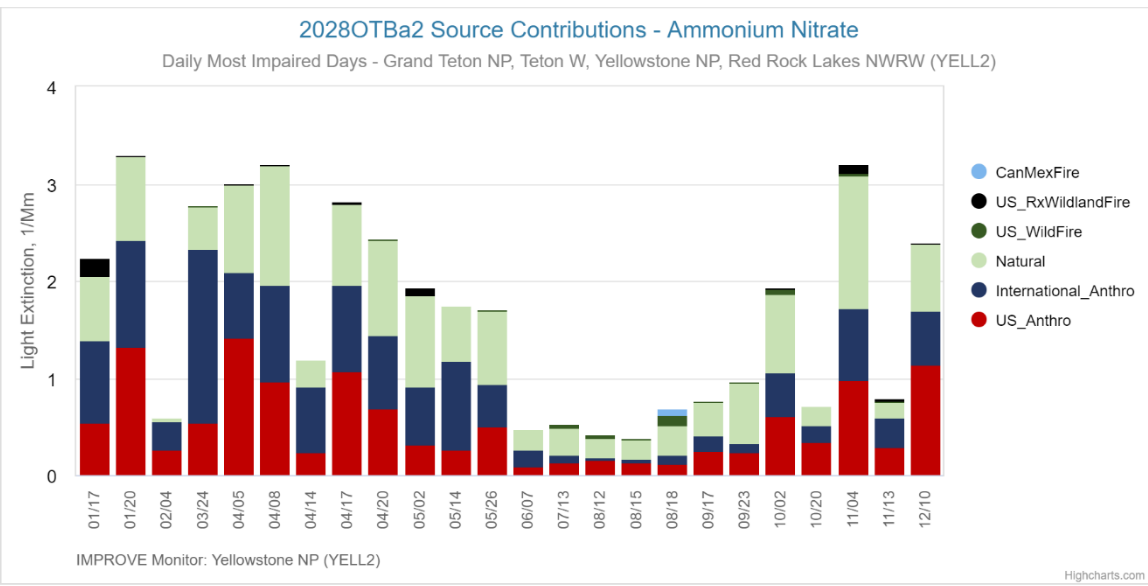
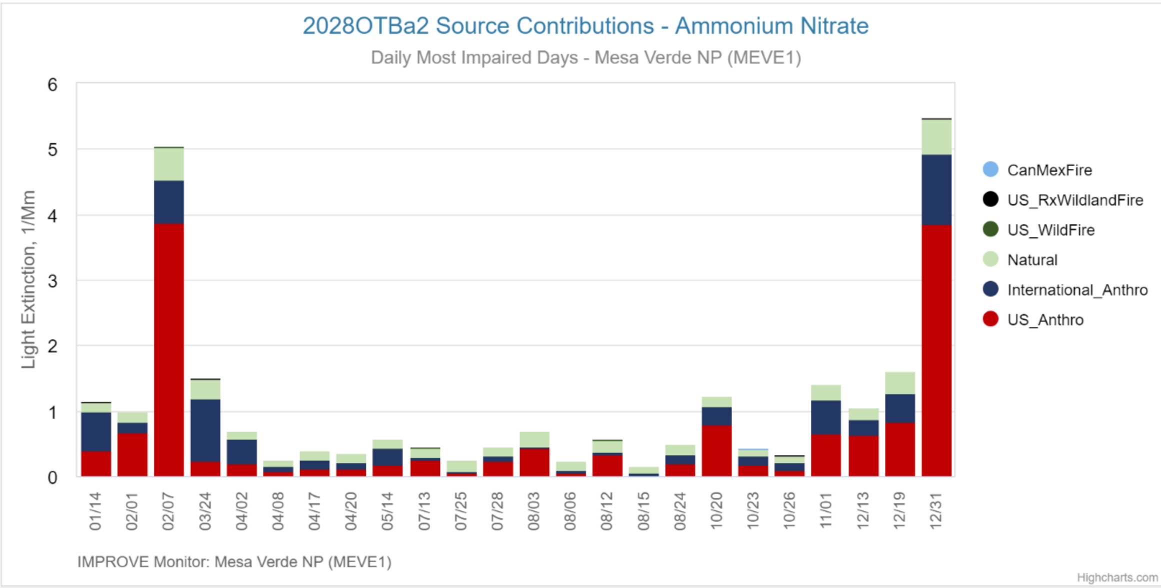


Figure 12b. 2028OTBa2 Regional Source Apportionment of Aerosol Light Extinction (Mm^{-1}) for daily 2014 IMPROVE most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor for U.S. Anthropogenic, International anthropogenic, Natural, and Fire emissions. TSS Modeling Express Tool # 13.



TSS Modeling Express Tool # 14 illustrated in **Figures 13a and 13b** for Yellowstone NP (YELL2) and **Figures 13c and 13d** for Mesa Verde NP (MEVE1) displays RepBase2 or 2028OTBa2 source apportionment results as a treemap (used to display hierarchal data.) Source categories are displayed in block colors with component source groups outlined within each source category total. Users can choose to display source apportionment results for total aerosol light extinction or single aerosol species extinction. Results in Figures 13a and 13c display total aerosol light extinction for 2028OTBa2; results in Figures 13b and 13d display light extinction due to AmmNO3 for 2028OTBa2.

Interpretation: at YELL2, for total aerosol extinction, natural sources are the largest contributors. International anthropogenic and U.S. anthropogenic have similar contributions, and wildfire is also an important source contribution. For AmmNO3, Natural, International anthropogenic and U.S. anthropogenic sources have very similar contributions. As shown in Figure 9a, at YELL2, U.S. anthropogenic emissions in 2028OTBa2 are projected to contribute less than 20% of total aerosol light extinction and less than 30% of extinction due to AmmNO3. These low fractions mean that it is more difficult to demonstrate changes visibility in response to changes in U.S. anthropogenic emissions.

At MEVE1, U.S. anthropogenic emissions are the largest source category for total aerosol extinction and for extinction due to AmmNO3 (Figures 13c, 13d). Visibility is more likely to respond to changes in U.S. anthropogenic emissions at MEVE1 than at YELL2.

Figure 13a. 2028OTBa2 Regional Source Apportionment of Total Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Yellowstone National Park (YELL2) for source groups contributing to U.S. Anthropogenic, International anthropogenic, Natural, and Fire source categories. TSS Modeling Express Tool # 14.

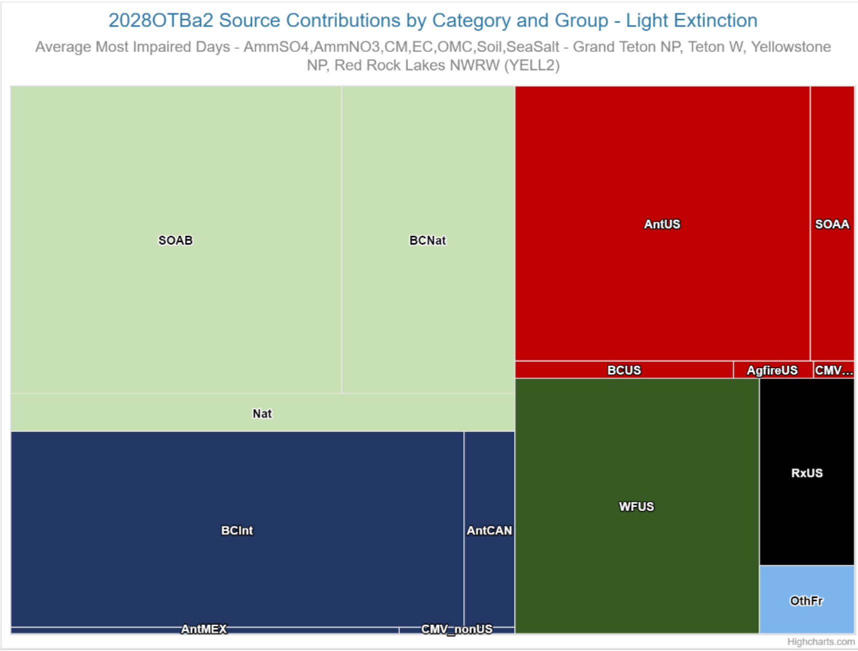


Figure 13b. 2028OTBa2 Regional Source Apportionment of Aerosol Light Extinction (Mm^{-1}) due to Ammonium nitrate for most impaired days at the Yellowstone National Park (YELL2) for source groups contributing to U.S. Anthropogenic, International anthropogenic, Natural, and Fire source categories. TSS Modeling Express Tool # 14.

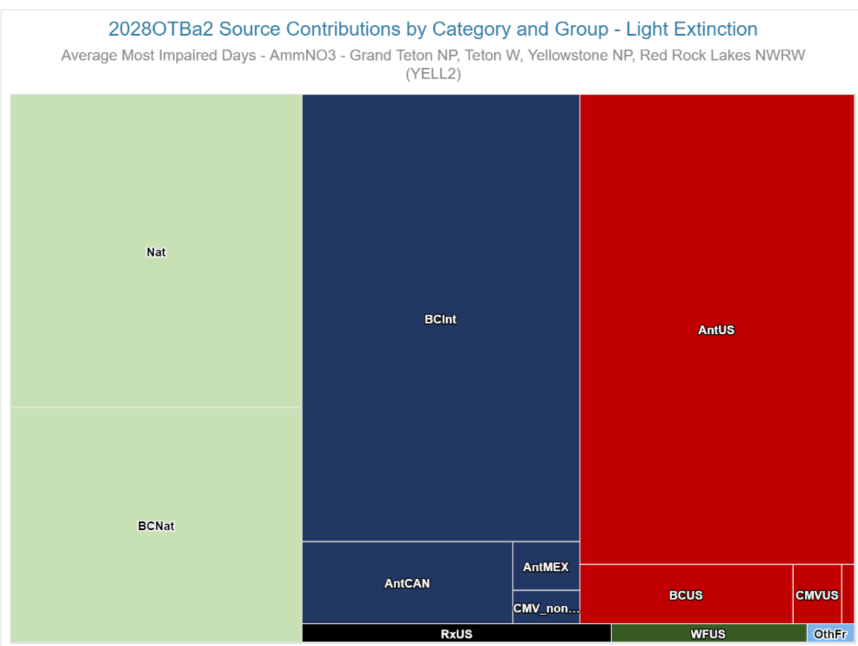


Figure 13c. 2028OTBa2 Regional Source Apportionment of Total Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Mesa Verde National Park (MEVE1) for source groups contributing to U.S. Anthropogenic, International anthropogenic, Natural, and Fire source categories. TSS Modeling Express Tool # 14.

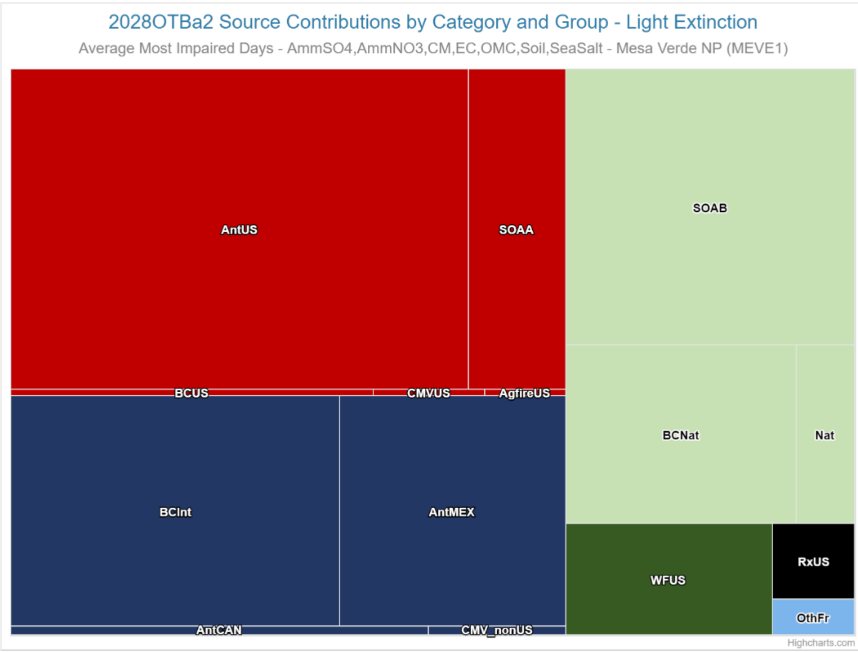
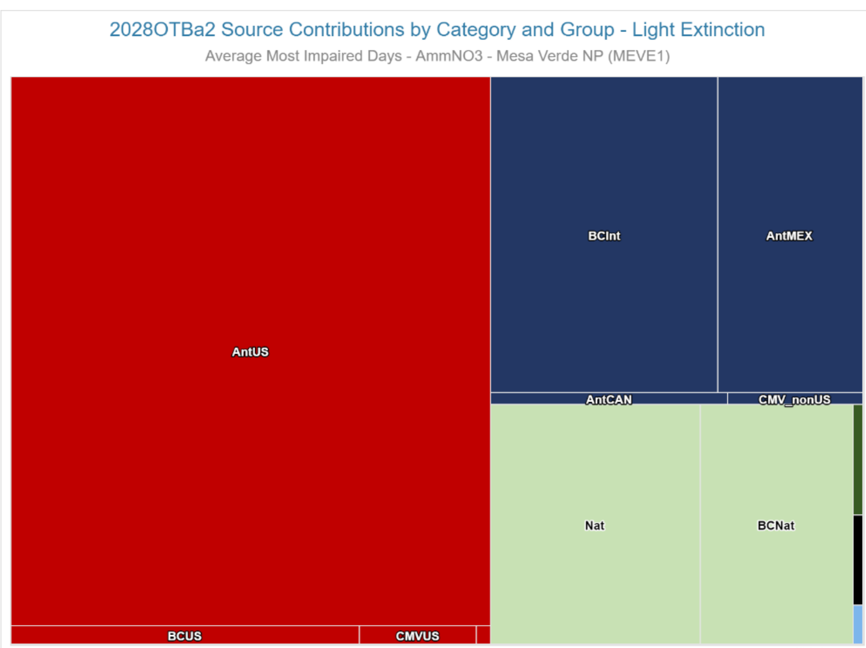


Figure 13d. 2028OTBa2 Regional Source Apportionment of Aerosol Light Extinction (Mm^{-1}) due to Ammonium Nitrate for most impaired days at the Mesa Verde National Park (MEVE1) for source groups contributing to U.S. Anthropogenic, International anthropogenic, Natural, and Fire source categories. TSS Modeling Express Tool # 14.



[TSS Modeling Express Tool](#) # 15 illustrated in **Figure 14a** for Yellowstone NP (YELL2) and **Figure 14b** for Mesa Verde NP (MEVE1), displays RepBase2 or 2028OTBa2 source apportionment results as a treemap (used to display hierarchal data.) Source categories are displayed in block colors with component aerosol species contributions outlined within each source category total. Users can choose to display source apportionment results for total aerosol light extinction or single aerosol species extinction. Results in Figures 14a and 14b display total aerosol light extinction for 2028OTBa2.

The same data are presented in TSS Modeling Express Tool #11 (Figures 10a and 10b.)

Interpretation: the tree map shows the aerosol species contributions to each source category. At both YELL2 and MEVE1, OMC is a large fraction of U.S. anthropogenic contributions, in addition to AmmNO3 and AmmSO4. OMC is also a large fraction of natural and fire contributions.

Figure 14a. 2028OTBa2 Regional Source Apportionment of Total Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Yellowstone National Park (YELL2) for aerosol species contributions to U.S. Anthropogenic, International anthropogenic, Natural, and Fire source categories. [TSS Modeling Express Tool](#) # 15.

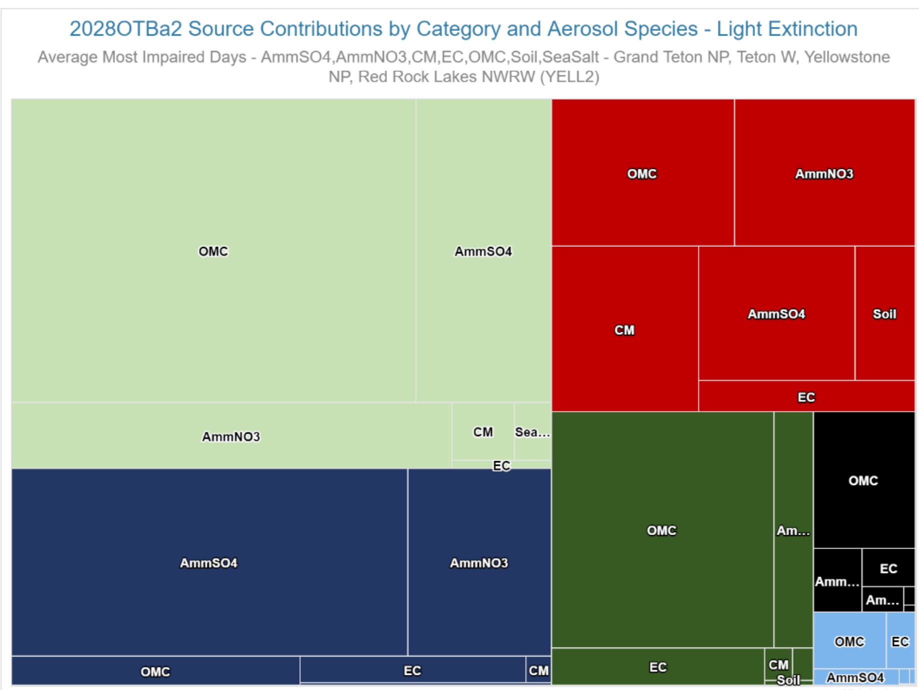
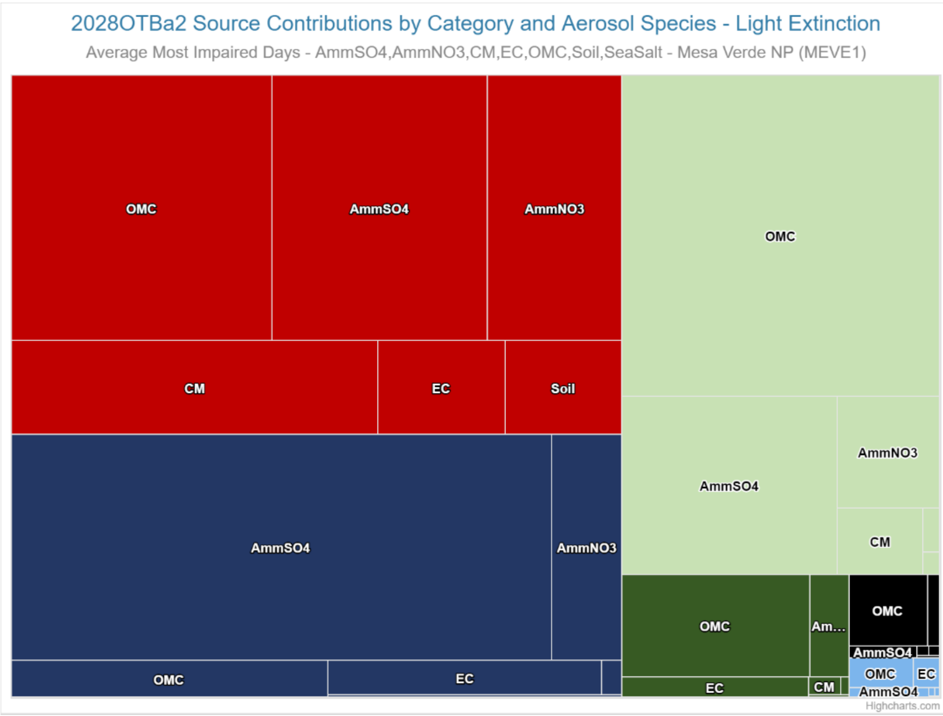


Figure 14b. 2028OTBa2 Regional Source Apportionment of Total Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Mesa Verde National Park (MEVE1) for aerosol species contributions to U.S. Anthropogenic, International anthropogenic, Natural, and Fire source categories. [TSS Modeling Express Tool](#) # 15.



[TSS Modeling Express Tool](#) # 16 illustrated in **Figure 15a** for Yellowstone NP (YELL2) and **Figure 15b** for Mesa Verde NP (MEVE1), displays RepBase2 or 2028OTBa2 source apportionment results as a treemap (used to display hierarchal data.) Aerosol species contributions are displayed in block colors with component source groups outlined within each aerosol species. total. Users can choose to display source apportionment results for total aerosol light extinction or single aerosol species extinction. Results in Figures 15a and 15b display total aerosol light extinction for 2028OTBa2.

The same data are presented in TSS Modeling Express Tool #12 (Figures 11a and 11b.)

Interpretation: at YELL2, U.S. anthropogenic contributions are the third most important for OMC, AmmSO4, and AmmNO3. At MEVE1 U.S. anthropogenic contributions are the largest factor for AmmNO3 and the second largest for AmmSO4 and OMC.

Figure 15a. 2028OTBa2 Regional Source Apportionment of Total Aerosol Light Extinction (Mm^{-1}) for most impaired days at Yellowstone National Park (YELL2) for source category contributions to individual aerosol species. [TSS Modeling Express Tool](#) # 16.

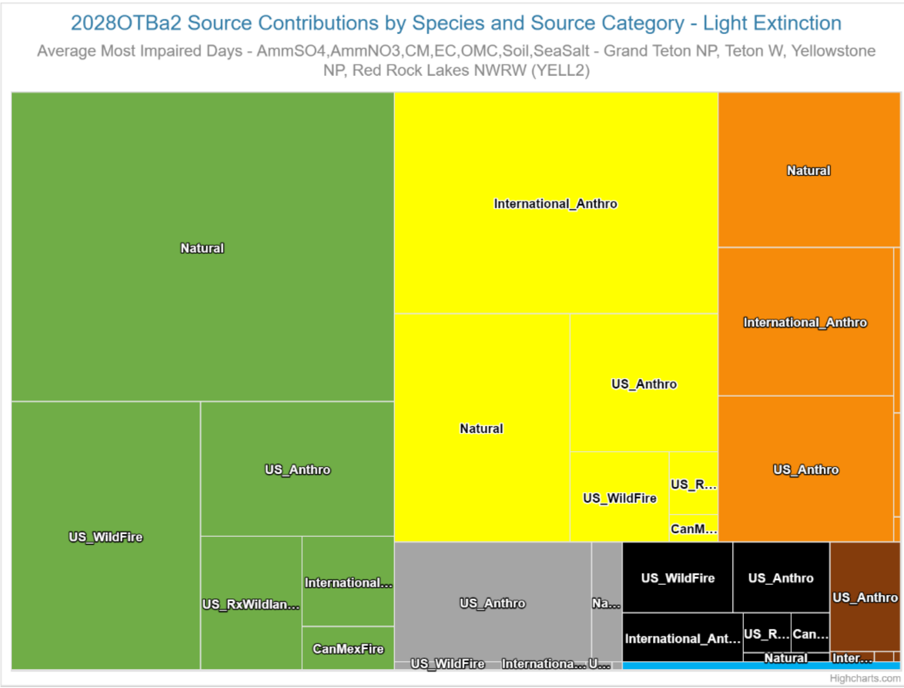
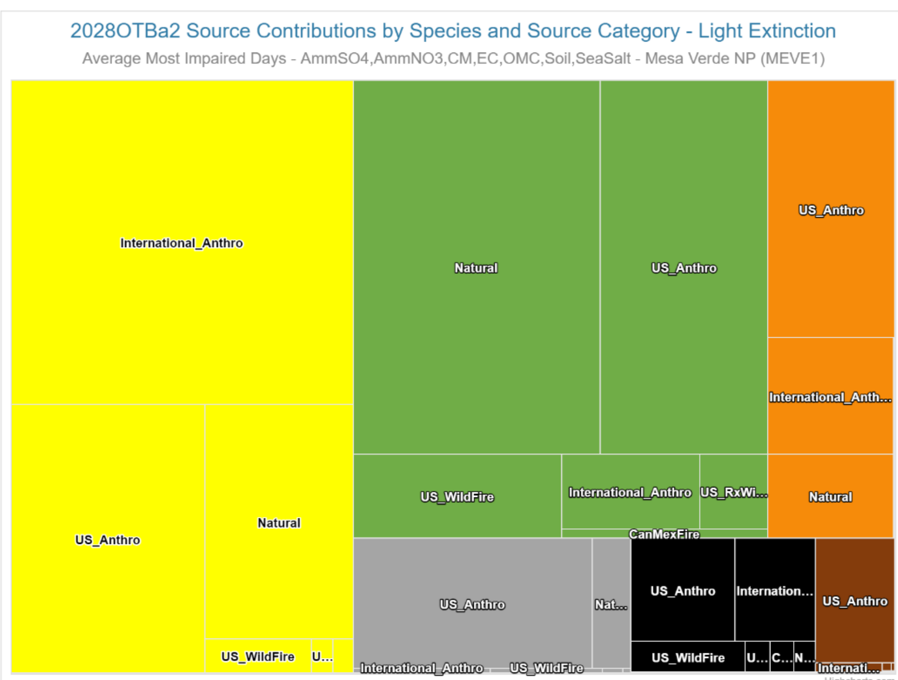


Figure 15b. 2028OTBa2 Regional Source Apportionment of Total Aerosol Light Extinction (Mm^{-1}) for most impaired days at Mesa Verde National Park (MEVE1) for source category contributions to individual aerosol species. [TSS Modeling Express Tool](#) # 16.



11.0 State and Sector (Low-level) Source Apportionment

For the future year 2028OTBa2 model scenario, PSAT was applied to further define U.S. anthropogenic contributions to AmmNO3 and AmmSO4 aerosols at western Class I areas from each of 13 WESTAR-WRAP states and all other non-WRAP U.S. states combined. Methods are further detailed in the run specification sheet for High-Level and Low-Level Source Apportionment Modeling using the RepBase2 and 2028OTBa2 model scenarios (September 2020).

State contributions to AmmNO3 and AmmSO4 were subdivided into five anthropogenic source categories:

- electric generating units (EGU)
- oil and gas (area plus point sources) (OilGas)
- remaining point sources (non-EGU)
- Mobile onroad, nonroad, rail, and commercial marine vessels (CMV 1, 2, and 3 within 200 km of U.S. coast) (Mobile)
- remaining anthropogenic sources (including Fugitive dust, Agriculture, Agricultural fire, residential wood combustion, and all remaining nonpoint sources)

For each Class I area, these results identify which source sectors and states are projected to have the greatest contributions in 2028OTBa2 to visibility impairment due AmmSO4 and AmmNO3. These results can assist states to prioritize which emissions reductions strategies might be most effective in improving visibility at western Class I areas.

The state and sector source apportionment results in TSS Modeling Express Tools # 9 are absolute model outputs; results are not normalized to IMPROVE monitoring data. Users can choose to display state and sector source apportionment results for most impaired days (EPA default 2014 IMPROVE days), modeled most impaired days, or clearest days. This document provides examples for most impaired days only.

TSS Modeling Express Tool # 9 illustrated in **Figures 16a and 16b** for Yellowstone NP (YELL2) and **Figures 16c and 16d** for Mesa Verde NP (MEVE1), displays RepBase2 or 2028OTBa2 source apportionment results for western states and source sectors for AmmNO3 or AmmSO4 light extinction, respectively.

Interpretation: at YELL2 PSAT projects that AmmNO3 contributions from individual states are 0.2 Mm^{-1} or less. PSAT identifies mobile sources from several western states as the most important U.S. anthropogenic contributors to AmmNO3 at YELL2 (**Figure 16a**). Idaho is shown as having the largest contributions to AmmNO3 from mobile, non-EGU and area sources.

For AmmSO4 at YELL2, PSAT projects that individual state contributions are small (0.15 Mm-1 or less). Non-EGU, EGU, and area sources in several states are identified as contributors.

Figure 16a. 2028OTBa2 State and Sector Source Apportionment of Ammonium Nitrate Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor. TSS Modeling Express Tool # 9

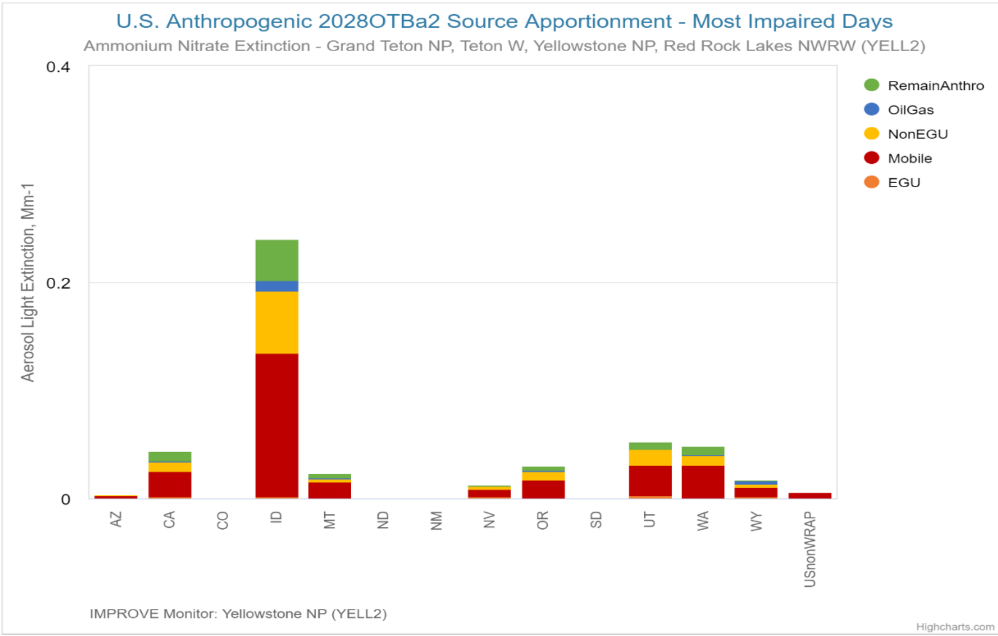


Figure 16b. 2028OTBa2 State and Sector Source Apportionment of Ammonium Sulfate Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor. TSS Modeling Express Tool # 9

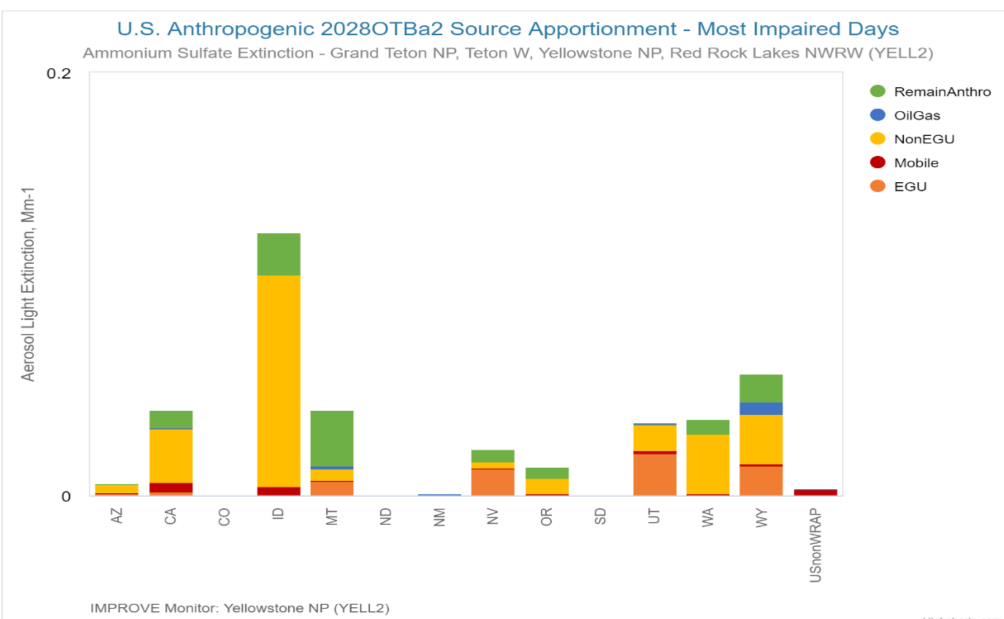


Figure 16c. 2028OTBa2 State and Sector Source Apportionment of Ammonium Nitrate Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor. TSS Modeling Express Tool # 9

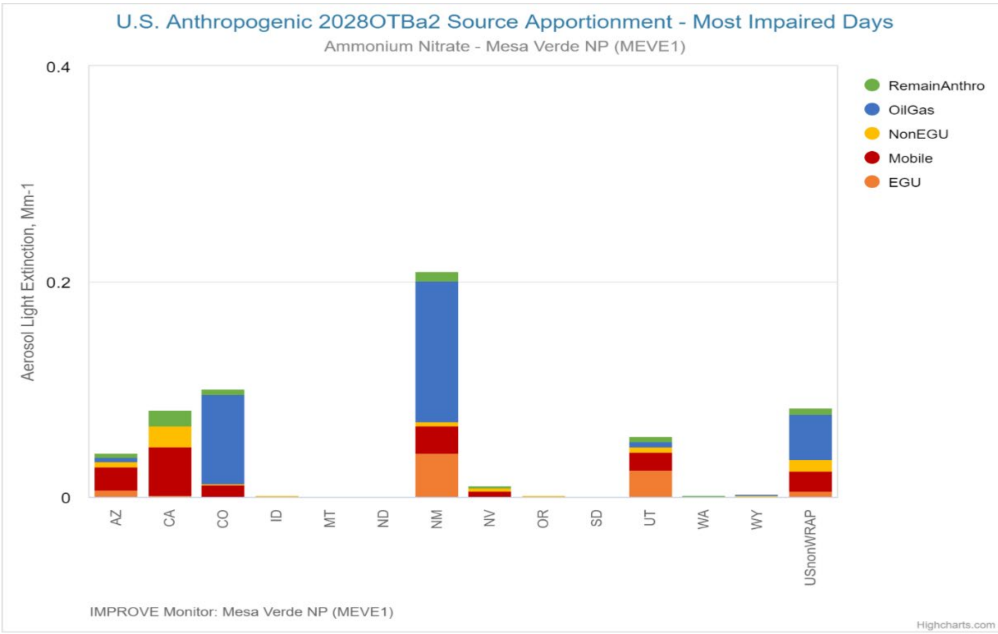
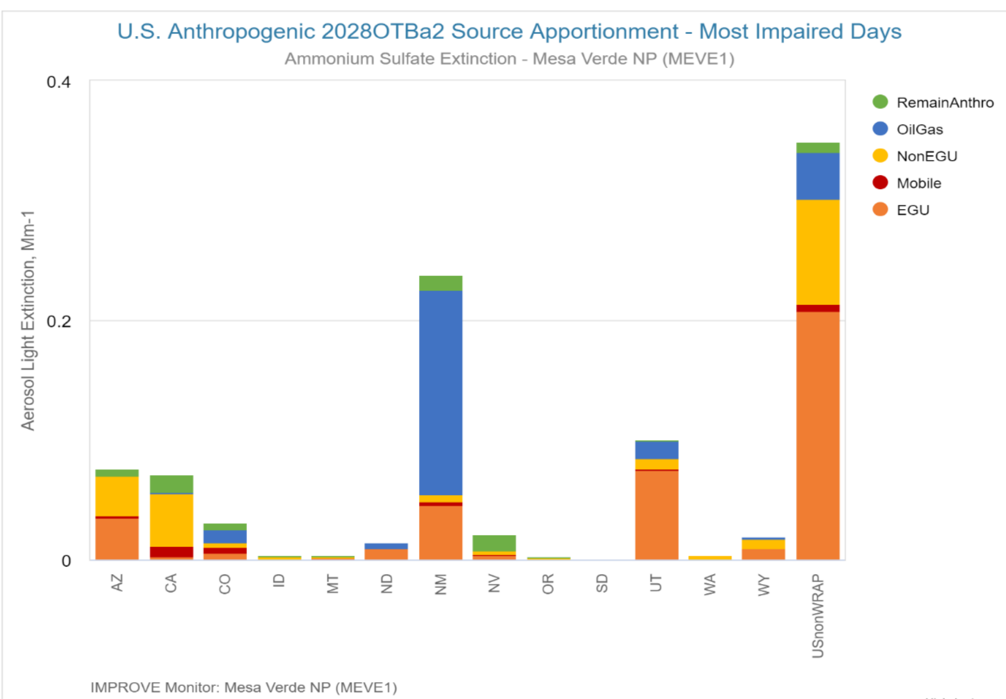


Figure16d. 2028OTBa2 State and Sector Source Apportionment of Ammonium Sulfate Aerosol Light Extinction (Mm^{-1}) for most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor. TSS Modeling Express Tool # 9



At MEVE1, AmmNO3 contributions from individual states are 0.2 Mm^{-1} or less. Oil and gas in NM, CO, and non-WRAP states are major contributors; oil and gas on tribal lands is included in the state contributions (see Table 3 in Section 3 of the TSS Emissions Reference document for breakdown of tribal vs non-tribal NOx emissions.) EGU and mobile source sectors are also contributors to AmmNO3. EGU from non-WRAP states and oil and gas in NM are the largest contributors to AmmSO4 at MEVE1. Weighted Emissions Potential plots for MEVE1 confirm the Four Corners region and Arizona as the highest transport area for AmmNO3 and that EGU in Texas contribute to AmmSO4 loadings.

In general, at western Class I areas mobile emissions and oil and gas emissions are significant contributors to AmmNO3, while electric generating units and remaining point sources are more important source categories for AmmSO4.

12.0 Weighted Emissions Potential

WRAP 2028 Weighted Emissions Potential maps were developed to illustrate the geographic areas of greatest emissions influence for aerosol extinction on most impaired days at 76 IMPROVE monitors representing 116 Class I areas in the 13 WESTAR-WRAP states and neighboring states. 72-hour back trajectory analyses (defined every 6 hours for multiple start heights) for most impaired days for the 5-year period 2014-2018 were used to define frequency of atmospheric transport. Gridded 2028 modeled emissions in 36-km grid cells, residence time defined by back trajectory transport frequency, residence time weighted aerosol extinction for most impaired days (also called area of influence), and weighted emission potential for gridded emissions can be downloaded from the Weighted Emissions Potential webpage. The weighted emissions potential defines relative source importance for each Class I area. These analyses provide weight of evidence in support of state and sector source apportionment results in Section 11.0.

Figure 17a (left) displays the areas of highest influence from NOx emissions, weighted by AmmNO3 extinction on the most impaired days for YELL2, highlighted in burgundy and orange elliptical shapes overlaying eastern Idaho and western Wyoming. **Figure 17a (right)** displays the individual 36-km model grid cells, color graded by importance of mobile source NOx emissions for AmmNO3 extinction on most impaired days at YELL2 (burgundy, orange, and green grid cells have the highest importance). **Figure 17b (left)** displays areas of highest influence from SO2 emissions, weighted by AmmSO4 extinction on the most impaired days for YELL2.

Interpretation: The Weighted Emissions Potential maps agree with the PSAT results (Section 11.0) for YELL2 and MEVE1. For YELL2 the geographic area of influence is similar for AmmNO3 and AmmSO4 extinction (**Figures 17a, left and 17b, left**.) For mobile sources, the highest contributors to AmmNO3 extinction on most impaired days at YELL2 include the mobile source corridors in Idaho and grid cells in Montana, Utah, Oregon and Washington (**Figure 17a, right**). Non-Electric generating point sources (non-EGU) in several states are seen as important contributors to AmmSO4 extinction on most impaired days at YELL2 (**Figure 17b right**). These results agree with PSAT results that identify mobile sources as largest contributors to AmmNO3 (**Figure 16a**) and non-EGU point sources as largest contributors to AmmSO4 extinction at YELL2 (**Figure 16b**).

Figure 17a. 2028OTBa2 Extinction Weighted Residence Time for Ammonium Nitrate (AmmNO3) Light Extinction (Mm^{-1}) (left) and NOx Weighted Emissions Potential for On-Road Mobile sources (right) for most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor. Weighted Emissions Potential

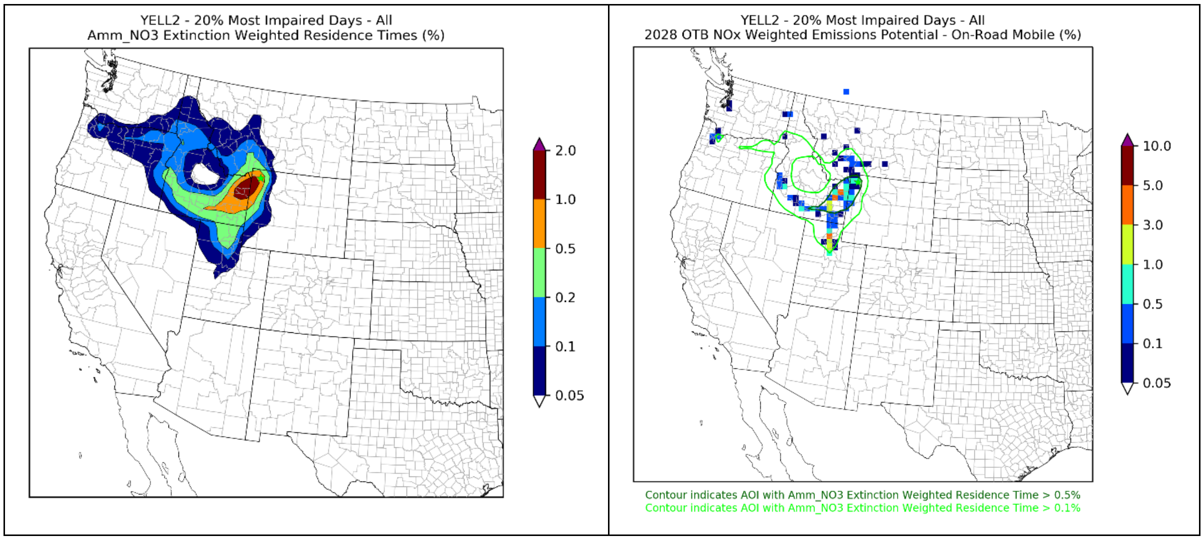
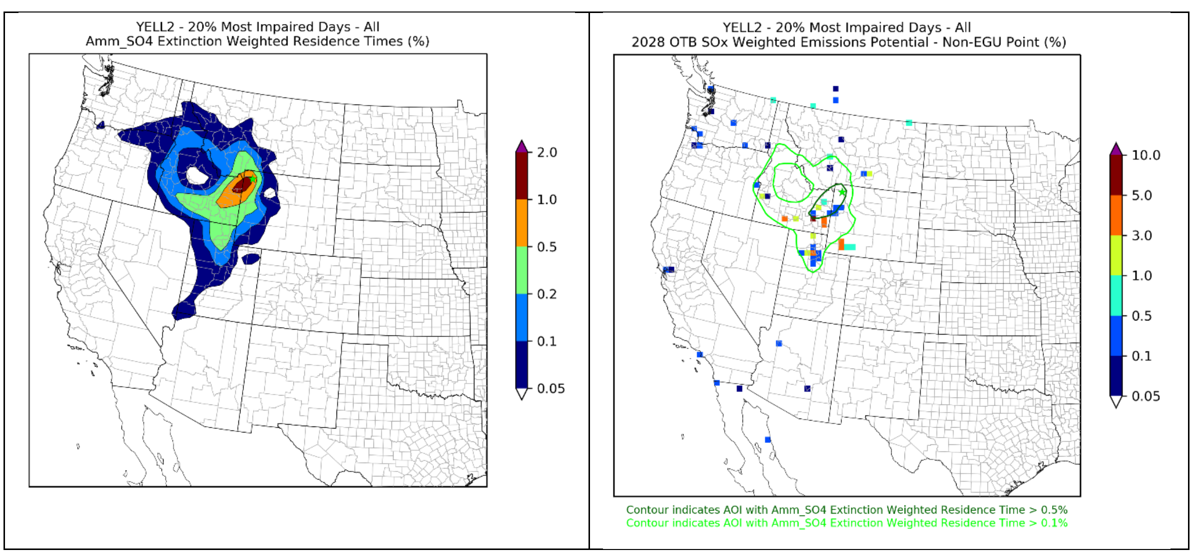


Figure 17b. 2028OTBa2 Extinction Weighted Residence Time for Ammonium Sulfate (AmmSO4) Light Extinction (Mm^{-1}) (left) and SO2 Weighted Emissions Potential for Non-Electric Generating Point sources (right) for most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor. Weighted Emissions Potential



For MEVE1, **Figure 17c, left** display the geographic areas of highest influence for NOx emissions, weighted by AmmNO3 extinction on the most impaired days. In **Figure 17c, right** the areas of highest influence are outlined in dark green and light green boundaries and oil and gas point and area sources contributions to AmmNO3 are defined in color-graded 36-km grid cells. **Figure 17d, left** displays a very similar geographic area of influence for SO2 emissions, weighted by AmmSO4 extinction on most impaired days. **Figure 17d, right** illustrates that electric generating units that influence AmmSO4 extinction at MEVE1 on most impaired days are geographically dispersed and not restricted to the geographic area of highest influence for total AmmSO4.

Figure 17c. 2028OTBa2 Extinction Weighted Residence Time for Ammonium Nitrate (AmmNO3) Light Extinction (Mm^{-1}) (left) and NOx Weighted Emissions Potential for On-Road Mobile sources (right) for most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor. Weighted Emissions Potential

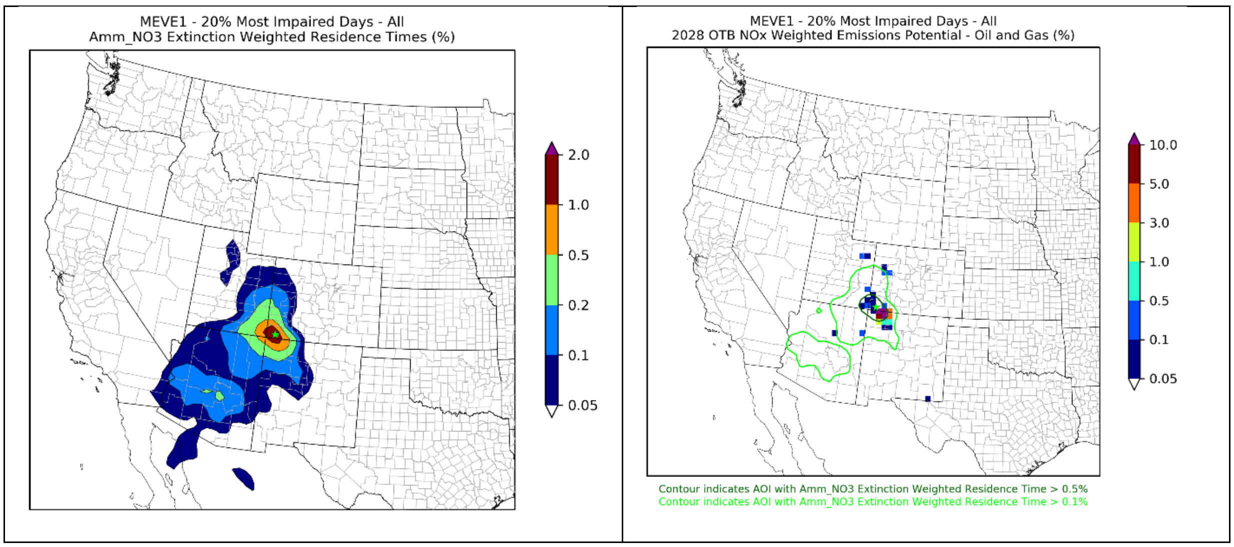
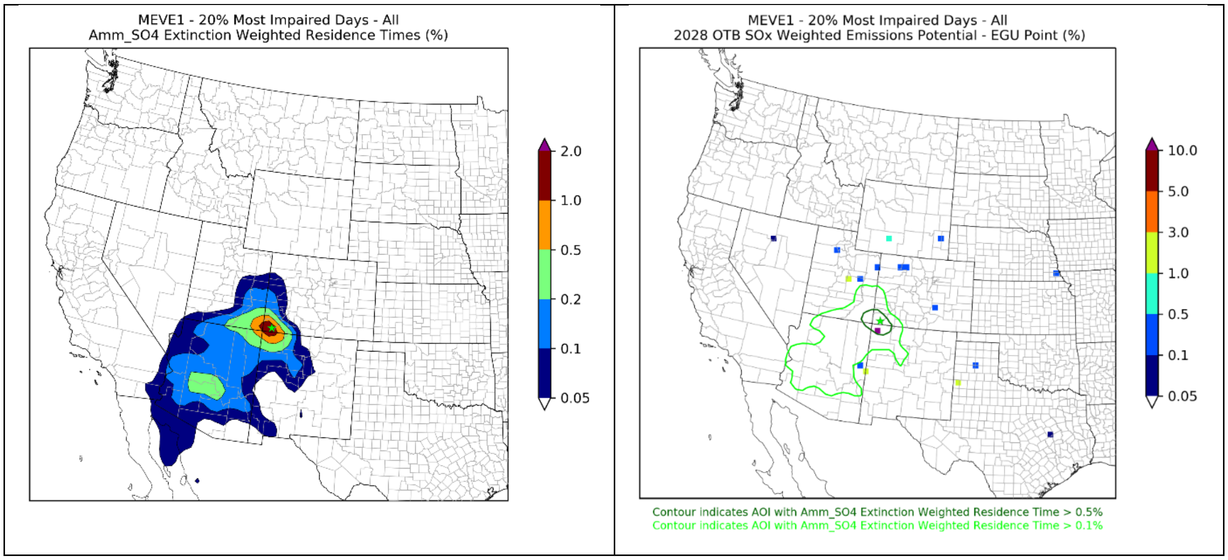


Figure 17d. 2028OTBa2 Extinction Weighted Residence Time for Ammonium Sulfate (AmmSO4) light Extinction (Mm^{-1}) (left) and SO2 Weighted Emissions Potential for Electric Generating Units (EGU) sources (right) for most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor. Weighted Emissions Potential



The area of greatest influence for AmmNO3 extinction on most impaired days at MEVE1 (**Figure 17c, left)** is centered over the Four Corners area. In **Figure 17c, right** the area of greatest influence is outlined in the dark green elliptical boundary over the Four Corners and the lighter green boundary over portions of the four states: AZ, CO, NM, and UT. On the same plot, the 36-km grid cells are color coded by importance of NOx emissions from oil and gas area and point sources. The oil and gas contributions are primarily located within the inner dark green area of influence.

The areas of greatest influence for AmmSO4 extinction on most impaired days at MEVE1 are illustrated in **Figure 17d, left** and **17d, right.** The areas of influence are similar to those for AmmNO3 extinction at MEVE1. The EGU plot illustrates emissions from elevated EGU point sources can influence visibility at a distant Class I area even if transport from the EGU point source is infrequent. These maps are consistent with the PSAT state and sector source apportionment for AmmNO3 and AmmSO4 at MEVE1 (Section 11.0)

13.0 Dynamic Model Evaluation

As part of the WRAP-WAQS 2014 modeling study, a dynamic model evaluation was conducted to test the model's ability to project changes in ambient aerosol visibility extinction at IMPROVE monitoring sites in response to changes in U.S. anthropogenic emissions. To conduct the dynamic model evaluation, in addition to the 2014v2, RepBase2 and 2028OTBa2 model scenarios already discussed, an additional scenario representing U.S. anthropogenic emissions for 2002 (2002 Hindcast) was run using the CAMx-PSAT photochemical grid model platform with 2014 meteorology and RepBase2 emissions for all other natural, fire, and international source groups. Only U.S. anthropogenic emissions changed between the 2002 Hindcast, RepBase2, and 2028OTBa2 model scenarios. 2002 U.S. Anthropogenic emissions were back cast from the 2014 National Emissions Inventory (NEI) using scaling factors based on EPA's NEI trends for most sectors, with exceptions that California Air Resources Board provided 2014 to 2002 scaling factors for California, and western states supplied 2002 emissions for point sources (electric generating units (EGU), oil and gas point sources, and other non-EGU point sources.) Methods for the 2002 Hindcast are further defined in the U.S. Anthropogenic Emissions Rate of Progress document (September 2021).

The dynamic model evaluation applied the same future year projection methods defined by Environmental Protection Agency modeling guidance (December 2018) to project 2014-2018 visibility from the 2002 Hindcast forward to the RepBase2 scenario. Relative response factors for each aerosol species were calculated (RepBase2 model results divided by 2002 Hindcast model results) and then multiplied by 2000-2004 IMPROVE observations for each species to project RepBase2 visibility. Model projected RepBase2 aerosol light extinction closely matched IMPROVE observed light extinction for 2014-2018 5-year average (**Figure 18a**). This confirmation increases confidence that the CAMx model and EPA projection methods can produce credible 2028 visibility projections. Backward projections of 2002 visibility from RepBase2 (relative response factors calculated as 2002 Hindcast divided by RepBase2 and then multiplied by 2014-2018 IMPROVE observations) had larger discrepancies from 2000-2004 IMPROVE observations than forward projections from 2002 to RepBase2, but still showed good agreed for most western IMPROVE sites (**Figure 18b**). The larger discrepancies for the 2002 Hindcast are likely due to a combination of (i) using RepBase2 levels of fire and international emissions for the 2002 Hindcast model run that differed from the actual emissions that contributed to 2000-2004 IMPROVE observations and (ii) using scaling factors to calculate 2002 Hindcast emissions from 2014v2 National Emissions Inventory that introduces errors for U.S. anthropogenic emissions (e.g., over estimating 2002 emissions for Commercial Marine Vessel emissions). A future dynamic model evaluation may want to back cast natural, fire and international emissions as well as U.S. anthropogenic emissions.

Figure 18a. Dynamic Model Evaluation applying EPA projection methods and comparing total aerosol light extinction for 2014-2018 IMPROVE observations (x-axis) to modeled RepBase2 (y-axis) for Class I areas in the 13 western states. U.S. Anthropogenic Emissions Rate of Progress

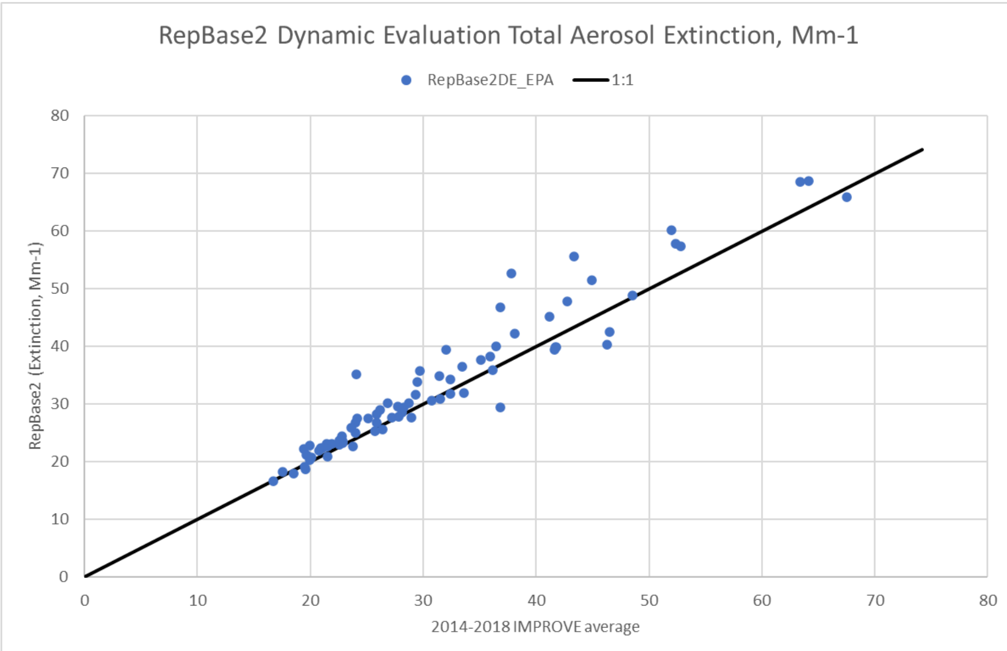
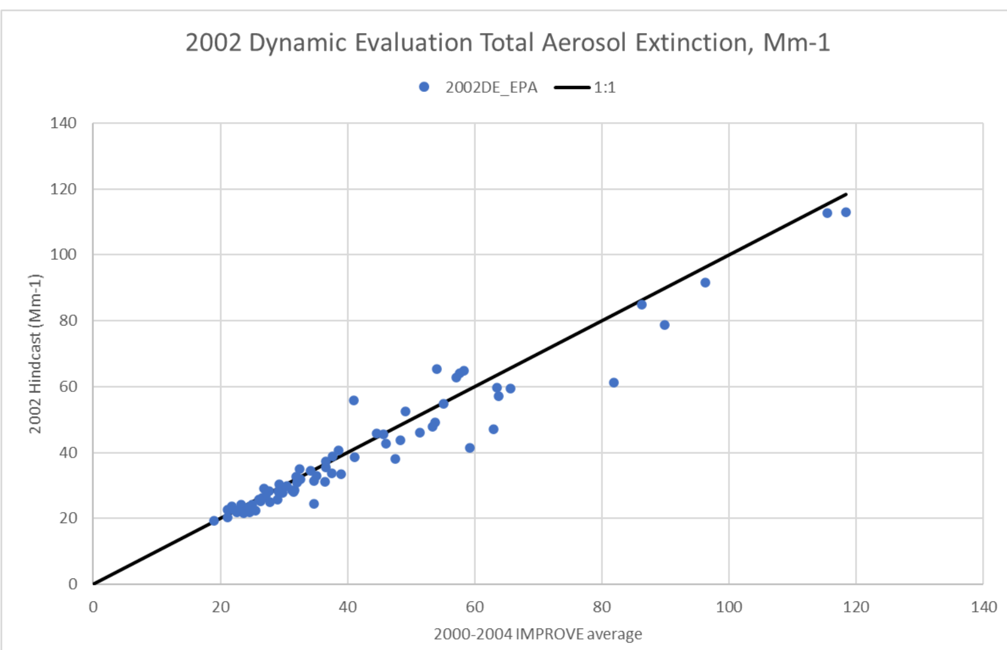


Figure 18b. Dynamic Model Evaluation applying EPA projection methods and comparing total aerosol light extinction for 2000-2004 IMPROVE observations (x-axis) to modeled 2002 Hindcast (y-axis) for Class I areas in the 13 western states. U.S. Anthropogenic Emissions Rate of Progress



14.0 U.S. Anthropogenic Emissions Rate of Progress

WRAP has defined a U.S. Anthropogenic Emissions Rate of Progress to demonstrate visibility progress at western Class I areas due to changes in U.S. Anthropogenic emissions between the 2002 Hindcast, RepBase2, and 2028OTBa2 model scenarios. Methods for the 2002 Hindcast, RepBase2 and 2028OTBa2 scenario development are further defined in the WRAP-WAQS run specification sheets

- Representative Baseline v2 and 2028OTBa2
- U.S. Anthropogenic Emissions Rate of Progress

The URP glidepath represents total haze from all source contributions on most impaired days. In the western U.S., haze is caused by international, natural, and fire emissions as well as U.S. anthropogenic emissions. Uncertainties in the URP glidepath construction are further described in the U.S. Anthropogenic Emissions Rate of Progress webpage.

The objective of the U.S. Anthropogenic Emissions Rate of Progress is to isolate the contributions of U.S. anthropogenic emissions to visibility at Class I areas in the WESTAR-WRAP states and to demonstrate the progress in improving visibility in response to changes in U.S. anthropogenic emissions between the 2002 Hindcast, RepBase2, and 2028OTBa2 scenarios.

- Only U.S. anthropogenic emissions change in the three model scenarios.
    - Any differences in aerosol extinction between the 2002, RepBase2, and 2028OTBa2 scenarios are due to changes in U.S. anthropogenic emissions.
    - We have greatest confidence in U.S. anthropogenic emissions.

- All other emissions (natural, fire, and international) are held constant at RepBase2 levels for the 2002 Hindcast and 2028OTBa2 scenarios.
    - Because RepBase2 international, fire, and natural emissions are used in the 2002 Hindcast scenario, the 2002 Hindcast results are not fully comparable to the 2000-2004 IMPROVE monitoring data.

- The source apportionment model results are not adjusted to the IMPROVE monitoring data.

- The U.S. Anthropogenic Emissions Rate of Progress is intended as an alternative to adjusting the 2064 endpoint of the URP glidepath using 2028 source apportionment results for international and U.S. wildland prescribed fire, per EPA guidance.

TSS Modeling Express Tool # 6, illustrated in **Figures 19a and 19b** displays US Anthropogenic, International Anthropogenic, Natural, Fire, and Rayleigh contributions to total light extinction for the 2002 Hindcast, RepBase2, and 2028OTBa2 model scenarios for the IMPROVE monitors at Yellowstone (YELL2) and Mesa Verde (MEVE1) National Parks, respectively.

Interpretation: at YELL2 U.S. Anthropogenic contributions are projected to be reduced by 2 Mm^{-1} (39%) between 2002 Hindcast and RepBase2 and by 1 Mm^{-1} (30%) between RepBase2 and 2028OTBa2. This rate of progress is below the straight line drawn from 2002 U.S. anthropogenic contribution to zero U.S. anthropogenic contribution in 2064. This is in contrast to conclusions following EPA guidance, where 2028OTBa2 visibility projections for YELL2 are not below the URP glidepath (Section 8.0). The modeled rate of U.S. anthropogenic progress is below the glidepath to no U.S. anthropogenic contribution.

At MEVE1, U.S. anthropogenic contributions are projected to be reduced by 3 Mm^{-1} (41%) between 2002 Hindcast and RepBase2 and by 0.8 Mm^{-1} (18%) between RepBase2 and 2028OTBa2. This rate of progress is below the straight line drawn from 2002 U.S. anthropogenic contribution to zero U.S. anthropogenic contribution in 2064.

Figure 19a. Contributions to Aerosol Light Extinction from U.S. Anthropogenic, International Anthropogenic, Natural, and Fire emissions, plus Rayleigh light scattering, for the 2002 Hindcast, RepBase2, and 2028OTBa2 model scenarios for most impaired days at Yellowstone National Park (YELL2) IMPROVE monitor. TSS Modeling Express Tool # 6

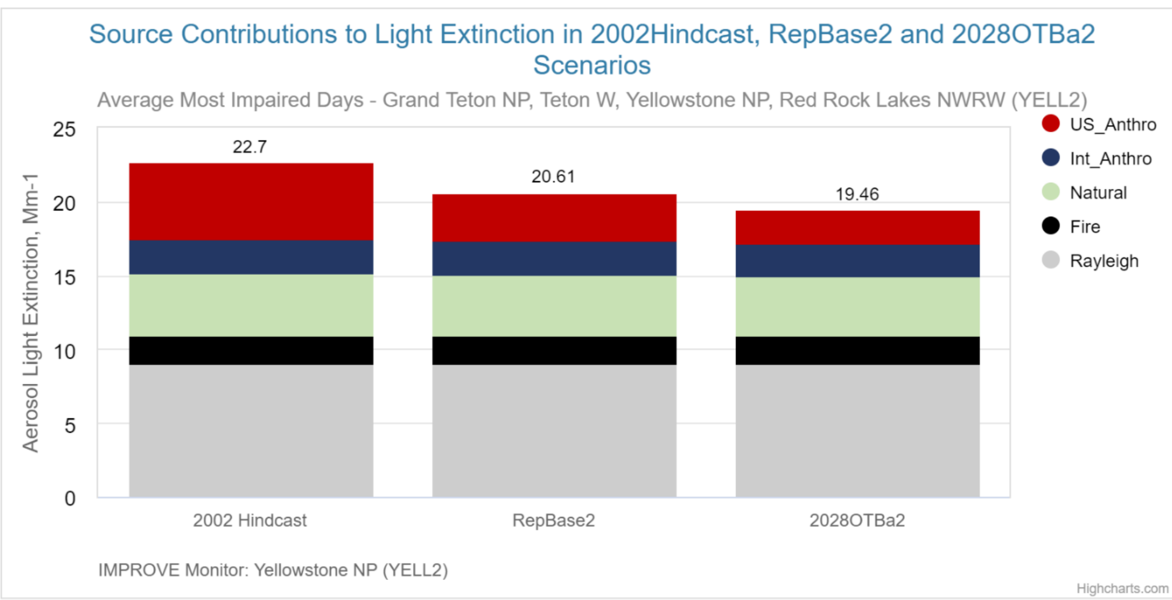
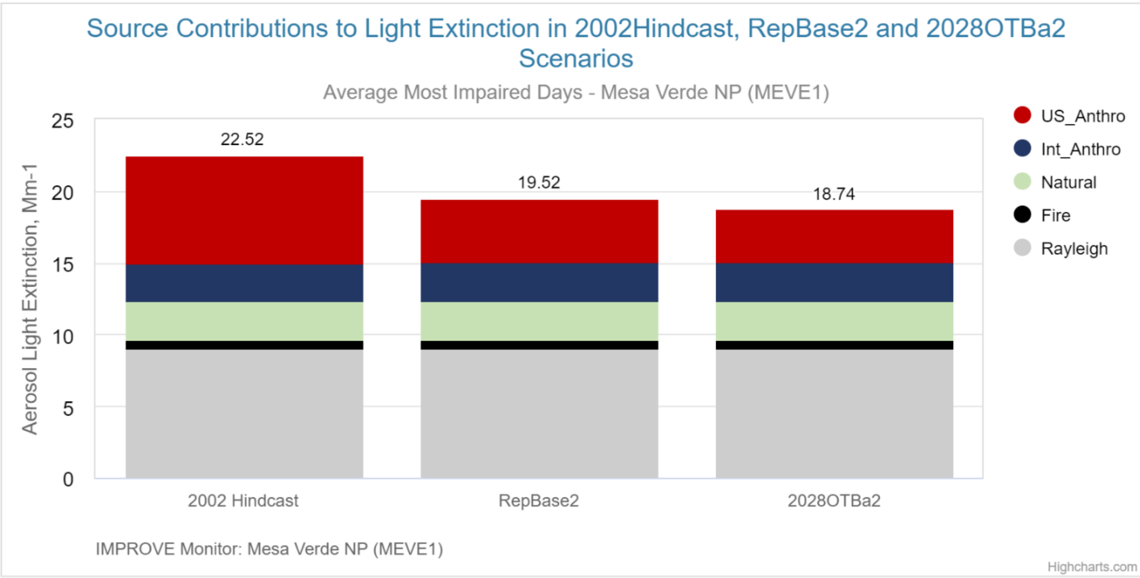


Figure 19b. Contributions to Aerosol Light Extinction from U.S. Anthropogenic, International Anthropogenic, Natural, and Fire emissions, plus Rayleigh light scattering, for the 2002 Hindcast, RepBase2, and 2028OTBa2 model scenarios for most impaired days at Mesa Verde National Park (MEVE1) IMPROVE monitor. TSS Modeling Express Tool # 6



TSS Modeling Express Tool # 7, illustrated in **Figures 20a and 20b** displays aerosol species contributions to just the U.S. Anthropogenic fraction of total light extinction for the 2002 Hindcast, RepBase2 and 2028OTBa2 model scenarios for the IMPROVE monitors at Yellowstone (YELL2) and Mesa Verde (MEVE1) National Parks, respectively.

- TSS Chart 7 does not address aerosol light extinction from sources other than U.S. Anthropogenic contributions.
- The source apportionment model results are not adjusted to the IMPROVE monitoring data.

Interpretation: at both YELL2 and MEVE1, reductions in U.S. anthropogenic contributions between 2002 Hindcast and RepBase2 are primarily due to reductions in AmmSO4 and OMC. At YELL2, reductions projected to occur between RepBase2 and 2028OTBa2 are primarily due to reductions in AmmNO3. At MEVE1, reductions in U.S. anthropogenic contributions between RepBase2 and 2028OTBa2 are projected due to small reductions in AmmNO3 and AmmSO4.

Figure 20a. U.S. Anthropogenic Contributions to Speciated Aerosol Light Extinction for the 2002 Hindcast, RepBase2, and 2028OTBa2 model scenarios for most impaired days at Yellowstone National Park (YELL2) IMPROVE monitor. TSS Modeling Express Tool # 7

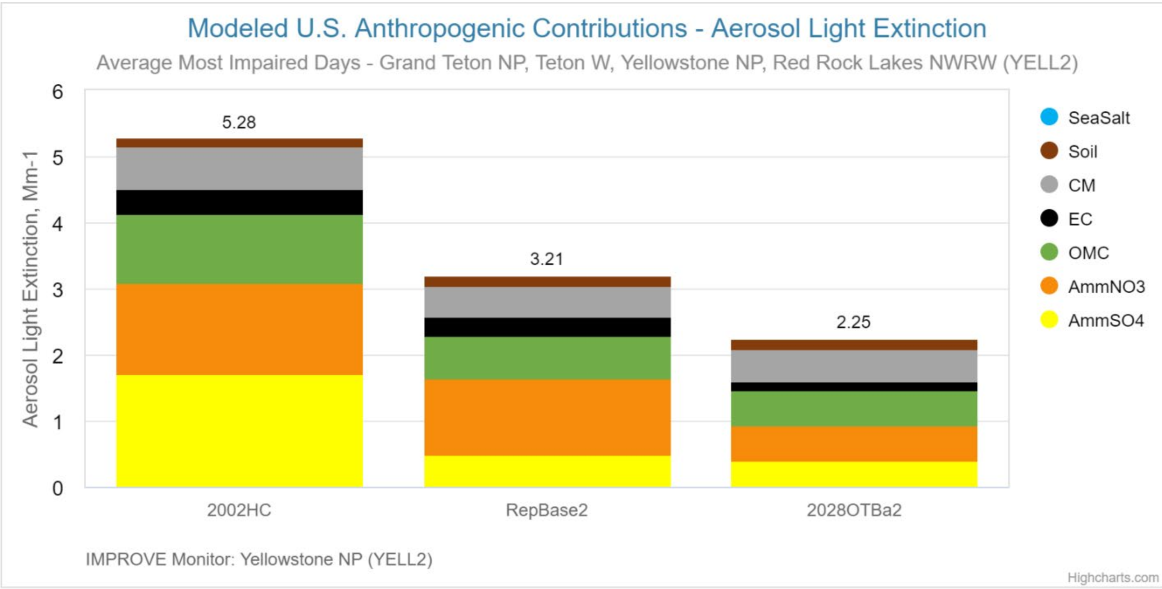
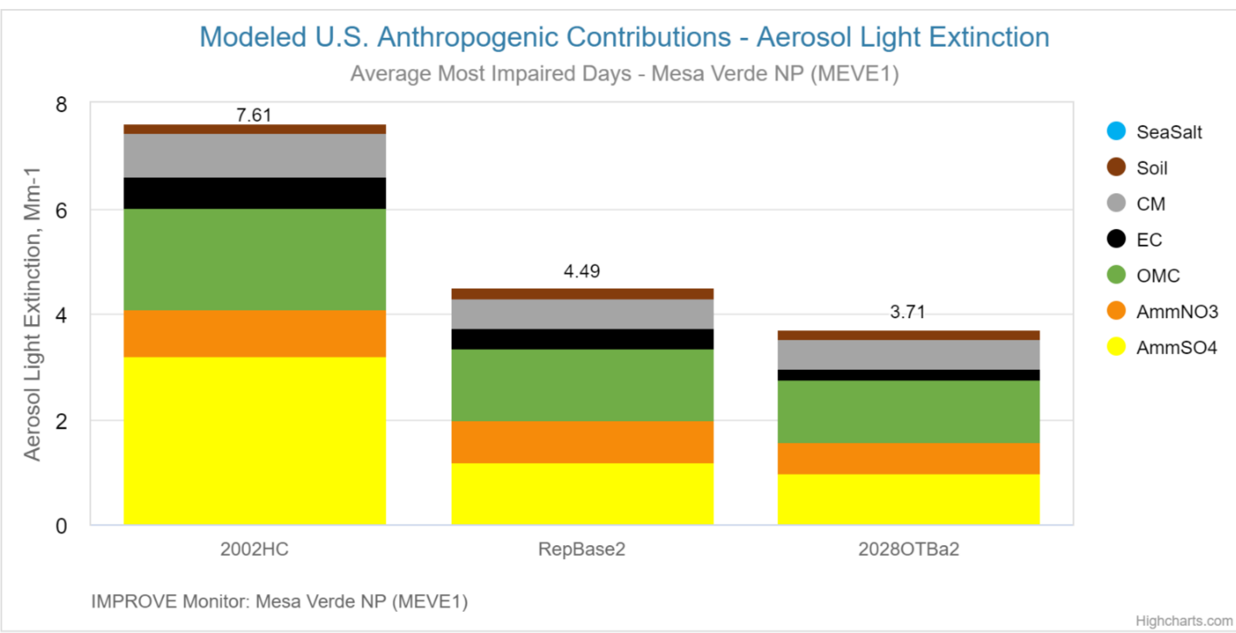


Figure 20b. 2028 U.S. Anthropogenic Contributions to Speciated Aerosol Light Extinction for the 2002 Hindcast, RepBase2, and 2028OTBa2 model scenarios for most impaired days at Mesa Verde National Park (MEVE1) IMPROVE monitor. TSS Modeling Express Tool # 7



15.0 Future Fire Sensitivities

Future fire sensitivities added wildfire emissions (FFS1) or wildland prescribed fire emissions (FFS2) as two potential future variations in fire activity that are not specific to any single future year. The fire sensitivities are added to the 2028OTBa2 reference case scenario to replace historic fire emissions used in the RepBase2 and 2028OTBa2 scenarios. All other 2028OTBa2 emissions: U.S. anthropogenic, international, natural, and non-US fire emissions are held constant. The only differences between the 2028OTBa2 and the fire sensitivities are due to the FFS1 and FFS2 assumptions.

- **FFS1** examines the effects of potential future changes in the timing, frequency, and intensity in terms of acres burned for **wildfires** compared to the Representative Baseline fires.
- **FFS2** examines the effects of potential future enhanced forest management practices defined as increases in **wildland prescribed burns**.

Emissions development of the future fire sensitivities is described in the Air Sciences, Inc. report Fire Emissions Inventories for Regional Haze Planning: Methods and Results (April 2020).

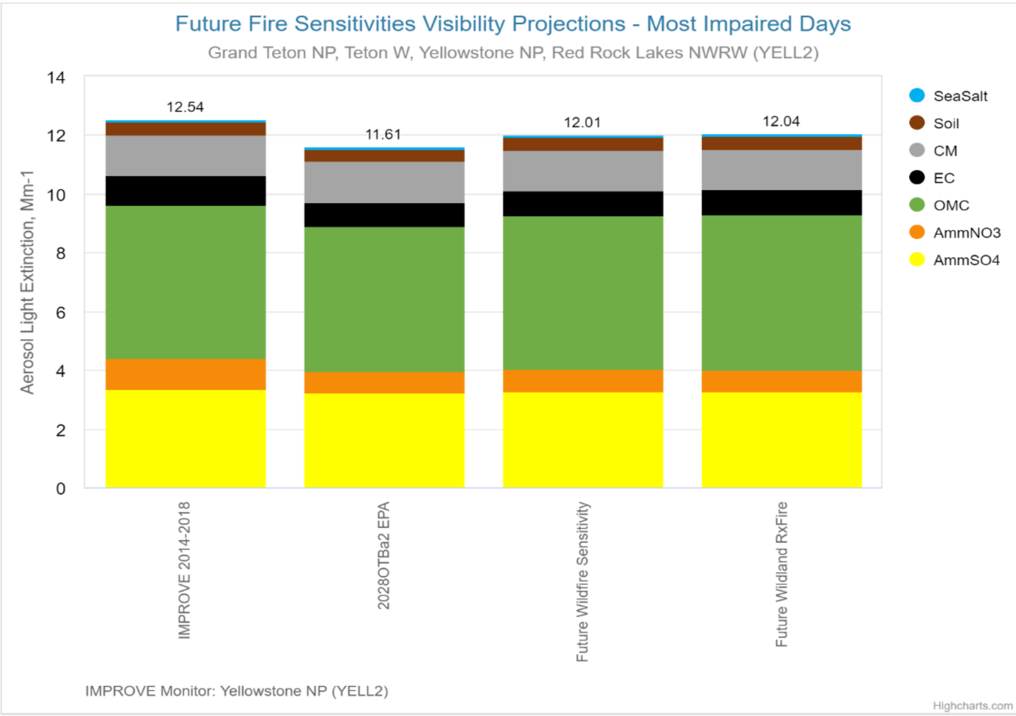
Modeling procedures are detailed in the run specification sheet for the Future Fire Simulations (August 2021).

TSS Modeling Express Tool # 18, illustrated in **Figures 21a and 21b**, displays IMPROVE 2014-2018 aerosol light extinction (Mm^{-1}) compared to the 2028 visibility projections for the 2028OTBa2, Future Wildfire Sensitivity, and Future Wildland Prescribed Fire Sensitivity scenarios for the IMPROVE monitors at Yellowstone (YELL2) and Mesa Verde (MEVE1) National Parks, respectively.

In TSS Modeling Express Tool # 18, fire sensitivities have been processed through the EPA Software for Modeled Attainment Test (normalized to IMPROVE 2014-2018 observations) to test the impact of changing fire regimes on 2028 regional haze visibility projections. The fire sensitivities for wildfire and wildland prescribed fire are compared to the 2028OTBa2 visibility projections for most impaired days or clearest days.

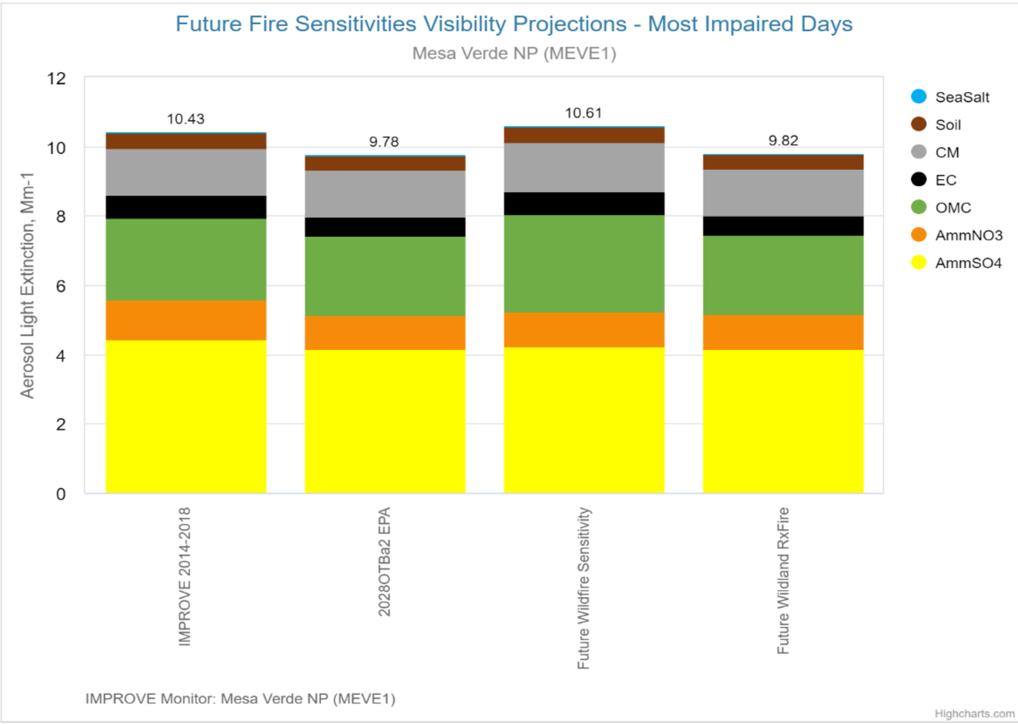
Interpretation: Added fire activity does not necessarily occur on 2014 IMPROVE most impaired days. The impacts of changing fire activity on the regional haze metrics are site-specific and may be small. IMPROVE 2014-2018 observations are included in TSS Modeling Express Tool #18 as the baseline data used with the relative response factors to calculate the 2028 visibility projections. At YELL2 (**Figure 21a)**, the 2028OTBa2 visibility projection shows small decreases in AmmNO3, OMC, and EC compared to 2014-2018 observations. The Future Wildfire Sensitivity and the Future Wildland Prescribed fire sensitivity show minor increases in OMC that can be attributed to changes in fire activity on some most impaired days in these sensitivities.

Figure 21a. IMPROVE 2014-2018 aerosol light extinction (Mm^{-1}) compared to the 2028 visibility projections (following EPA guidance) for the 2028OTBa2, Future Wildfire Sensitivity, and Future Wildland Prescribed Fire Sensitivity scenarios for most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor. TSS Modeling Express Tool # 18



At MEVE1 (**Figure 21b**), OMC is a smaller contributor on most impaired days than at YELL2. 2028OTBa2 visibility projection shows small decreases in AmmSO4 and AmmNO3 compared to the 2014-2018 IMPROVE observations. OMC increases in the Future Wildfire sensitivity indicating increased fire emissions on some most impaired days for this sensitivity. OMC is little changed in the Future Wildland Prescribed fire sensitivity compared to 2028OTBa2.

Figure 21b. IMPROVE 2014-2018 aerosol light extinction (Mm^{-1}) compared to the 2028 visibility projections (following EPA guidance) for the 2028OTBa2, Future Wildfire Sensitivity, and Future Wildland Prescribed Fire Sensitivity scenarios for most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor. TSS Modeling Express Tool # 18



TSS Modeling Express Tool # 19, illustrated in **Figures 22a and 22b**, displays absolute model results (not adjusted to IMPROVE observations) for 2028OTBa2 and the future fire sensitivities as monthly averages for all IMPROVE sample collection days. This chart illustrates when changes in wildfire or wildland prescribed fire activity are projected to occur and how the changes affect visibility compared to the 2028OTBa2 fire assumptions. These results are not 2028 visibility projections (adjusted to IMPROVE data) for regional haze planning purposes.

Interpretation: at YELL2 (**Figure 22a**) in several months there are small differences in AmmSO4, AmmNO3, and OMC between the 2028OTBa2 scenario and the Future Fire Sensitivities. The Future Wildfire Sensitivity is higher than 2028OTBa2 in July, September and October, while the Future Wildland Prescribed Fire Sensitivity is higher in January, February, April, May, October, and November. Not all the fire activity changes occurred on most impaired days so the impacts on the 2028 visibility projections are small.

Figure 22a. Monthly average aerosol extinction (Mm^{-1}) for the 2028OTBa2, Future Wildfire Sensitivity, and Future Wildland Prescribed Fire Sensitivity scenarios for most impaired days at the Yellowstone National Park (YELL2) IMPROVE monitor. TSS Modeling Express Tool # 19

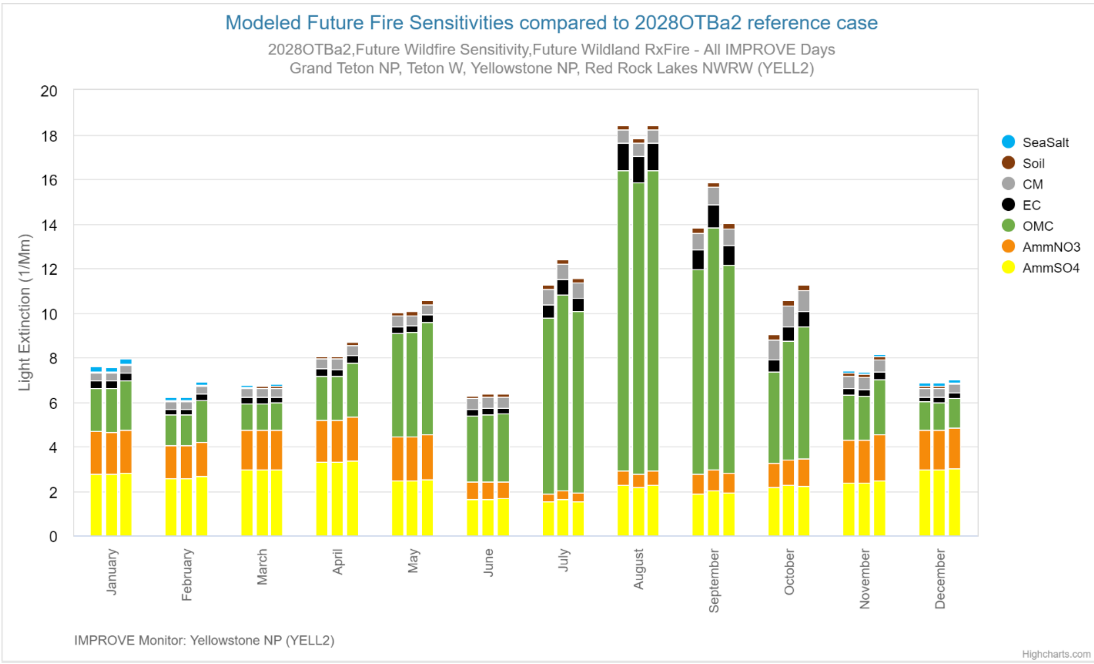
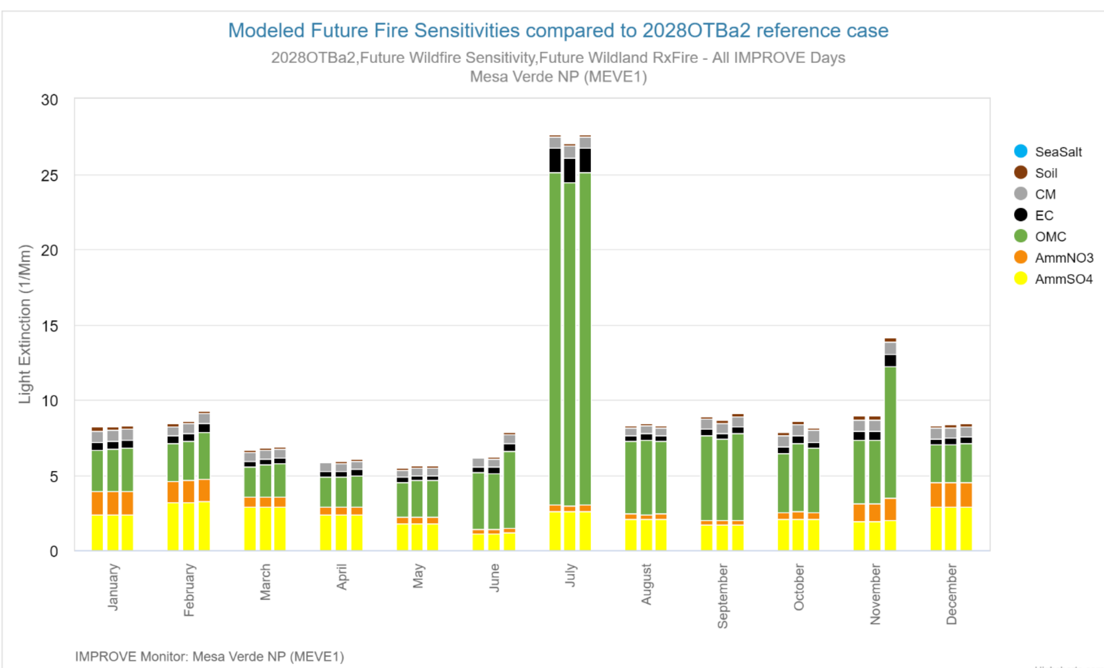


Figure 22b. Monthly average aerosol extinction (Mm^{-1}) for the 2028OTBa2, Future Wildfire Sensitivity, and Future Wildland Prescribed Fire Sensitivity scenarios for most impaired days at the Mesa Verde National Park (MEVE1) IMPROVE monitor. TSS Modeling Express Tool # 19

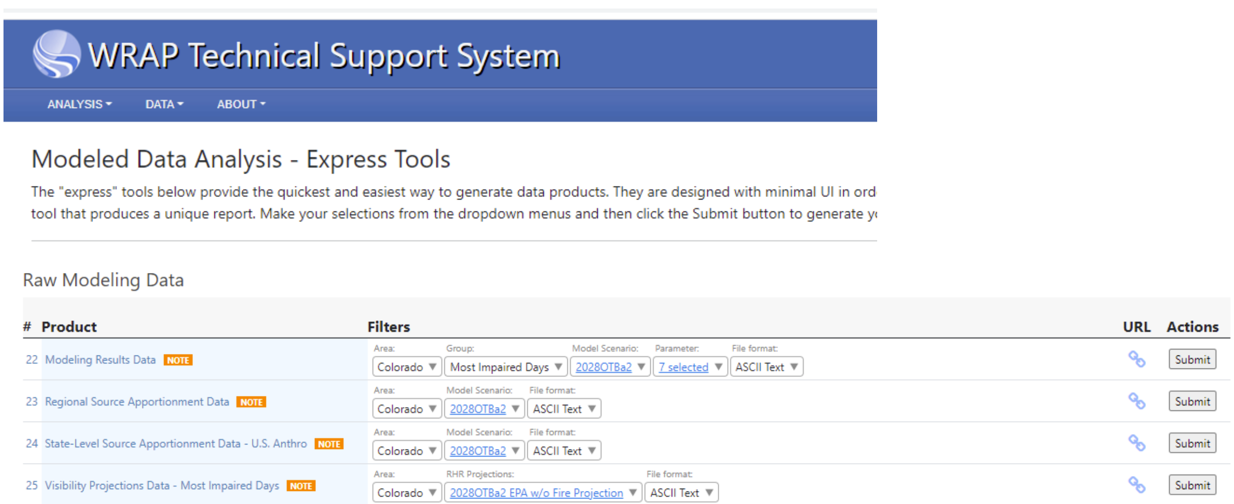


At MEVE1 (**Figure 22b**) the Future Wildfire Sensitivity shows very slight monthly differences compared to the 2028OTBa2 scenario, even though the Future Wildfire visibility projection has slightly higher OMC than the 2028OTBa2 projection (**Figure 21b**). This suggests that wildfire activity added on a few most impaired days was offset by decreased wildfire activity on other days in the monthly averages. The Future Wildland Prescribed Fire Sensitivity in June and November show slightly higher OMC than 2028OTBa2, but little change in the 2028 visibility projection.

At some western Class I areas, the added future fire sensitivities have larger impacts than seen as these two sites. Fires will continue to be a major contributor to haze in western states, however the regional haze tracking metric may not be the best measure of changes in future fire activity.

16.0 Modeling Data files

Raw modeling data files can be downloaded from the TSS Modeling Express Tools #22-25 as illustrated below. Data are sorted by geographic area, by IMPROVE data groups, Model scenarios, pollutant parameters, and regional haze projection methods. Data can be downloaded as ASCII text, Microsoft Excel, or JSON format.



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(no new citations in Sections 9.0-15.0)