SPECIFICATION SHEET

FUTURE FIRE SENSITIVITY SIMULATIONS

WRAP Regional Haze Modeling Study
August 3, 2021

Run Names:	**Future Fire Scenario 1 (FFS1)** **Future Fire Scenario 2 (FFS2)**
Model:	CAMx v7.0
Domains:	36US1 and 12WUS2 two-way nesting (see Figure 1)
Period:	Representative Baseline with 2014 annual period meteorology
Emissions:	2028OTBa2 with only fire emissions changed and tested separately (wildfire, wildland prescribed fire)
Boundary Conditions:	WRAP Revised 2014 GEOS-Chem Base Case
Source Apportionment:	None, brute force sensitivity scenarios
Purpose:	To analyze visibility effects of possible future fire activity changes from climate change (wildfire) and land management (wildland prescribed fire) perspectives, respectively. The modeled results are intended to provide bounding estimates of future visibility if these scenarios were to occur, compared to the 2028OTba2 reference case.

BACKGROUND

The Western Regional Air Partnership (WRAP[1]) Fire and Smoke Work Group (FSWG[2]) has developed four sets of fire emissions to be modeled for the WRAP 2014-based Regional Haze modeling platform that uses the Comprehensive Air-quality model with extensions (CAMx[3]) photochemical grid model. The WRAP Workplan (updated April 2019)[4] identifies that fire emissions, both natural and anthropogenic, are important pollution sources across the western U.S. and are expected to increase in intensity, area burned, and duration for a variety of reasons, including accumulated fuels, climate change, drought, and other factors. Estimating and tracking fire emissions will improve the understanding of the role of fire and smoke in NAAQS attainment and for Regional Haze planning, both now and in the future. Modeling a range of future fire emissions will help visualize potential future impacts from this sector.

[1] https://www.wrapair2.org/
[2] Fire & Smoke Work Group (wrapair2.org)
[3] http://www.camx.com/
[4] 2018-2019 WRAP Workplan update Board Approved April.3.2019.pdf (wrapair2.org)

2014 actual wildfires and wildland prescribed fires were used in the CAMx 2014v2 base case simulation for the model performance evaluation.[5] The FSWG also developed Representative Baseline fire emissions for wildfire that were used with the CAMx Representative Baseline (RepBase2) scenario to represent the fires for the 2014-2018 5-year planning period. The 2014 actual wildland prescribed fire emissions were used without change in the RepBase2 scenario. The fire emissions from the RepBase2 scenario were also used without changes in the 2028 On-the-Books (2028OTBa2) future year modeling scenario[6]. The 2028OTBa2 reference case scenario holds fire emissions constant with the past and is the basis of visibility Reasonable Progress Goals calculated following EPA technical guidance[7] and augmented by procedures developed by the WRAP[8].

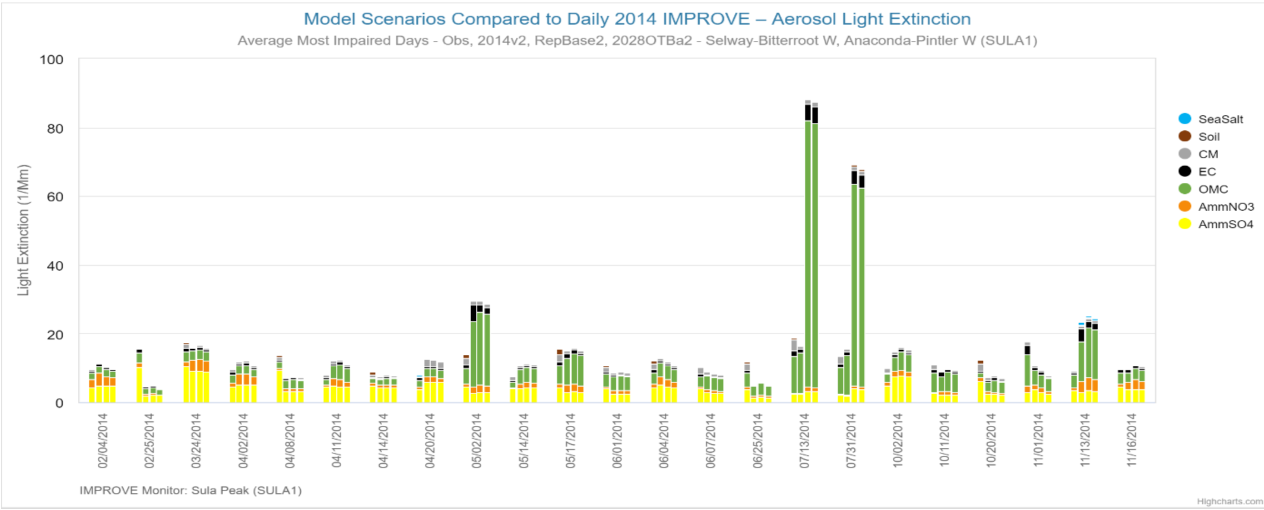
REPRESENTATIVE BASELINE AND 2028 ON THE BOOKS (2028OTBa2) WILDFIRE EMISSIONS

Details on the development of the fires for the WRAP 2014 modeling platform modeling can be found in the Air Sciences, Inc. report "Fire Emissions Inventories for Regional Haze Planning: Methods and Results."[9] Air Sciences, Inc. developed historical wildfire probability distributions for ecoregions across the continental U.S. using the Forest Service Research Data Archive (FSRDA[10]) which covers the period 1992–2015 and includes wildfire events on all federal lands as well as some state-reported wildfire events. Using these historic probability distributions, a RepBase2 population of wildfire events was generated where the number of wildfires, distribution of wildfire sizes, wildfire-start months, and burn durations for each ecoregion were randomly selected. The RepBase2 wildfire events' timing of occurrence and locations were the same as 2014 fire occurrences. Emissions were then estimated for CO_2, CO, CH_4, NMOC, NO_x as NO, SO_2, $PM_{2.5}$, OC, BC, NH_3, NO_2, and PM_{10}, and applied in the modeling scenarios.

The RepBase2 wildfire events may not occur on the most impaired days that are used as the regional haze tracking metric. This can be evaluated using the WRAP Technical Support System Modeling Express Tools Chart #2 which illustrates aerosol extinction for 2014 IMPROVE most impaired days monitoring data and the 2014v2, RepBase2, and 2028OTBa2 model scenarios. For example in Figure 1, at the SULA1 IMPROVE monitoring site that represents the Selway-Bitterroot and Anaconda-Pintler Wilderness Areas, organic carbon is a large fraction of total extinction on most impaired days. Additional organic carbon occurs in the RepBase2 and 2028OTBa2 scenarios on two most impaired days in July that is not seen in the 2014 IMPROVE data or the 2014v2 scenario. This additional organic carbon is an example of the aerosol response to a change in wildfire activity in the RepBase2/2028OTBa2 scenarios.

[5] IWDW WRAPWAQS2014v2MPE (colostate.edu)
[6] IWDW WAQS 2014v2 Specification Sheets (colostate.edu)
[7] EPA Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, PM2.5, and Regional Haze (final- November 2018)
[8] Procedures for Making Visibility Projections and Adjusting Glidepaths using the WRAP-WAQS 2014 Modeling Platform (March 1, 2021, final draft)
[9] https://www.wrapair2.org/pdf/fswg_rhp_fire-ei_final_report_20200519_FINAL.PDF
[10] https://www.fs.usda.gov/rds/archive/

Figure 1. Model Scenarios compared to daily 2014 IMPROVE observations in aerosol light extinction from TSS Modeling Express Chart 2.



FUTURE FIRE SENSITIVITY EMISSIONS

Emissions for two "no specific year" Future Fire Scenarios (FFS) with the same emissions species types were developed for use with the 2028OTBa2 emissions for all other source categories to create future year visibility modeling results to help bound and understand the effects of potential future changes in wildland fires on visibility at Class I areas (CIAs). The wildfire FFS was developed at ecoregion level (maps in Figure 2); results are then shown in Figure 3. The FFS' are not intended to specifically represent fire activity or associated emissions in the year of 2028. The two Future Fire Scenarios are:

- **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**.

Figure 2. Ecoregions used to map fire activity changes in FFS1 and FFS2.

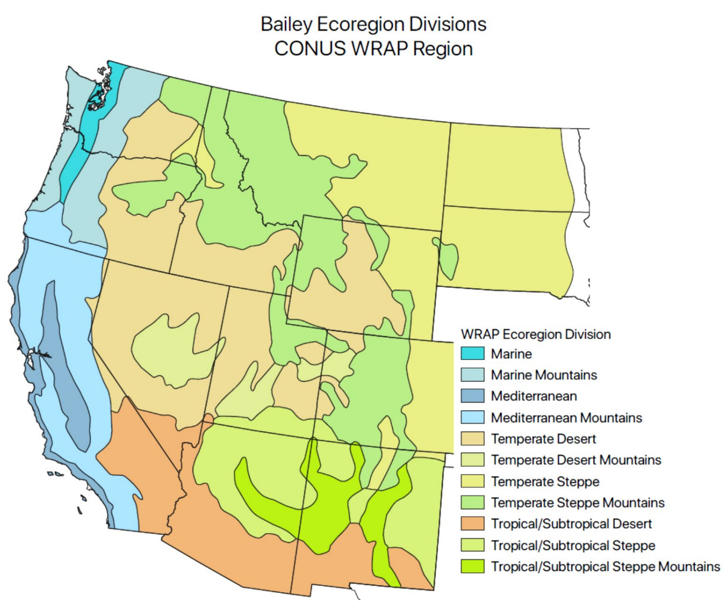
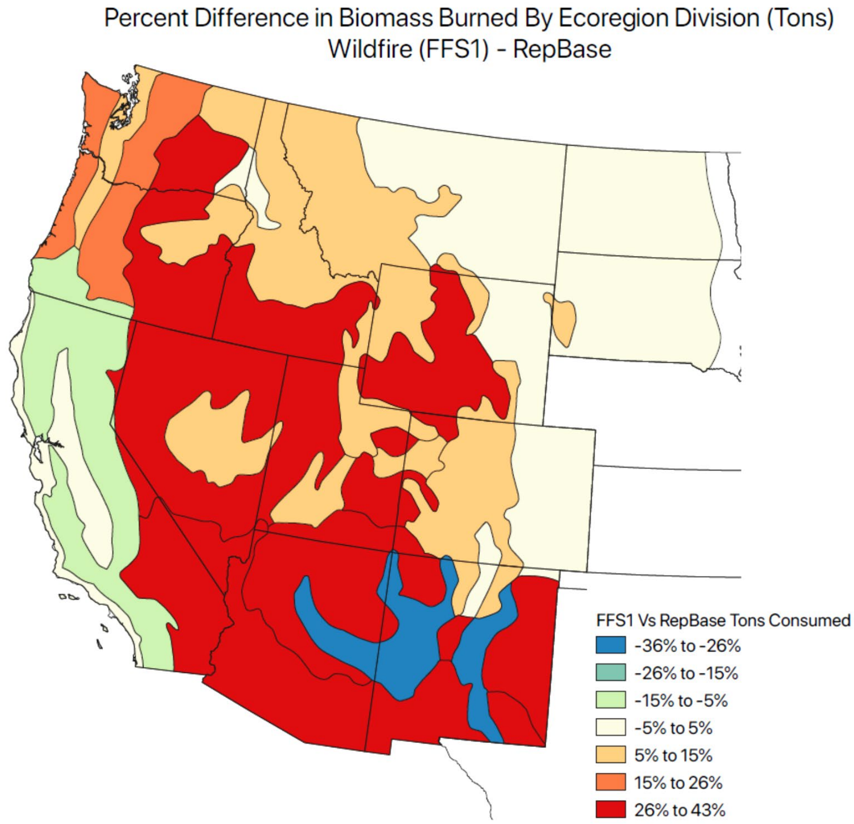
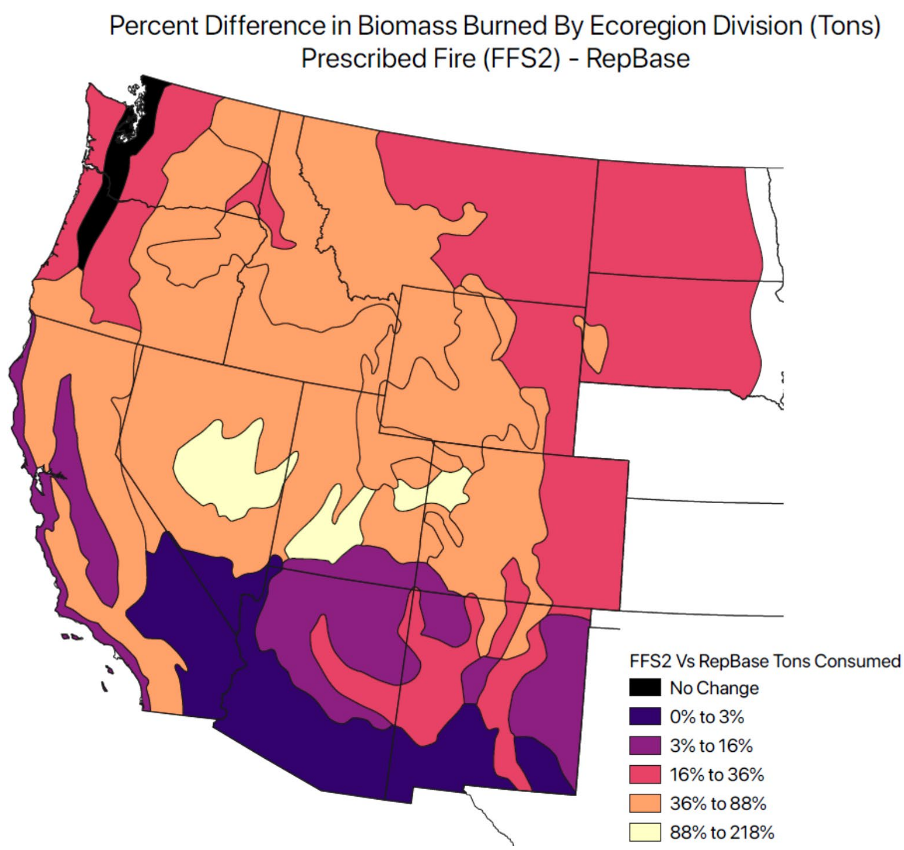


Figure 3. Ecoregion maps showing changes in wildfire (top) and wildland prescribed fire (bottom) emissions relative to Representative Baseline fire emissions for each of these 2 source types.

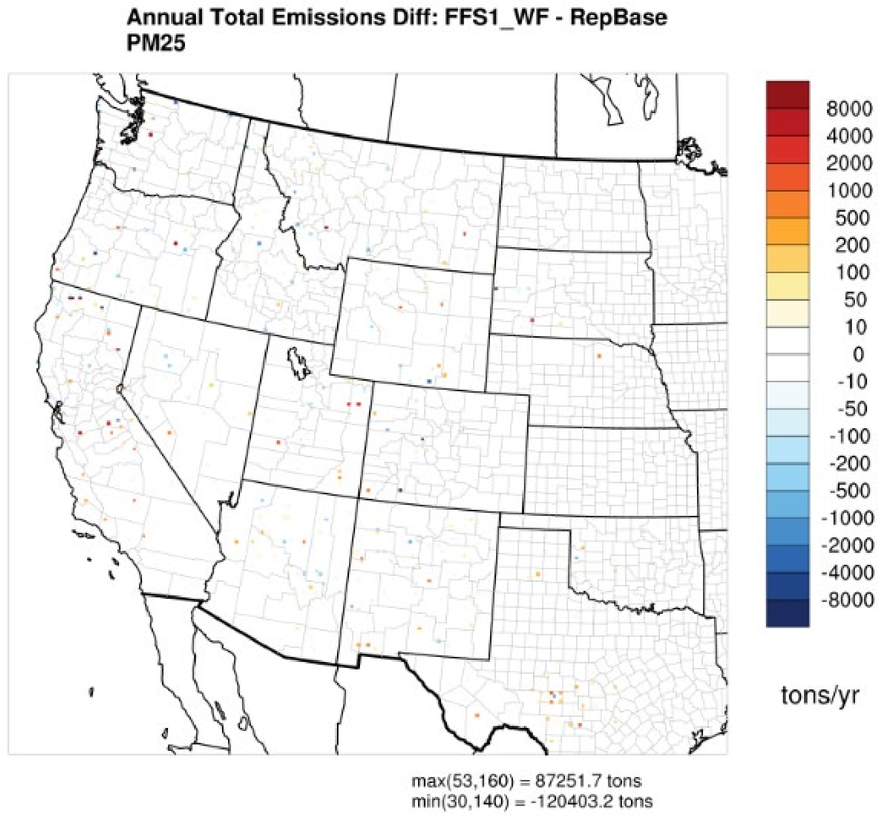


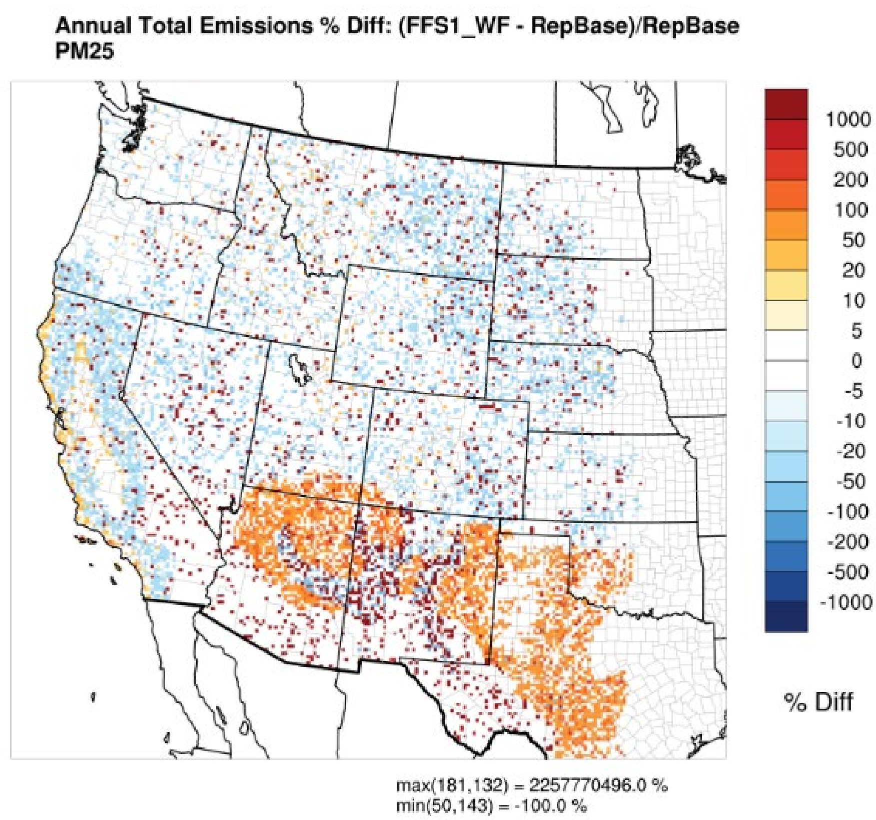


FFS1 only changed the emissions for wildfires with wildland prescribed burns and agricultural burning left identical to the Representative Baseline fires. For the FFS1 sensitivity, a separate population of wildfire events was generated with a different distributions of component fire characteristics from Representative Baseline wildfires. The FFS1 and Representative Baseline fire distributions were rank ordered and spatially matched. The FFS1 fires were scaled to 2028 using ecoregion-specific growth factors from Yue, Xu, et al., 2013.[11] In FFS1, there are both increases and decreases in the geographic extent of wildfires, as illustrated in Figure 4, compared to Representative Baseline wildfires. The dates of the future wildfires are independent of the dates of the 2014 actual fires and may not occur on the most impaired days used for the regional haze tracking metric.

[11] Yue, Xu, et al. 2013. "Ensemble projections of wildfire activity and carbonaceous aerosol concentrations over the western United States in the mid-21st century." Atmospheric Environment 77 (2013): 767-780

Figure 4. Annual grid cell $PM_{2.5}$ emissions changes for FFS1 wildfire minus Representative Baseline total all sources, changing only wildfire emissions. Results in tons (top) and percent (bottom).

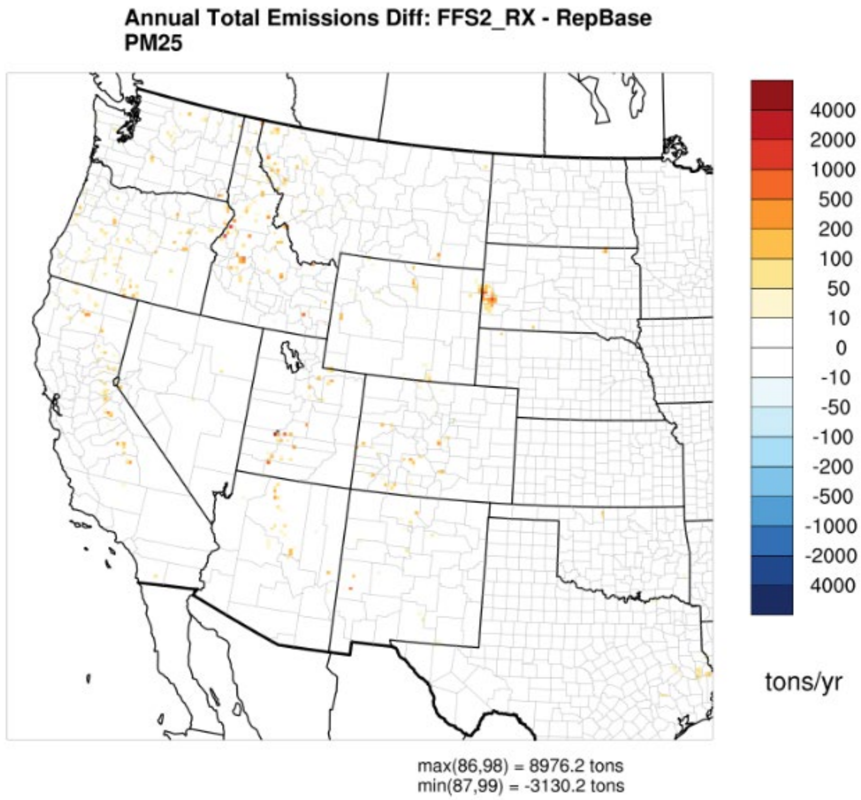


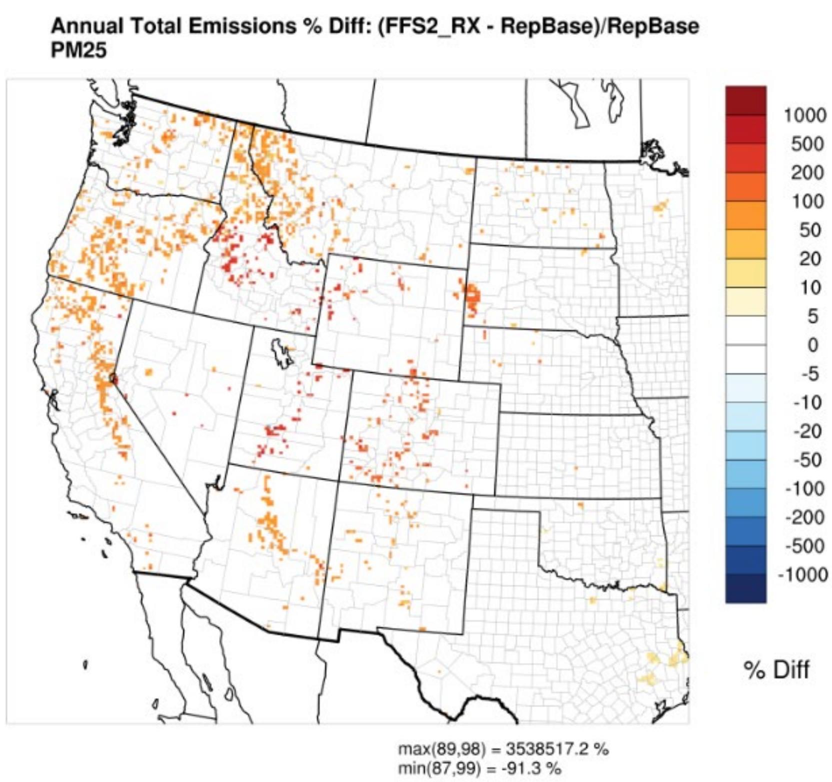


Likewise, FFS2 only changed wildland prescribed burns with wildfires and agricultural burning left unchanged from the Representative Baseline. For the FFS2 sensitivity, the location of each prescribed fire event in the Representative Baseline dataset was assigned to a geographic ecoregion and scaled by ecoregion to adjust the acres for that event. Emissions were then recalculated using the new acres value. All other aspects of the Representative Baseline fire dataset were left intact. The dates of the future wildland prescribed fires are the same as the dates of the 2014, RepBase2, and 2028OTBa2 representative wildfires however the magnitude of emissions increase. Future wildland prescribed fires may not occur on the 2014 most impaired days that are used for the regional haze tracking metric.

The differences between FFS2 and Representative Baseline wildland prescribed burns $PM_{2.5}$ emissions are illustrated in Figure 5.

Figure 5. Annual grid cell $PM_{2.5}$ emissions changes for FFS2 wildland prescribed fire minus Representative Baseline total for all sources, changing only wildland prescribed fire emissions. Results in tons (top) and percent (bottom).





ACTIVITY AND EMISSIONS DIFFERENCES

Table 1. Comparison of fire emissions for the Wildfire (FFS1) modeling sensitivity scenario, relative to historic fire data held constant in RepBase2/2028OTBa2 scenarios by fire event, acres burned, and tons of fuel consumed and $PM_{2.5}$ emissions, and percent differences.

	Wildfire (FFS1)				RepBase2 / 2028OTBa2				Percent Difference			
State	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$
AZ	2,461	278,146	565,862	7,168	2,810	219,779	554,371	7,238	-12%	27%	2%	-1%
CA	6,502	1,058,201	29,353,059	434,630	7,004	822,112	30,274,941	450,970	-7%	29%	-3%	-4%
CO	1,816	88,746	1,343,955	19,970	2,103	209,106	6,014,389	89,965	-14%	-58%	-78%	-78%
ID	1,908	350,939	1,333,867	17,495	2,082	331,911	2,977,946	42,601	-8%	6%	-55%	-59%
MT	3,016	585,817	5,645,173	75,799	3,443	345,932	3,368,691	43,866	-12%	69%	68%	73%
NV	1,233	221,413	730,140	9,169	1,540	268,607	643,098	7,437	-20%	-18%	14%	23%
NM	3,298	914,977	1,116,799	11,131	4,418	543,192	893,910	9,760	-25%	68%	25%	14%
ND	317	7,582	89,675	784	377	8,007	90,876	774	-16%	-5%	-1%	1%
OR	2,453	822,417	16,240,735	239,672	2,583	558,944	10,731,358	157,441	-5%	47%	51%	52%
SD	740	292,610	4,146,708	43,847	891	321,681	4,649,179	49,242	-17%	-9%	-11%	-11%
UT	1,194	478,045	1,771,838	24,057	1,382	295,023	1,257,384	17,174	-14%	62%	41%	40%
WA	1,500	243,934	12,817,841	192,062	1,566	184,553	9,378,215	140,516	-4%	32%	37%	37%
WY	2,187	347,097	1,065,757	10,175	2,478	367,253	1,098,031	10,982	-12%	-5%	-3%	-7%
Total	28,625	5,689,923	76,221,409	1,085,959	32,677	4,476,101	71,932,389	1,027,966	-12%	27%	6%	6%

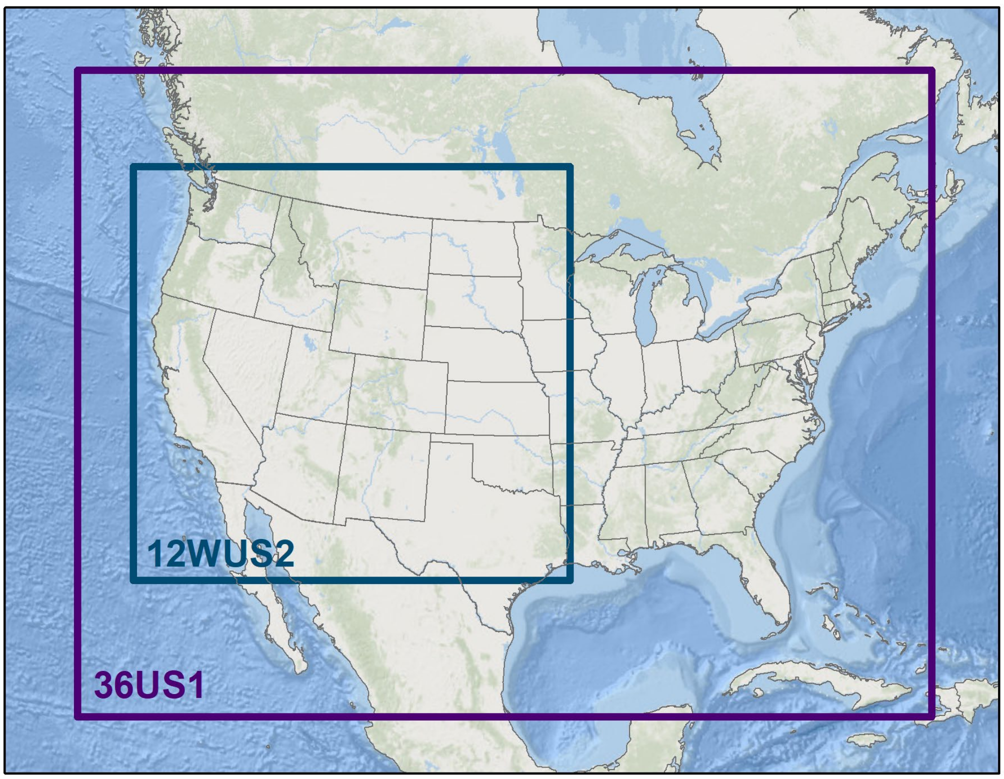
Table 2. Comparison of fire emissions for the Wildland Prescribed fire (FFS2) modeling sensitivity scenario, relative to historic fire data held constant in RepBase2/2028OTBa2 scenarios by fire event, acres burned, and tons of fuel consumed and $PM_{2.5}$ emissions, and percent differences.

	Prescribed Burning (FFS2)				RepBase2 / 2028OTBa2				Percent Difference			
State	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$	Events	Acres	Tons Fuel Consumed	Tons $PM_{2.5}$
AZ	595	185,102	1,239,269	18,491	595	141,195	907,285	13,533	0%	31%	37%	37%
CA	993	184,688	3,280,671	48,672	993	130,965	2,197,780	32,518	0%	41%	49%	50%
CO	374	88,032	983,959	14,674	374	48,732	475,867	7,070	0%	81%	107%	108%
ID	1,824	268,469	3,600,038	53,594	1,824	137,990	1,905,385	28,367	0%	95%	89%	89%
MT	1,480	201,931	2,507,741	35,679	1,481	161,093	1,837,448	25,822	0%	25%	36%	38%
NV	95	22,369	130,444	1,872	95	16,270	72,430	1,013	0%	37%	80%	85%
NM	258	113,215	745,557	11,039	258	88,247	511,013	7,530	0%	28%	46%	47%
ND	214	47,591	232,775	2,375	214	39,193	197,939	2,013	0%	21%	18%	18%
OR	2,525	378,621	5,298,344	77,827	2,525	302,136	4,218,348	61,808	0%	25%	26%	26%
SD	394	112,840	2,287,843	33,795	394	64,568	1,062,962	15,449	0%	75%	115%	119%
UT	224	220,746	1,565,240	22,939	224	71,512	486,573	7,116	0%	209%	222%	222%
WA	1,278	147,728	1,890,834	28,087	1,278	123,228	1,540,525	22,864	0%	20%	23%	23%
WY	283	70,749	867,832	12,624	283	43,306	421,667	6,021	0%	63%	106%	110%
Total	10,537	2,042,079	24,630,545	361,670	10,538	1,368,436	15,835,221	231,125	0%	49%	56%	56%

MODELING DESCRIPTION

The remainder of this document describes how the CAMx modeling was performed for the FFS1 and FFS2 fire sensitivity scenarios and how the results were analyzed. The WRAP/WAQS 36-km 36US1 and 12-km 12WUS2 CAMx modeling domains are illustrated in Figure 6. Except for wildfire (FFS1) and wildland prescribed fire (FFS2) emissions, the CAMx 2028OTBa2 FFS1 and FFS2 fire sensitivity modeling scenarios used the same emissions as the 2028OTBa2 scenario that is described in the RepBase2/2028OTBa2 Run Specification Sheet referenced in Footnote 6 above. The meteorological conditions, anthropogenic and natural emissions (i.e., biogenic, lightning NOx, oceanic and windblown dust) and boundary conditions (BCs) were held constant at 2014v2 actual levels.

Figure 6. WRAP/WAQS 36-km 36US1 and 12-km 12WUS2 modeling domains used in the WRAP 2014v2, RepBase2, 2028OTBa2 and 2028OTBa2 FFS1 & FFS2 CAMx simulations.



WILDFIRE (FFS1) AND WILDLAND PRESCRIBED FIRE (FFS2) POSTPROCESSING PROCEDURES

For the Fire Sensitivities, of the three different WRAP procedures for projecting the observed 2014-2018 IMPROVE Most Impaired Days (MID) visibility to the 2028 future year[12], WRAP is using only the EPA default projection procedures to analyze the FFS1 and FFS2 modeling results. Here is a summary of the three projection procedures:

- EPA: Using the EPA default projection procedures using species-specific Relative Response Factors (RRFs) based on the ratio of 2028 to RepBase2 modeling results on the 2014 IMPROVE MIDs.

[12] Procedures for Making Visibility Projections and Adjusting Glidepaths using the WRAP-WAQS 2014 Modeling Platform (March 1, 2021, final draft)

- EPAwoF: The EPA without fire method is like the default EPA method only the RRFs use modeling results without any fire (WF, Rx and Ag) contributions, as determined by source apportionment[13].
- ModMID: RRFs are based on the RepBase2 modeled 20% days with the highest U.S. anthropogenic emissions impairment and also do not use fire contributions like EPAwoF; both are determined by source apportionment.

The EPAwof and ModMID visibility projection approaches were not used for the 2028 fire sensitivity projections because the 2028OTBa2 FFS1 and FFS2 CAMx simulations are brute force sensitivity simulations and do not use source apportionment, so there is no way to remove fire contributions. By design, days in the IMPROVE MID are defined to greatly reduce the contributions of fires by removing the largest carbon-influenced sample days from the MID. Thus, making visibility projections for the 2028 Regional Haze Rule milestone planning year of the 2014-2018 IMPROVE MID using the results from 2028OTBa2 FFS1 and FFS2 scenarios may conflict with the strictest interpretation of what the Regional Haze Rule MID methodology is purported to accomplish, but holding fire emissions constant in the future is not scientifically valid or meaningful. Changes from the 2028OTBa2 visibility projections would be solely due to the increased or decreased sizes of the same RepBase2 fires used in the 2028OTBa2 FFS1 and FFS2 scenarios, which would occur on the same days as in the RepBase2 and 2028OTBa2 scenarios; the multi-day effects of large increases in wildfire and/or wildland prescribed fire emissions near one or more CIAs may be a concern.

FIRE SENSITIVITY RESULTS

Fire sensitivity model results are presented on the WRAP Technical Support System[14] (TSS) in Modeling Express Tools charts # 18 and 19 for each IMPROVE site representing CIAs in the 13 WRAP and neighboring states.

TSS Modeling Express Tool 18 presents 2028 visibility projections in aerosol extinction for the most impaired days, following EPA guidance, for the 2028OTBa2 reference case and the 2 fire sensitivities. 2028 Visibility projections are calculated using average relative response factors (2028 scenario modeled values divided by RepBase2 modeled values) for each aerosol species multiplied by the daily aerosol value for each most impaired day in the 2014-2018 IMPROVE record. The intent is to account for the relative change between the model scenarios by weighting or normalizing the modeled values to monitoring data. Differences between the 2028OTBa2 and the fire sensitivity projections demonstrate how changes in wildfire activity could affect the 2028 visibility projections using the regional haze tracking metric. If modeled carbon contribution doesn't change between the future fire sensitivity and RepBase2 on the most impaired days, then the relative response factor (future fire divided by RepBase2) equals 1 and the carbon contribution is little changed from the 2014-2018 observations for purposes of calculating the 2028 visibility projection. Because the modeled future fire activity may not occur on most impaired days, the regional haze tracking metric may not be the most useful measure of the impacts of the future fire activity.

TSS Modeling Express Tool 19 presents the monthly average extinction by aerosol species on the ~120 IMPROVE sampling days for the 2028OTBa2, FFS1 and FFS2 scenarios. These values are absolute model outputs and have not been adjusted to IMPROVE observations. The monthly average values indicate temporally when the fire

[13] High-Level and Low-Level Source Apportionment using the RepBase2 and 2028OTBa2 Emissions Scenarios

[14] WRAP TSS (colostate.edu)

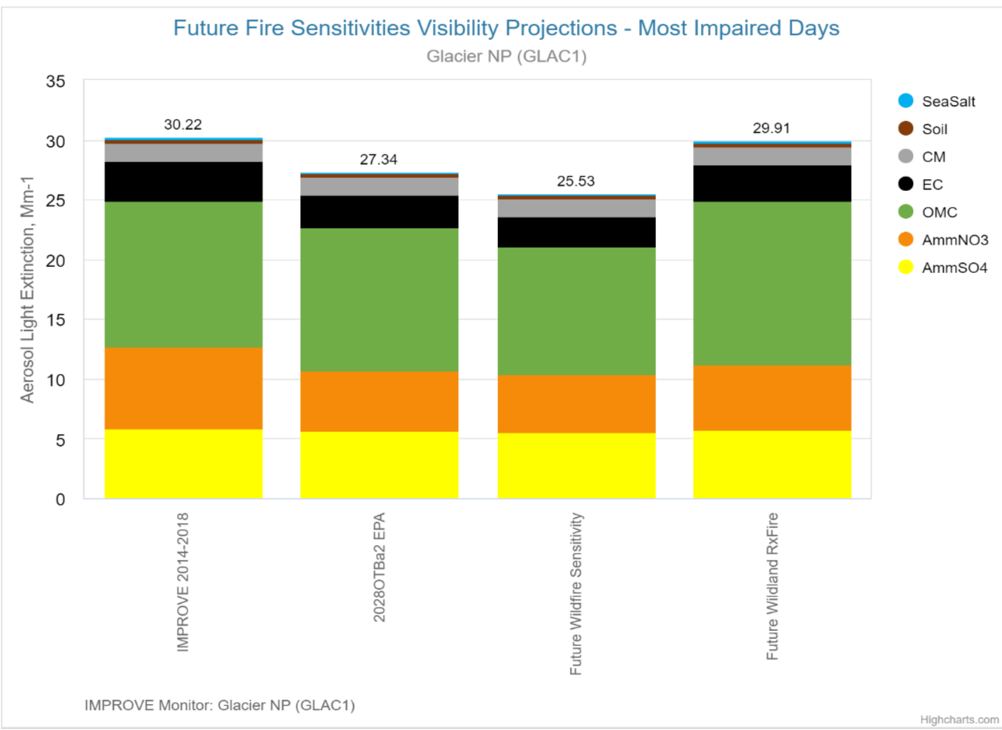
activity changes have the greatest impacts on visibility compared to the 2028OTBa2 reference case.

TSS Modeling Express Tool 20 allows users to download and compare daily modeling results data for all 365 modeling days at each western U.S. Class I area in the modeling year for these scenarios.

Below is an example analysis for Glacier National Park in Montana comparing the fire sensitivity results for 2028 visibility projections for the most impaired days to the monthly average absolute model outputs.

In Figure 7 (TSS Modeling Express Chart 18) Future Fire Sensitivities Visibility Projections for Glacier National Park (GLAC1) the 2028OTBa2 projection is compared to the Future Wildfire and Future Wildland Prescribed fire projection. The IMPROVE 2014-2018 average observations are shown as reference for the model projections. The only differences between the model scenarios are due to the fire activity assumptions. The Future Wildfire sensitivity indicates reduced fire contributions on the most impaired days compared to the 2028OTBa2 reference case, while the Future Prescribed Wildland Fire indicates increased fire contributions.

Figure 7. TSS Modeling Express Chart 18) Future Fire Sensitivities Visibility Projections (https://views.cira.colostate.edu/tssv2/Express/ModelingTools.aspx) for Glacier National Park (GLAC1)



In Figure 8 (TSS Modeling Express Chart 19) Monthly average aerosol extinction for all IMPROVE days, absolute modeled outputs (not adjusted to 2014-2018 IMPROVE observations) are compared for 2028OTBa2 and the two future fire sensitivities. In the case of Glacier National Park, carbon from the future wildfire sensitivity is reduced in July and October and increased in September compared to the 2028OTBa2 reference case. Carbon from the future wildland prescribed fire sensitivity is increased in May, September, October, and November compared to the 2028OTBa2 reference case.

Figure 8 TSS Modeling Express Chart 19 Monthly average aerosol extinction for all IMPROVE days at Glacier National Park (GLAC1)

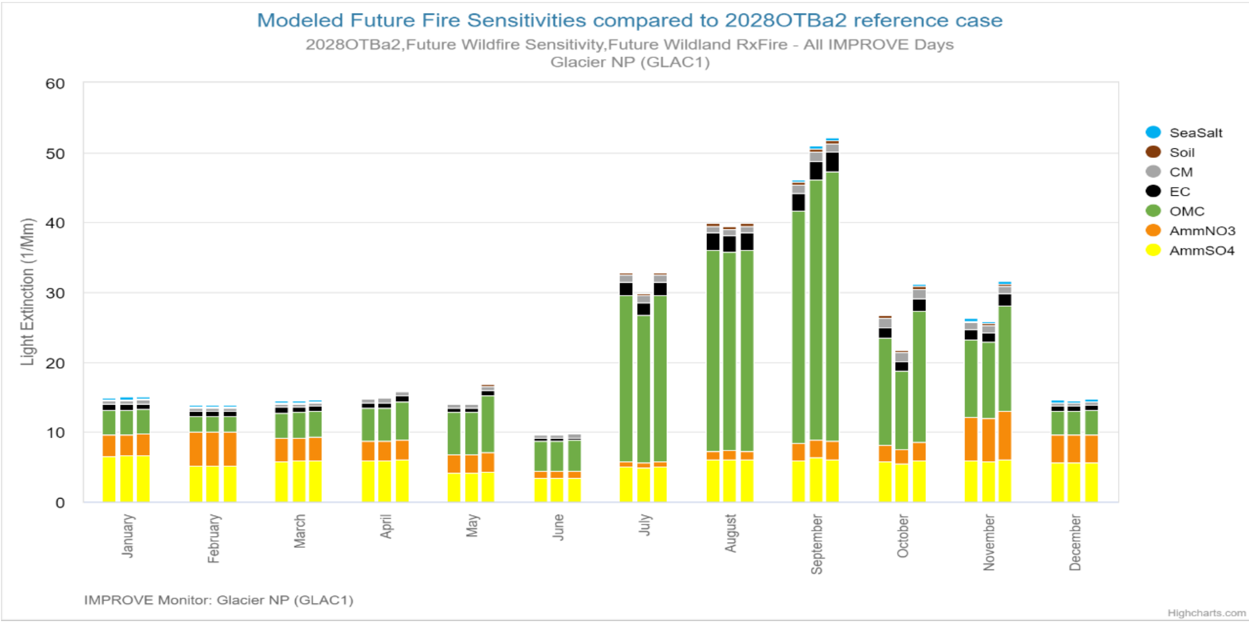
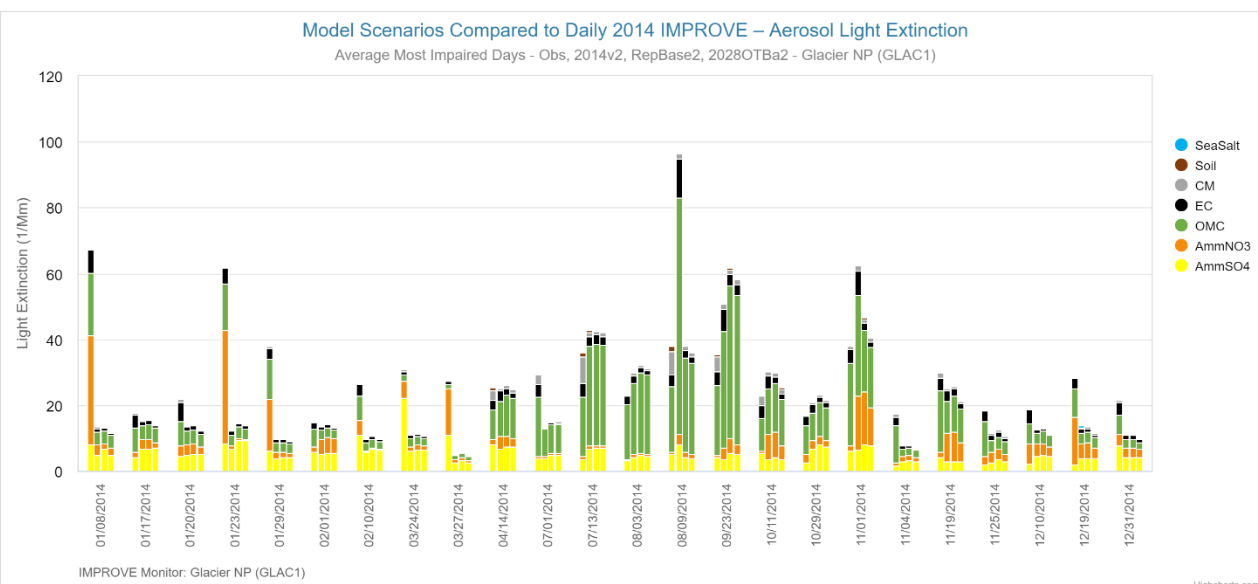


Figure 9 (TSS Modeling Express Chart 2, Model to Observations) is useful to understand the absolute model outputs on individual most impaired days for 2014v2, RepBase2, and 2028OTBa2, compared to monthly averages in Figure 8 (TSS Modeling Express Chart 19) above. At Glacier National Park carbon dominates 2014 IMPROVE most impaired days (left bar) in July through November. Model performance is fairly good for carbon (comparing 2014 IMPROVE observations to 2014v2 model scenario, second bar), except 08/09/2021 when carbon is overpredicted. RepBase2 and 2028OTBa2 carbon contributions are similar to 2014v2 for individual most impaired days. None of the most impaired days include extreme carbon values in the 2028OTBa2 scenario. Daily fire sensitivity results to compare to daily 2028OTBa2 scenario results in Figure 9 can be downloaded from the dataset posted in TSS Modeling Express Chart 20.

Figure 9. TSS Modeling Express Chart 2, Model to Observations for Glacier National Park (GLAC1)



We conclude that the regional haze metric is not the most useful way to look at the impact of changing fire regimes in the future. The monthly average aerosol extinction as illustrated in Chart 8 (TSS Modeling Express Chart 19) is a better way to convey the timing and magnitude of the fire sensitivities changes from the 2028OTBa2 reference case fire assumptions. Note that fire activity for RepBase and the future fire sensitivities was randomly generated. Repeating the future fire emissions methodology would result in a different set of fire assumptions.