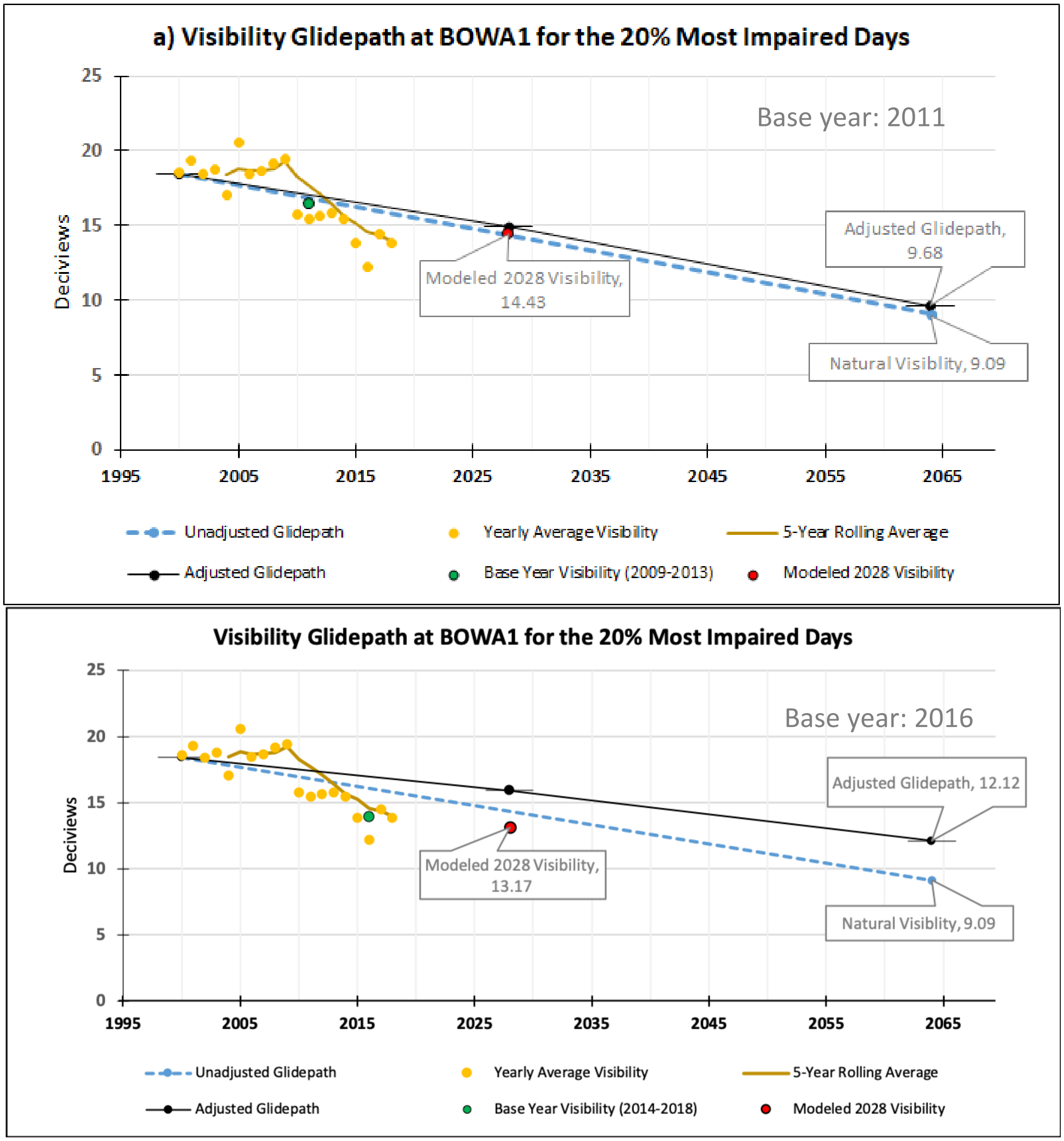


Figure 7-1. Visibility glidepath at BOWA1 IMPROVE site for the 20% most impaired days based on the (a) 2011 based 2028 prediction and (b) the 2016 based 2028 prediction[28].

[28] Note that the adjusted glidepath for the 2011 based prediction is accounted only the contribution from Mexico & Canada anthropogenic emissions, while the adjusted glidepath for 2016 based prediction was accounted for contributions from Mexico & Canada anthropogenic, Non-US C3 commercial marine, international boundary condition and wildland prescribed fire emissions.

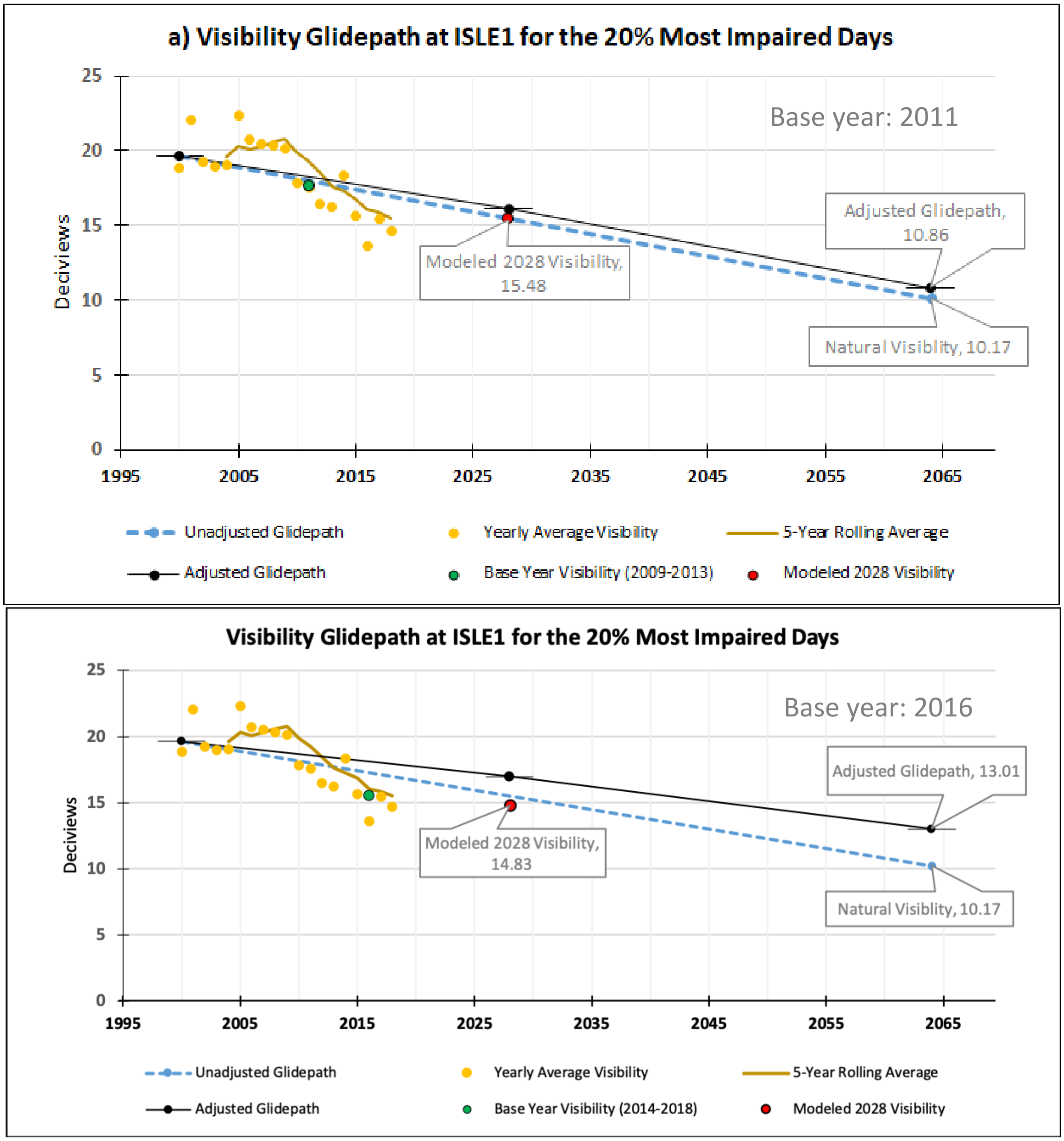


Figure 7-2. Visibility glidepath at ISLE1 IMPROVE site for the 20% most impaired days based on the (a) 2011 based 2028 prediction and (b) the 2016 based 2028 prediction.

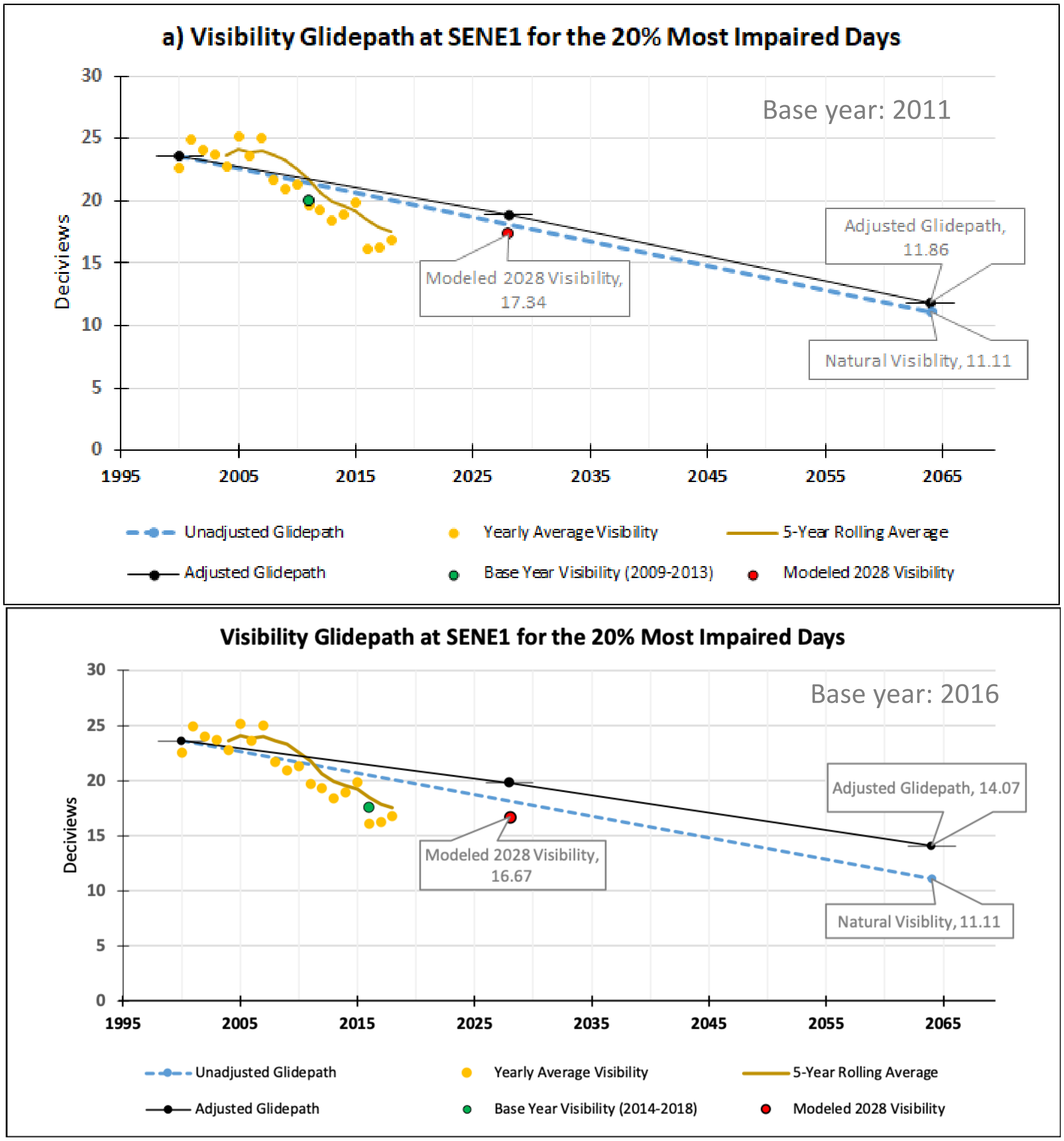
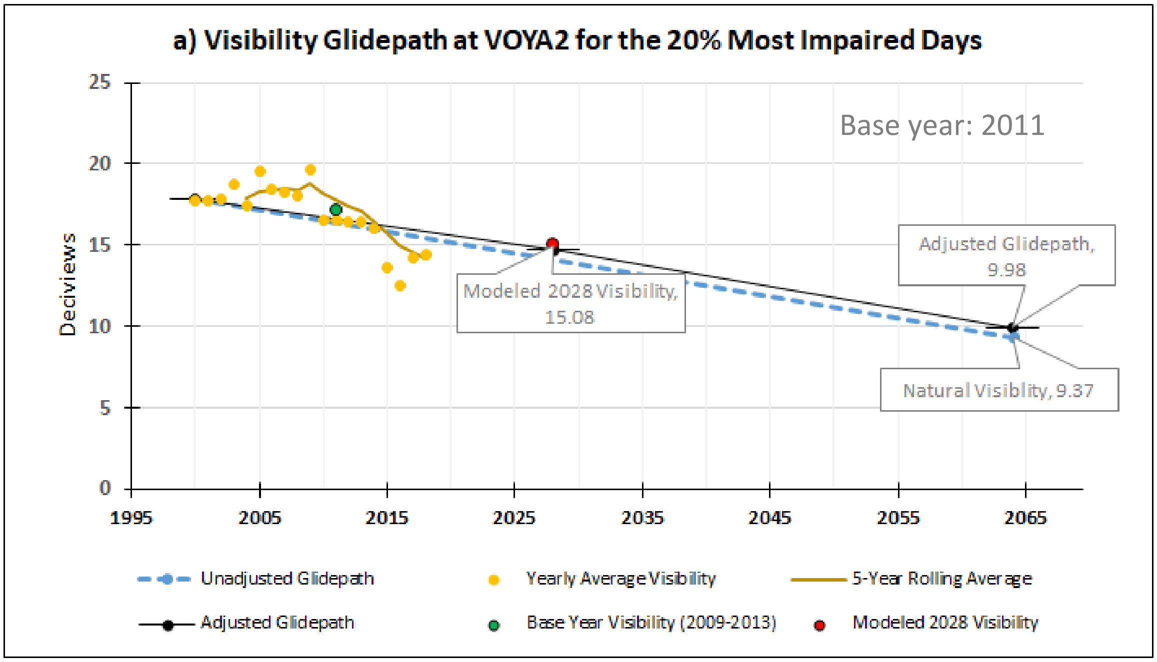


Figure 7-3. Visibility glidepath at SENE1 IMPROVE site for the 20% most impaired days based on the (a) 2011 based 2028 prediction and (b) the 2016 based 2028 prediction.



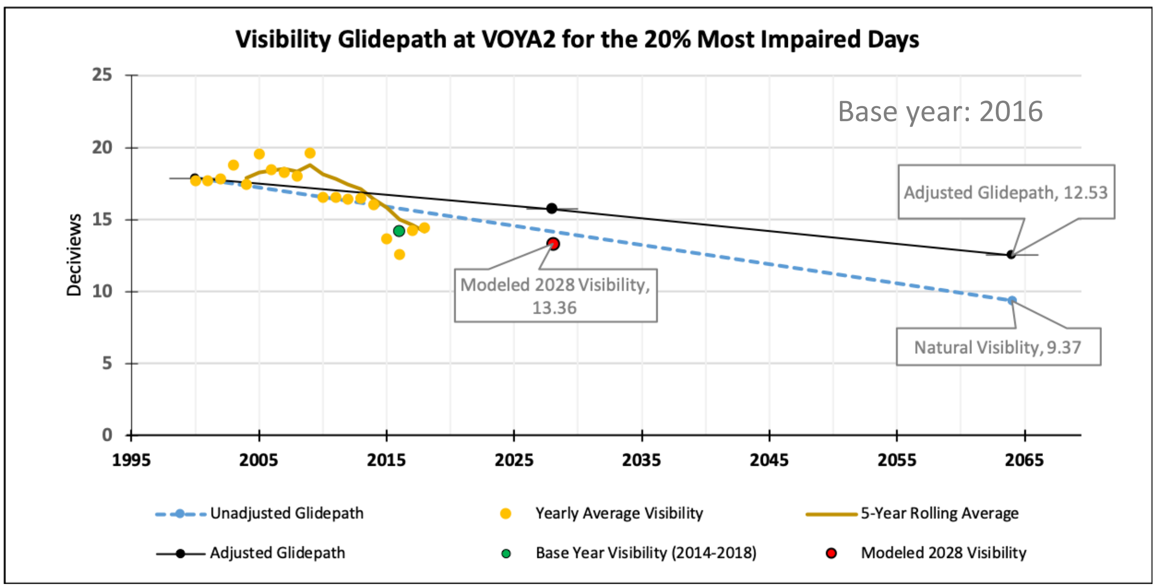


Figure 7-4. Visibility glidepath at VOYA2 IMPROVE site for the 20% most impaired days based on the (a) 2011 based 2028 prediction and (b) the 2016 based 2028 prediction.

The information in these figures is tabulated in Table 7-4 and Table 7-6. The glidepath plots show that the yearly average dv values at the IMPROVE monitors in the LADCO region are decreasing from year to year. One notable trend in these plots is the reduction in the base year visibility (green dot) in the 2016 base year relative to 2011. The 2016 base year visibility conditions are all well below the glidepath. Predicted 2028 visibility conditions based on the 2016 modeling platform shows that the visibility in the

Class I areas in Minnesota and Michigan is about 1.4 dv below the unadjusted glidepath line (i.e., URP). Accounting for the adjustment due to the international contribution, LADCO estimated 2028 visibility on the 20% most impaired days to be about 2.6 dv below the URP line. Table 7-5 and Table 7-7 show the baseline and predicted visibility on the 20% clearest days for the 2011 and 2016-based LADCO modeling.

Table 7-4. Comparison of observed and projected visibility on the 20% most impaired days at Class I areas within LADCO region (2011 base year)

IMPROVE Site ID	Visibility on 20% Most Impaired Days for the 2011 base year (dv)					Impact of Glidepath Adjustment (2028) (B-A)
	Observed Baseline (2000-2004)	Observed Base Years (2009-2013)	Projected Year (2028) (A)	Unadjusted Glidepath Value (2028) (B)	Natural Conditions (2064)	
BOWA1	18.43	16.42	14.43	14.69	9.09	-0.26
VOYA2	17.88	17.12	15.08	14.48	9.37	0.60
ISLE1	19.63	17.63	15.48	15.85	10.17	-0.37
SENE1	23.58	19.92	17.34	18.59	11.11	-1.25

Table 7-5. Comparison of observed and projected visibility on the 20% clearest days at Class I areas within LADCO region (2011 base year)

IMPROVE Site ID	Visibility on 20% Clearest Days for the 2011 base year (dv)			
	Observed Baseline (2000-2004)	Observed Base Years (2009-2013)	Projected Year (2028)	Natural Conditions (2064)
BOWA1	6.50	4.83	4.79	3.48
VOYA2	7.15	5.68	5.60	4.27
ISLE1	6.77	5.40	5.29	3.72
SENE1	7.14	5.50	5.35	3.74

Table 7-6. Comparison of observed and projected visibility on the 20% most impaired days at Class I areas within LADCO region (2016 base year)

IMPROVE Site ID	Visibility on 20% Most Impaired Days for the 2016 base year (dv)					Impact of Glidepath Adjustment (2028) (B-A)
	Observed Baseline (2000-2004)	Observed Base Years (2014-2018)	Projected Year (2028) (A)	Unadjusted Glidepath Value (2028) (B)	Natural Conditions (2064)	
BOWA1	18.43	13.96	13.17	14.69	9.09	-1.52
VOYA2	17.88	14.18	13.36	14.48	9.37	-1.12
ISLE1	19.63	15.54	14.83	15.85	10.17	-1.02
SENE1	23.58	17.57	16.67	18.59	11.11	-1.92

Table 7-7. Comparison of observed and projected visibility on the 20% clearest days at Class I areas within LADCO region (2016 base year)

IMPROVE Site ID	Visibility on 20% Clearest Days for the 2016 base year (dv)			
	Observed Baseline (2000-2004)	Observed Base Years (2014-2018)	Projected Year (2028)	Natural Conditions (2064)
BOWA1	6.50	4.48	4.41	3.48
VOYA2	7.15	5.31	5.25	4.27
ISLE1	6.77	5.30	5.23	3.72
SENE1	7.14	5.27	5.17	3.74

8 PSAT Source Apportionment Results

LADCO conducted source apportionment modeling with CAMx to quantify source-receptor relationships for PM and haze in 2028. The PSAT results show the extent to which emission from different source regions impair visibility in downwind Class I areas. In particular, the techniques used by LADCO to process the PSAT results provide information on the sources that contribute to haze on both the most impaired and clearest days at Class I areas.

In Section 3.5, we discussed the Particulate Matter Source Apportionment Technique (PSAT) configurations for the LADCO 2011-based and 2016-based CAMx simulation. The configuration descriptions included the PSAT emission source or sector tags for quantifying the contributions of upwind states, regions, and inventory sectors at downwind Class I areas. For the 2011-based 2028 PSAT run, LADCO tagged the 2028 emissions by individual LADCO states and neighboring regions (Table 8-1).

CAMx PSAT uses multiple tracer families to track the fate of both primary and secondary PM species, including sulfate (PSO4), particulate nitrate (PNO3), ammonium (PNH4), primary elemental carbon (PEC), primary organic aerosol (POA), secondary organic aerosol (SOA), and primary fine and coarse particles. In addition, PSAT can track contributions from the initial and boundary conditions to the model.

For the 2011-based simulation, LADCO used all of the PSAT tracer families to quantify the haze contributions at Class I areas. Based on those results, we refined the PSAT configuration for the 2016-based simulation to exclude the SOA tracer because it is both computationally expensive to simulate and anthropogenic sources are small contributors to SOA in the LADCO-region Class I areas.

Table 8-1. Source Tag Descriptions for CAMx PSAT runs for 2028_{2011} and 2028_{2016} simulations

Tag #	2028_{2011} Tag Description	2028_{2016} Tag Description
1	Biogenic	Other
2	IL	IL
3	WI	WI
4	IN	IN
5	OH	OH
6	MI	MI
7	MN	MN
8	IA	IA
9	MO	MO
10	AR	TX
11	LA	LA, OK, KS, NE, AR
12	TX	ME, NH, VT, MA, RI, CT, NY, NJ, PA, DE, MD, DC
13	OK	WV, KY, VA, NC, SC, TN, GA, AL, MI, FL
14	KS	NM, AZ, CO, UT, WY, MT, ID, WA, OR, CA, NV, ND, SD
15	NE	Canada/Mexico
16	ND	Commercial Marine (C1/C2/C3)
17	SD	Fires
18	WV	Rockport EGU (IN)
19	KY	Gibson EGU (IN)
20	ME, NH, VT, MA, RI, CT, NY, NJ, PA, DE, MD, DC	All other IN EGUs
21	VA, NC, SC, TN, GA, AL, MI, FL	IN Cement Manufacturing
22	NM, AZ, CO, UT, WY, MT, ID, WA, OR, CA, NV	IN Iron and Steel
23	Canada/Mexico	IN Plastics and Resin
24	Fire	IN Aluminum Production
25	Offshore	All other IN point sources
26	Tribes	IC
27	IC	BC
28	BC	

8.1 PSAT Post-processing for Source Contribution Estimates

LADCO post-processed the CAMx PSAT tagged species model outputs to create SMAT-CE input files. This process involved operations on both the 2028 "bulk outputs" and the source sector specific (or "tagged") source apportionment outputs. The "bulk outputs" are the total PM species concentrations (e.g. sulfate, nitrate, etc.) that are identical to the total species concentrations from the non-source apportionment model run for 2028. However, the source apportionment tracking of PM species uses slightly different variables names for the tagged outputs. The SMAT-CE input variable names and matching CAMx species names for the 2028 bulk and 2028 tagged outputs are tabulated in Table 8-2.

Table 8-2. SMAT input variables and their matching species names for CAMx "bulk" and "PSAT" source output files

SMAT-CE species	SMAT-CE species name	"Combine file" output species	CAMx species in "bulk output"	CAMx species in "tag output"
SO4	Sulfate	PM25_SO4	PSO4	PS4
NO3	Nitrate	PM25_NO3	PNO3	PN3
NH4[29]	Ammonium	PM25_NH4	PNH4	PN4
EC	Elemental carbon	PM25_EC	PEC	PEC
OC[30]	Organic carbon	PM25_OM	POA+SOA1+SOA2+SOPA+SOA3+SOA4+SOPB	POA+PO1+PO2+PPPA+O3+PO4+PPB
CRUSTAL[31]	Crustal	PM25_CRUSTRAL	FPRM+FCRS	PFN+PFC
CM	Coarse PM	PMC_TOT	CCRS+CPRM	PCS+PCC
PM25[32]	Total $PM_{2.5}$	PM25_TOT	PSO4+PNO3+PNH4+PEC+NA+PCL+FPRM+FCRS+SOA1+SOA2+SOPA+SOA3+SOA4+SOPB+POA	PS4+PN3+PN4+POA+PEC+PO1+PO2+PO3+PO4+PPA+PPB+PFN+ PFC

[29] Modeled ammonium concentrations are not used in the post-processing of the 2028 visibility values because the IMPROVE network does not measure ammonium. The IMPROVE equation assumes that sulfate and nitrate is fully neutralized by ammonia.

[30] LADCO's 2028_{2016} CAMx PSAT simulation did not include the organic carbon tracers

[31] LADCO's 2028_{2011} CAMx PSAT simulation was run without writing individual crustal fine particles, thus, the crustal amount was estimated by the sum of fine crustal particles (FCRS) and other fine particles (FPRM).

[32] Total PM2.5 concentration data is needed as a SMAT input variable, however, it is not used in the visibility calculations for regional haze. Visibility calculations only use the species specific model outputs.

The model attainment test software SMAT-CE processes daily total and speciated PM concentrations from the base and future year model (bulk and PSAT) runs from a 3 grid cell x 3 grid cell matrix surrounding each IMPROVE monitor location in the CAMx modeling domain. LADCO used the following steps to prepare the SMAT-CE input files and to run the software to calculate future year visibility at the Class I areas:

1. Combine hourly CAMx "bulk output" into hourly total and speciated PM concentrations (File A) using the species shown in Table 8-2.
2. Generate hourly pseudo total and speciated PM concentration outputs (File X') for each source tag by subtracting the tagged source apportionment output (File X) from File A.
3. Generate daily average total (File $\bar{A}$) and speciated PM (File $\bar{X}'$) concentration files from File A and File X', respectively
4. Extract the results in File $\bar{A}$ and File $\bar{X}'$ from 3x3 grid cells surrounding each IMPROVE monitor location in the modeling domain. LADCO then converted the extracted netCDF data to comma-delimited (CSV) files in the SMAT-CE input file format; the CSV outputs for File $\overline{A2}$ and File $\overline{X2'}$ were then ready for SMAT-CE.
5. Run SMAT-CE version 1.6 using the File $\overline{A2}$ and File $\overline{X2'}$ with observed IMPROVE data as inputs and with the settings in Table 7-1. In this SMAT-CE run, LADCO used the advanced option "Create forecast IMPROVE visibility file" to output the future year (2028) daily species extinction values at each IMPROVE monitor for each of the 20% best and the 20% most impaired days. With this configuration, SMAT-CE generated a "Forecast IMPROVE Daily Data.csv" file, which we used in the next step for calculating the visibility contributions for each PSAT tag.
6. We then used R to prepare the raw SMAT-CE for easy import to a spreadsheet for plotting and tabulation of the results.

LADCO created a comprehensive spreadsheet for each 2028 simulation that included dynamic plotting features with information on natural conditions, baseline visibility, base year and projected year visibility conditions at the Class I areas. We combined this information with the glidepath results described in the previous section.

LADCO's CAMx PSAT visibility forecasts are available in an electronic docket to this TSD in the following spreadsheets:

LADCO 2011-based 2028 Class I Area Visibility Forecasts (6.6 Mb XLSX file)

LADCO 2016-based 2028 Class I Area Visibility Forecasts (2.2 Mb XLSX file)

8.2 2011 Platform PSAT Results

This section presents the results from the LADCO CAMx 2011-based 2028 PSAT configuration that are included in the spreadsheets described in the previous section.

8.2.1 Source Region Tracer Results

The LADCO CAMx 2028_{2011} PSAT modeling estimated the state, biogenic, initial and boundary condition (ICBC), and international (Canada and Mexico) anthropogenic emissions source contributions to visibility in the U.S. Class I areas (Table 8-3 and Figure 8-1). CAMx estimated the average light extinction in 2028 across all of the LADCO region Class I areas to be about 50 Mm^{-1}. CAMx estimated that about 24% of the extinction is due to Rayleigh scattering, 20% from ICBC (mostly from boundary condition), 7-14% from the residing state, about 6% from biogenic emissions, and about 3% from the international anthropogenic emissions, mostly from Canada. The remainder of the extinction comes from other states. Figure 8-1 illustrates the results in Table 8-3 as a stacked bar plot. An aggregation of the PSAT source region tags to regional planning organization (RPO) area for the LADCO's Class I areas is shown in Figure 8-2. Natural sources such as Rayleigh, sea salt, biogenic and fire emissions are projected to contribute 28-36 % of the light extinction coefficients in the LADCO's Class I areas, while the LADCO and CenSARA RPOs are projected to contribute 23-24% and 8-13% of the extinction, respectively.

Table 8-3. 2028_{2011} tracer contributions to b_{ext} on the most impaired days at the LADCO Class I areas

Source region tags	Source contributions to 2028 visibility at IMPROVE Sites (Mm^{-1})					Percent source contributions to 2028 visibility at IMPROVE Sites (%)			
IMPROVE Sites	ISLE1	SENE1	BOWA1	VOYA2		ISLE1	SENE1	BOWA1	VOYA2
Total Bext	50.5	60.7	45.3	47.7					
Rayleigh	12.0	12.0	11.0	12.0		24%	20%	24%	25%
Sea salt (SS)	0.2	0.2	0.1	0.2		0%	0%	0%	1%
Biogenic	3.2	3.7	2.9	3.0		6%	6%	7%	6%
ICBC	10.0	11.1	8.9	8.9		20%	18%	20%	19%
Fire	1.5	1.1	1.6	2.5		3%	2%	3%	5%
Int'l anthropogenic	2.0	2.4	1.5	1.6		4%	4%	3%	3%
Tribal	0.0	0.0	0.0	0.0		0%	0%	0%	0%
Offshore	0.1	0.1	0.0	0.0		0%	0%	0%	0%
West	0.6	0.8	0.8	0.7		1%	1%	2%	1%
Northeast	0.4	1.2	0.2	0.2		1%	2%	0%	0%
Southeast	0.2	0.5	0.1	0.1		0%	1%	0%	0%
IL	2.3	3.4	0.8	1.0		5%	6%	2%	2%
WI	3.5	4.5	2.2	1.7		7%	7%	5%	4%
IN	1.2	2.9	0.5	0.6		2%	5%	1%	1%
OH	0.6	1.5	0.4	0.5		1%	3%	1%	1%
MN	2.4	1.7	6.2	6.5		5%	3%	14%	14%
MI	3.3	6.5	0.8	0.7		7%	11%	2%	2%
IA	1.3	1.3	1.8	1.7		3%	2%	4%	4%
MO	1.4	1.3	0.8	0.9		3%	2%	2%	2%
AR	0.3	0.4	0.2	0.3		1%	1%	1%	1%
LA	0.1	0.1	0.1	0.0		0%	0%	0%	0%
TX	1.3	0.5	1.2	1.0		3%	1%	3%	2%
OK	0.4	0.2	0.6	0.6		1%	0%	1%	1%
KS	0.3	0.4	0.5	0.5		1%	1%	1%	1%
NE	0.9	0.8	0.9	1.0		2%	1%	2%	2%
ND	0.7	0.7	0.8	0.9		1%	1%	2%	2%
SD	0.2	0.2	0.3	0.3		0%	0%	1%	1%
WV	0.1	0.3	0.1	0.1		0%	1%	0%	0%
KY	0.3	0.8	0.1	0.2		1%	1%	0%	0%
Aggregated by RPO									
Natural	4.7	4.9	4.5	5.5		9%	8%	10%	11%
LADCO	13.2	20.6	10.9	11.1		26%	34%	24%	23%
WRAP	1.5	0.8	1.9	1.9		2%	2%	5%	5%
CenSARA	6.0	5.0	6.0	6.0		12%	8%	13%	13%
VISTAS	0.6	1.7	0.3	0.4		1%	3%	1%	1%

Note: Natural (Sea Salt, Fire, Biogenic); LADCO (MN, MI, WI, IL, IN, OH); WRAP (ND, SD, West); CenSARA (IA, MO, AR, LA, TX, OK, KS, Northeast); VISTAS (WY, KY, Southeast)

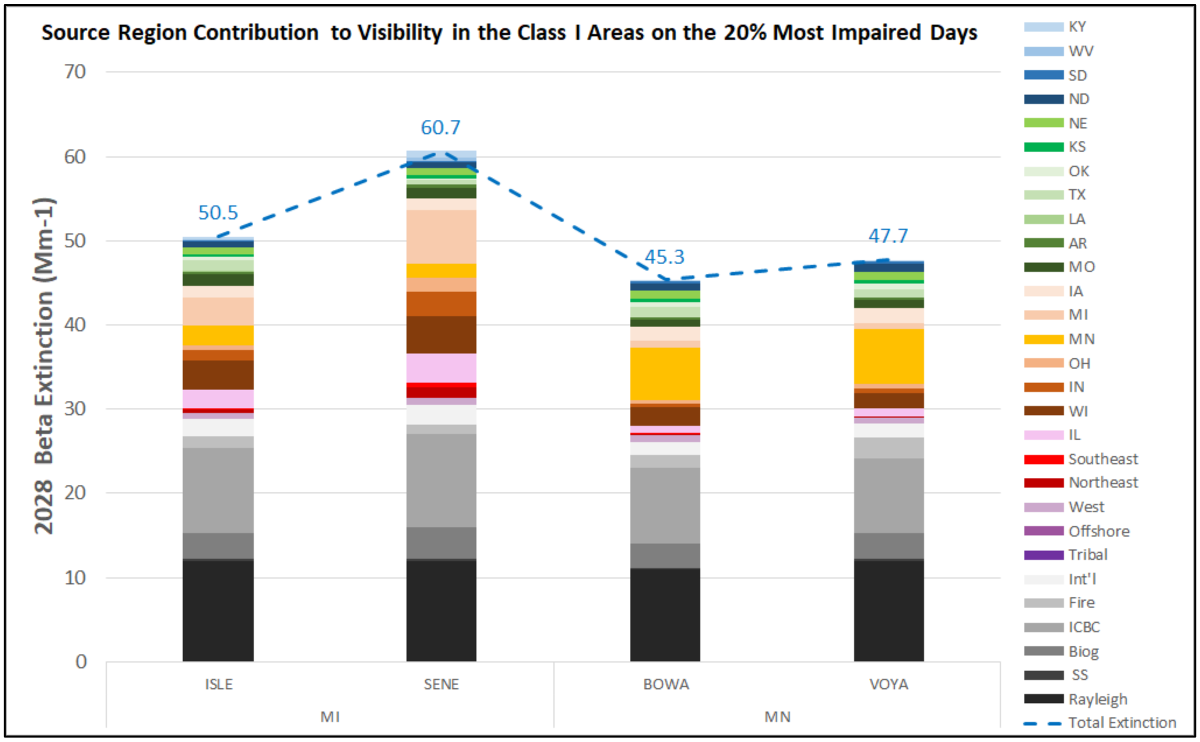


Figure 8-1. State and regional 2028_{2011} tracer contributions to b_{ext} on the 20% most impaired days at the LADCO region class I areas

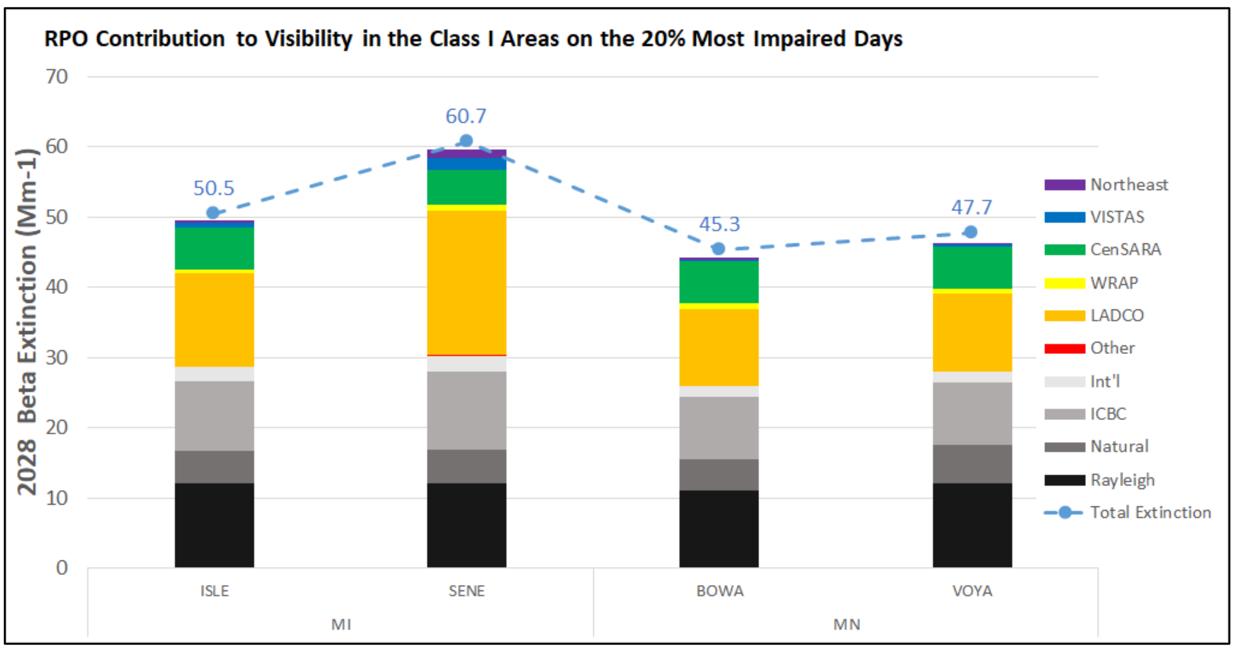


Figure 8-2. RPO 2028_{2011} tracer contributions to b_{ext} on the 20% most impaired days at the LADCO region class I areas

8.2.2 Speciated PM Tracer Results

In addition to quantifying the total contribution from each tracer at receptor areas in the model, the PSAT results can be used to quantify how much each PM species contributes to visibility conditions at the receptors. Figure 8-3 through Figure 8-14 are examples of PSAT tracer footprint plots. These plots show the maximum gridded concentrations of particulate nitrate and sulfate tracers on the 20% most impaired days at different Class I areas in the LADCO. The purpose of the footprint plot is to give a qualitative picture of the spatial signature of sources that contribute to haze impairment at Class I areas. In other words, these plots shows the maximum area of impact of each source region on sulfate and nitrate concentrations during the 20% most impaired days at the different Class I areas. Although PM concentrations do not linearly correspond with visibility impairment, they are a good qualitative surrogate for examining the linkages between emissions sources and downwind visibility impairment.

Figure 8-5 and Figure 8-6 show the maximum nitrate and sulfate tracer forecast (2028_{2011}) concentrations from sources in Minnesota during the 20% most impaired days at the Boundary Waters Canoe Area (BOWA). LADCO estimated that on the 20% most impaired days at BOWA[33], about 2-4 ug/m^3 nitrate and about 1-2 ug/m^3 sulfate concentrations originated from emissions sources in Minnesota. Figure 8-7 and Figure 8-8 show that the LADCO CAMx simulation estimated that a similar amount of nitrate and sulfate originate from the model boundary conditions.

The U.S. EPA's updated 2028 regional haze modeling study (U.S. EPA. 2019b) discussed that the impacts from both nitrate and sulfate are relatively large in the northern states. Based on the U.S. EPA's discussion on Canadian wintertime nitrate and sulfate impacts in the northern states, the modeled concentrations at the Class I areas in the LADCO region could have a minimum of 30-50% contributions from Canada anthropogenic emissions. Figure 8-3 and Figure 8-4 show that the LADCO 2028_{2011} predicted fairly small tracer impacts (<1 μg/m^3) at BOWA from Canadian sources of nitrate and sulfate.

Figure 8-5 through Figure 8-14 show home state maximum particulate nitrate and sulfate tracer concentrations on the 20% most impaired days at Voyageurs National Park, Isle Royale National Park

[33] The tracer footprint plots use the 20% most impaired days from the base year from which the modeling is projected (i.e., 2011 or 2016)

and Seney National Wildlife area, respectively. These figures show sulfate and nitrate contributions on the order of 1-1.5 $\mu g/m^3$ from emissions in the home state to each monitor.

LADCO generated footprint plots for all of the Class I areas in and around the LADCO region from our 2011-based 2028 CAMx simulation. The plots are available as an electronic docket to this TSD and can be found on the LADCO website through the following link:

LADCO 2011-based 2028 PM tracer footprint plots

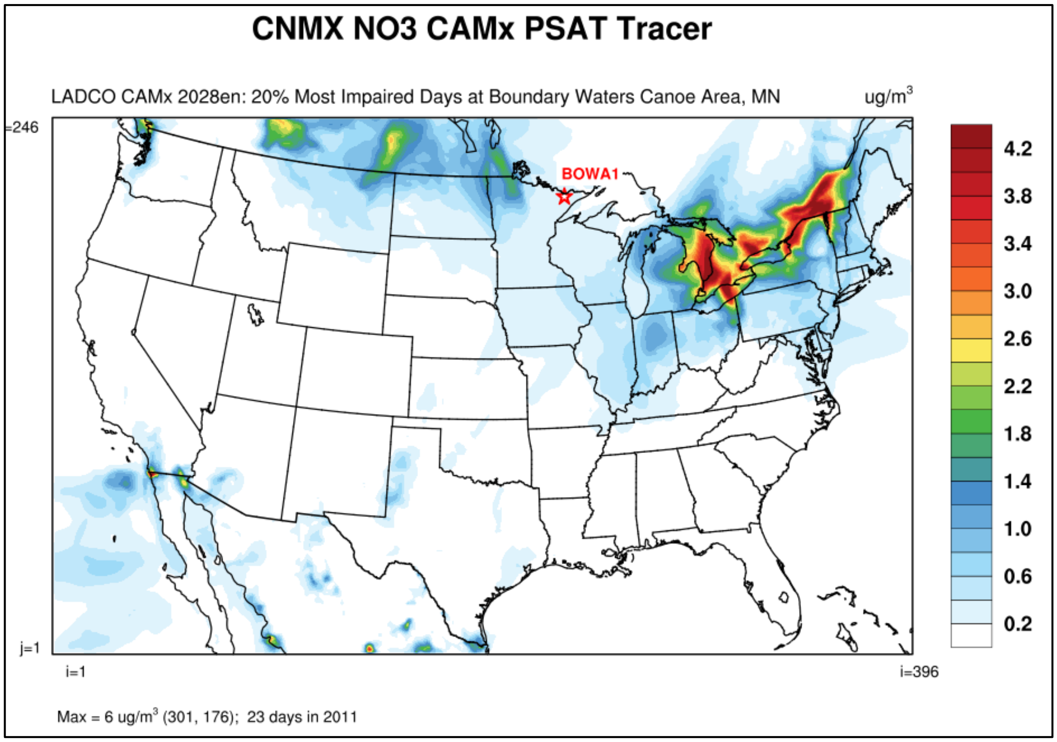


Figure 8-3. Maximum 2028_{2011} nitrate tracer concentration from Canada and Mexico sources on the 20% most impaired days at Boundary Waters, MN

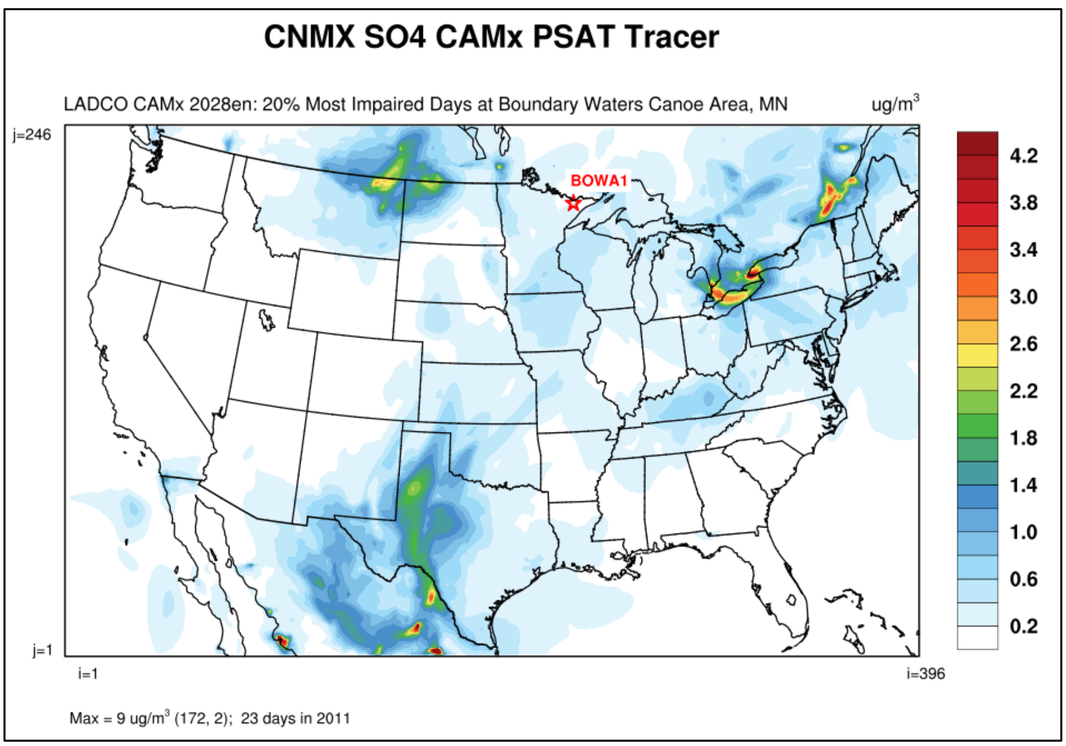


Figure 8-4. Maximum 2028_{2011} sulfate tracer concentration from Canada and Mexico sources on the 20% most impaired days at Boundary Waters, MN

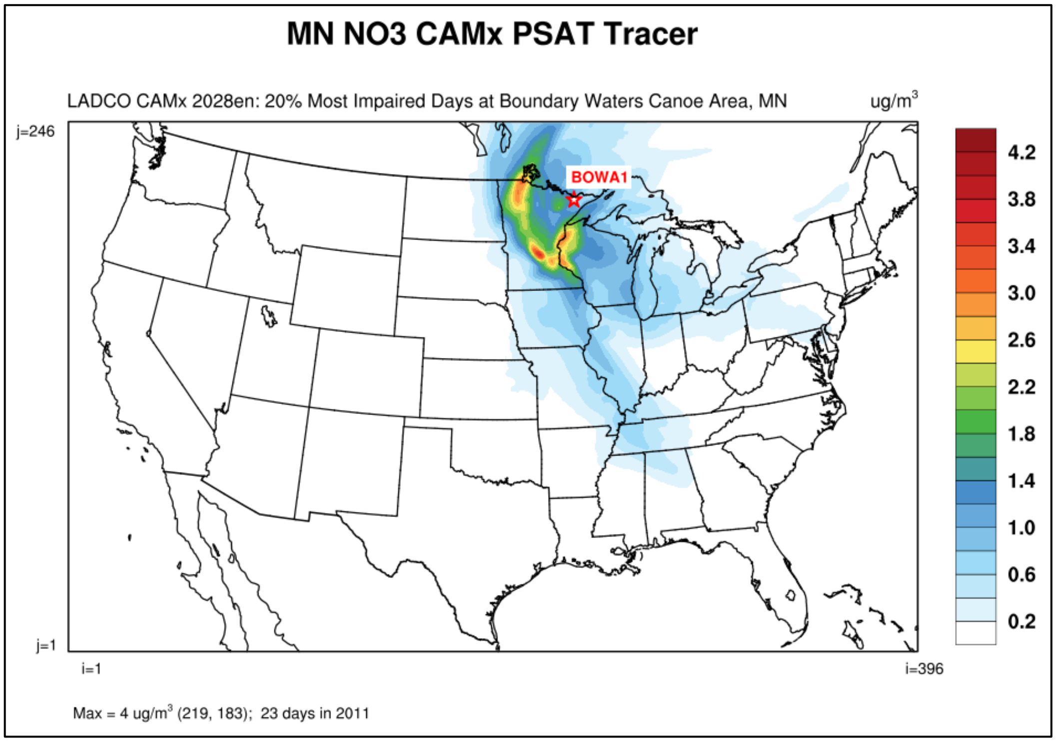


Figure 8-5. Maximum 2028_{2011} nitrate tracer concentration from MN sources on the 20% most impaired days at Boundary Waters, MN

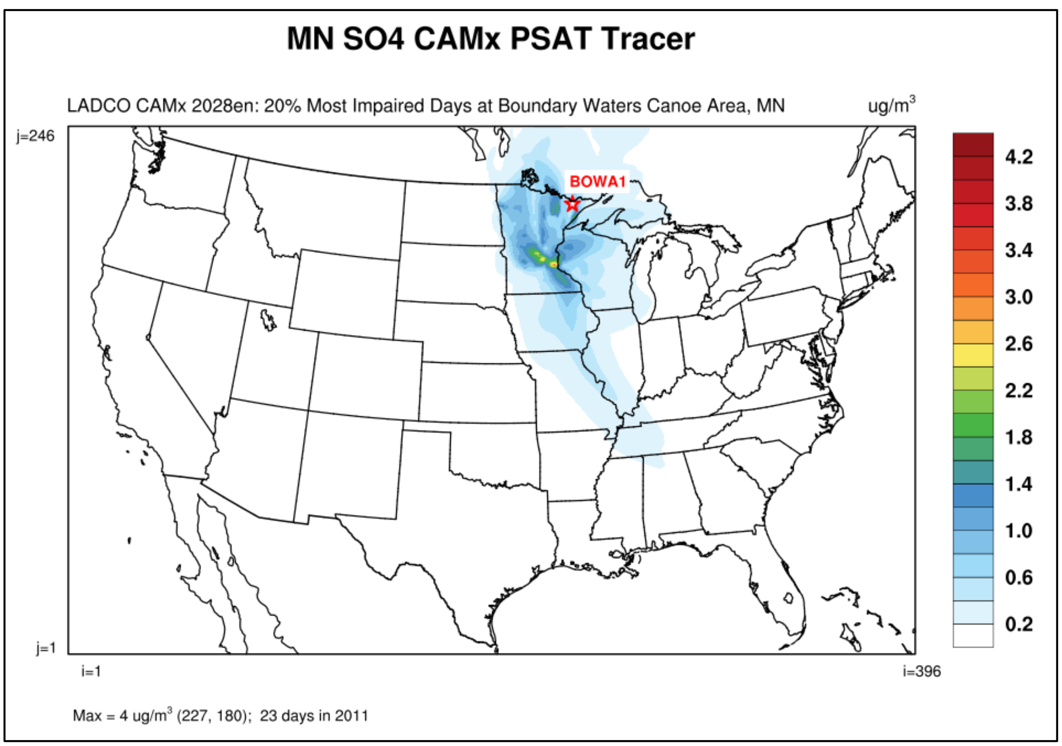


Figure 8-6. Maximum 2028_{2011} sulfate tracer concentration from MN sources on the 20% most impaired days at Boundary Waters, MN

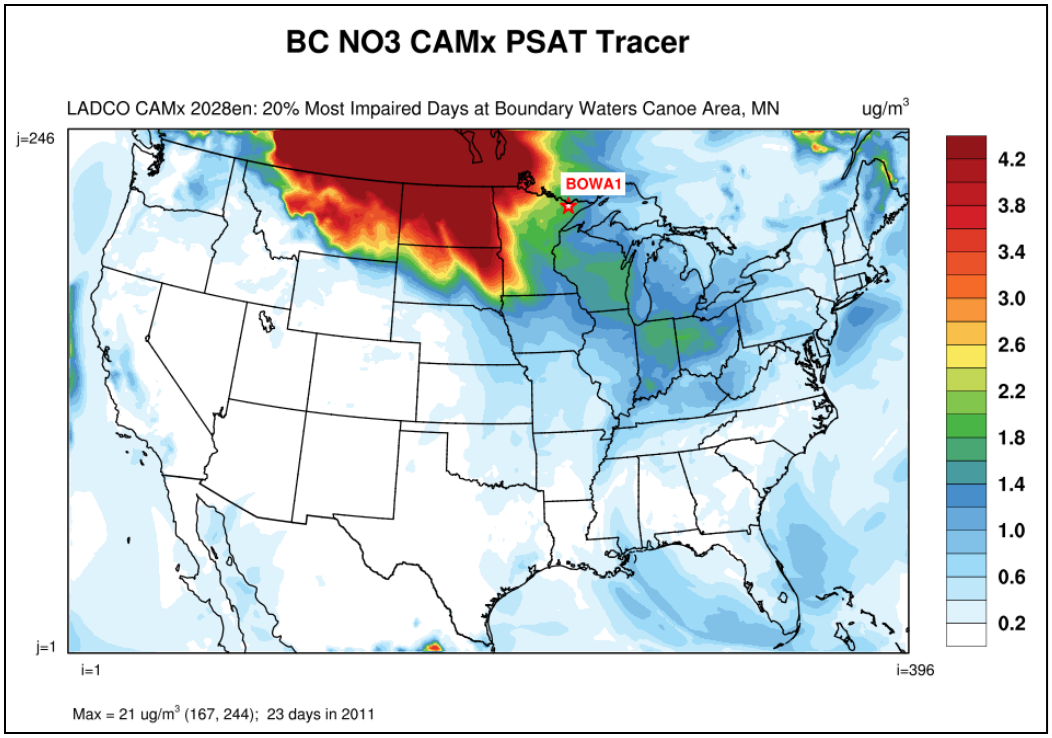


Figure 8-7. Maximum 2028$_{2011}$ nitrate tracer concentration from boundary condition on the 20% most impaired days at Boundary Waters, MN

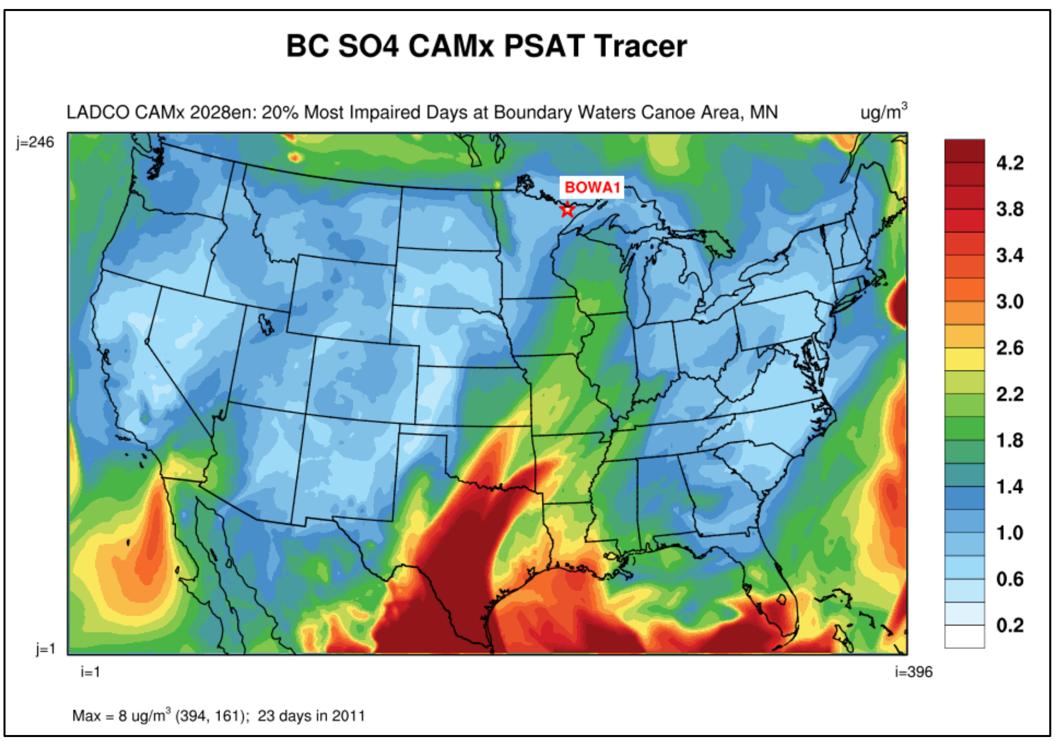


Figure 8-8. Maximum 2028$_{2011}$ sulfate tracer concentration from boundary condition on the 20% most impaired days at Boundary Waters, MN

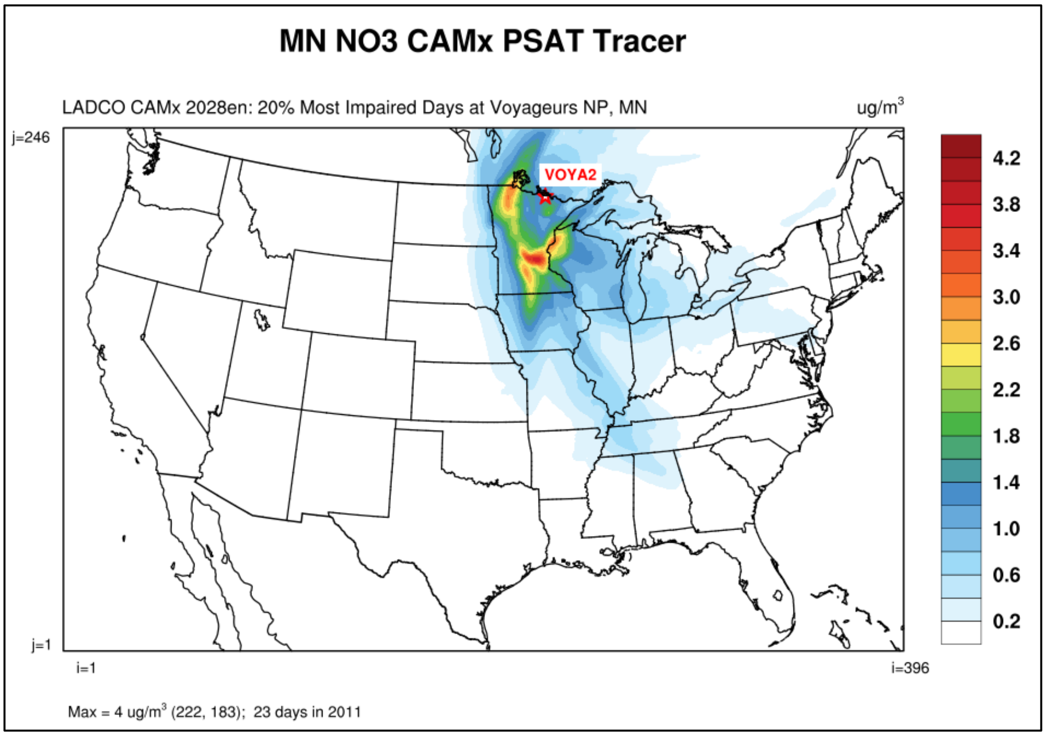


Figure 8-9. Maximum 2028_{2011} nitrate tracer concentration from MN sources on the 20% most impaired days at Voyageurs NP, MN

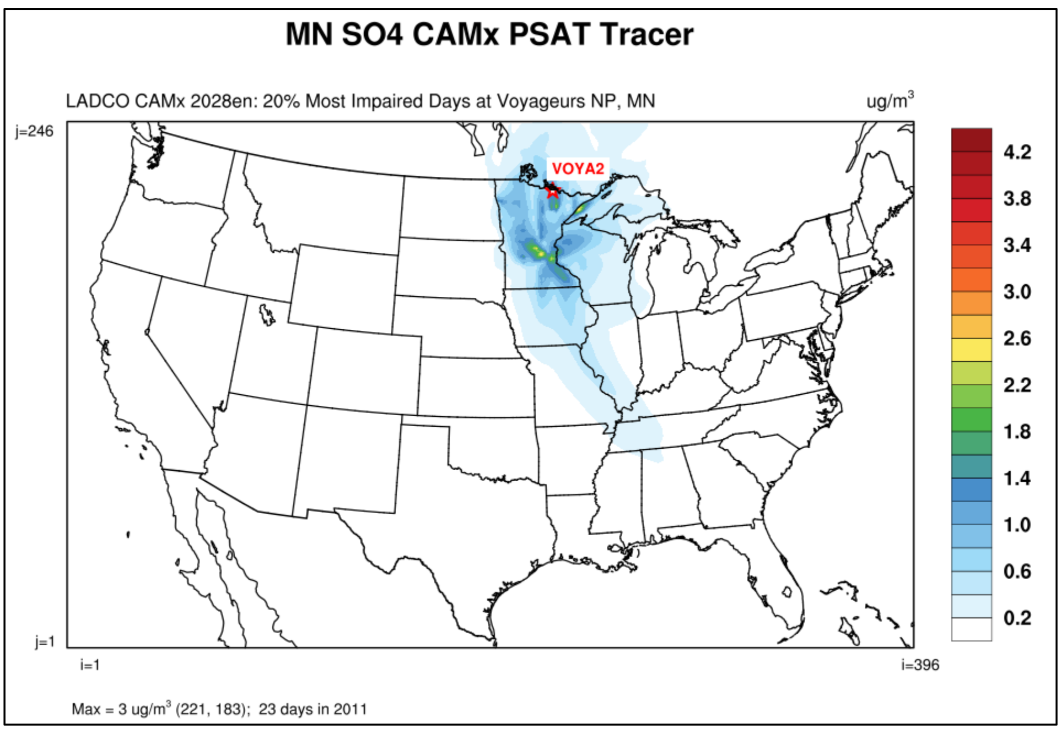


Figure 8-10. Maximum 2028_{2011} sulfate tracer concentration from MN sources on the 20% most impaired days at Voyageurs NP, MN

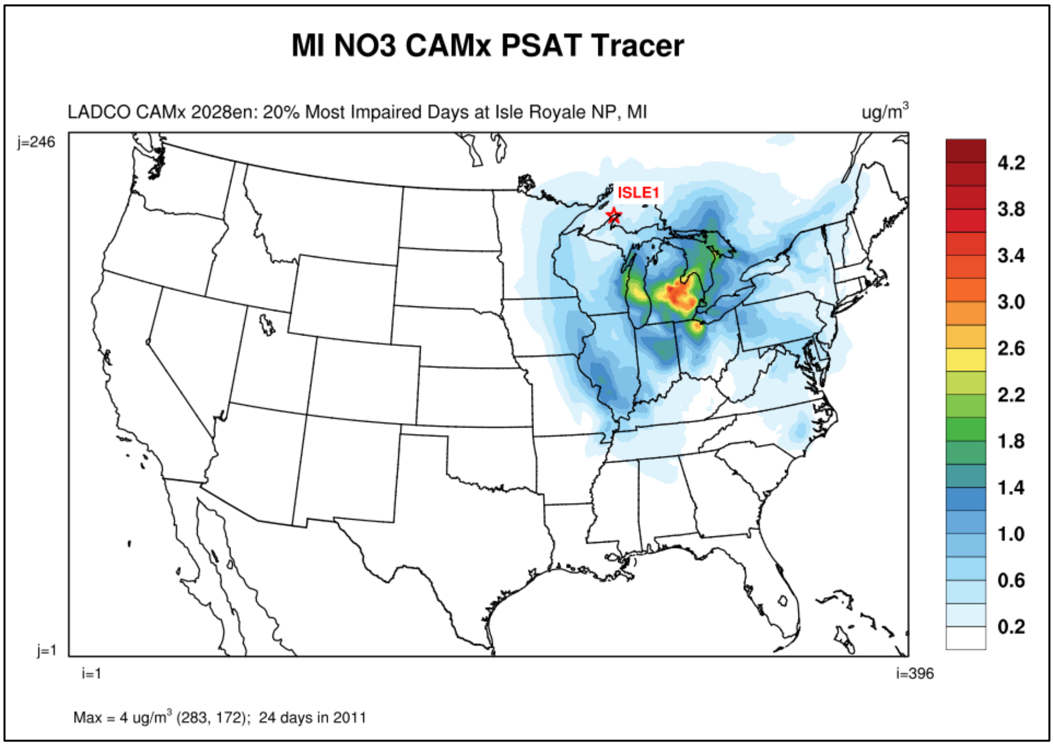


Figure 8-11. Maximum 2028_{2011} nitrate tracer concentration from MI sources on the 20% most impaired days at Isle Royale NP, MI

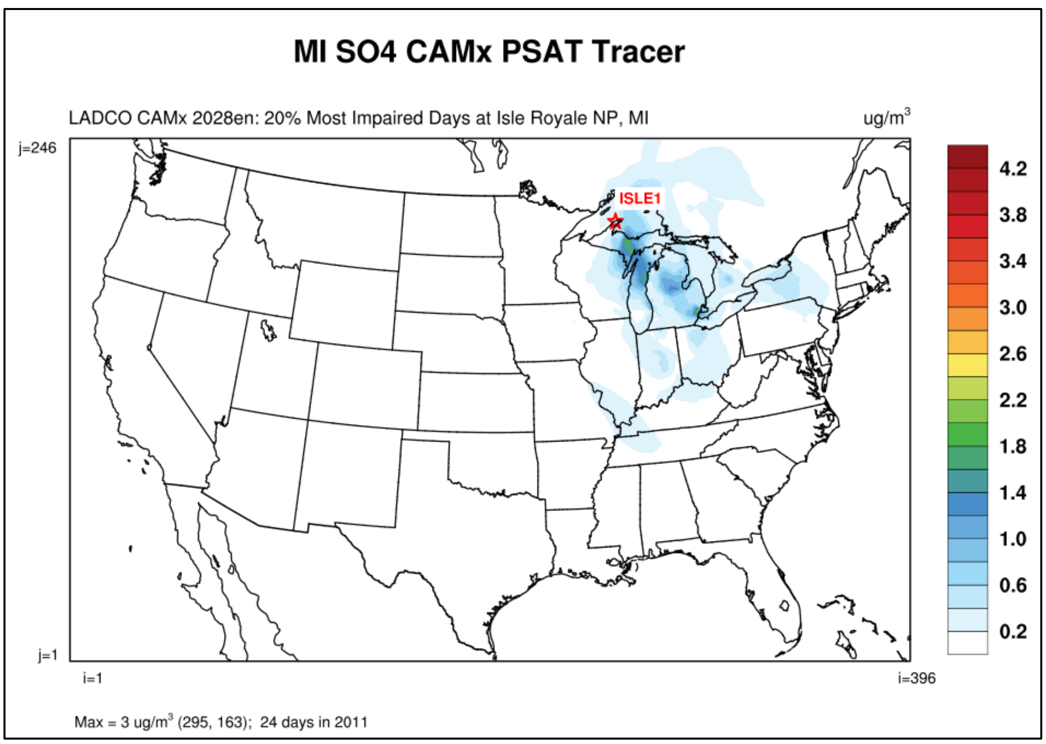


Figure 8-12. Maximum 2028_{2011} sulfate tracer concentration from MI sources on the 20% most impaired days at Isle Royale NP, MI

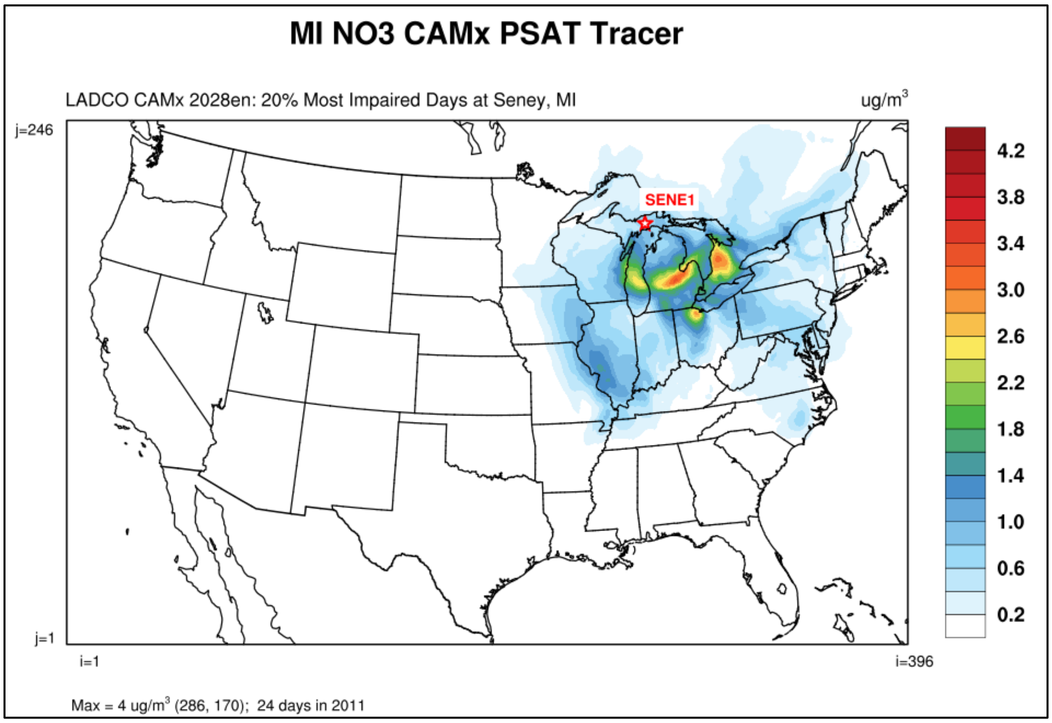


Figure 8-13. Maximum 2028_{2011} nitrate tracer concentration from MI sources on the 20% most impaired days at Seney, MI

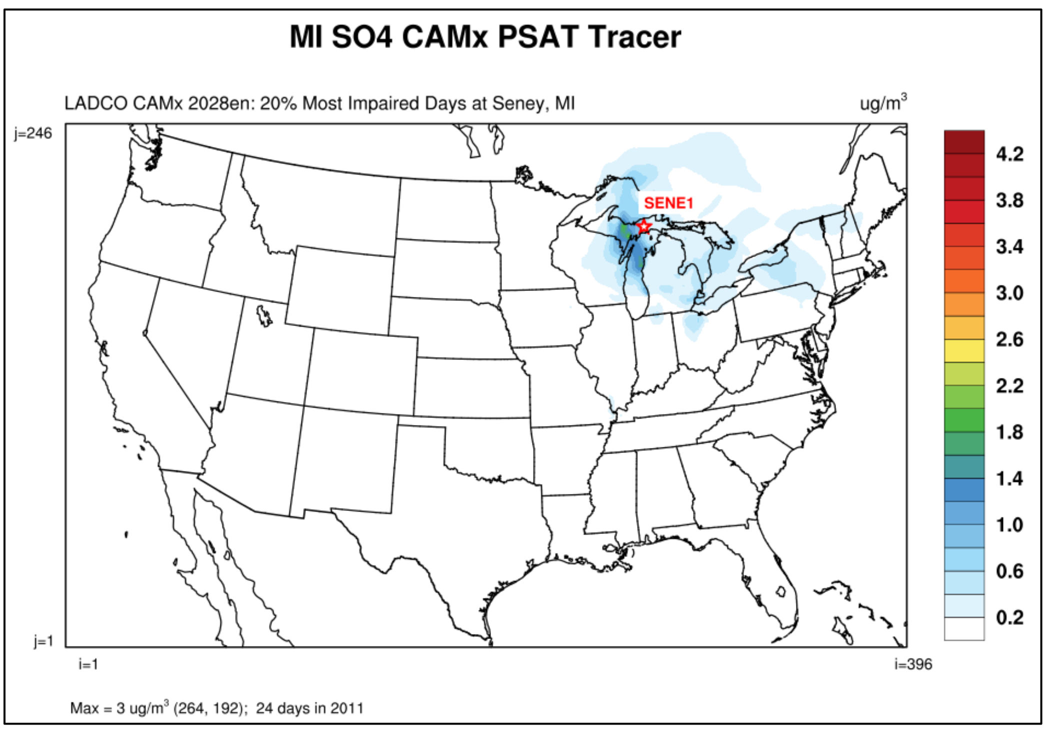


Figure 8-14. Maximum 2028_{2011} sulfate tracer concentration from MN sources on the 20% most impaired days at Seney, MI

The CAMx PSAT results can also be used to quantify the light extinction at the Class I areas by $PM_{2.5}$ composition. LADCO post-processed our CAMx 2028_{2011} modeling results to estimate individual $PM_{2.5}$ species contributions to total light extinction on the 20% most impaired days at the Class I areas. The speciated tracer result for the LADCO region Class I areas are shown in Table 8-4 and in Figure 8-15.

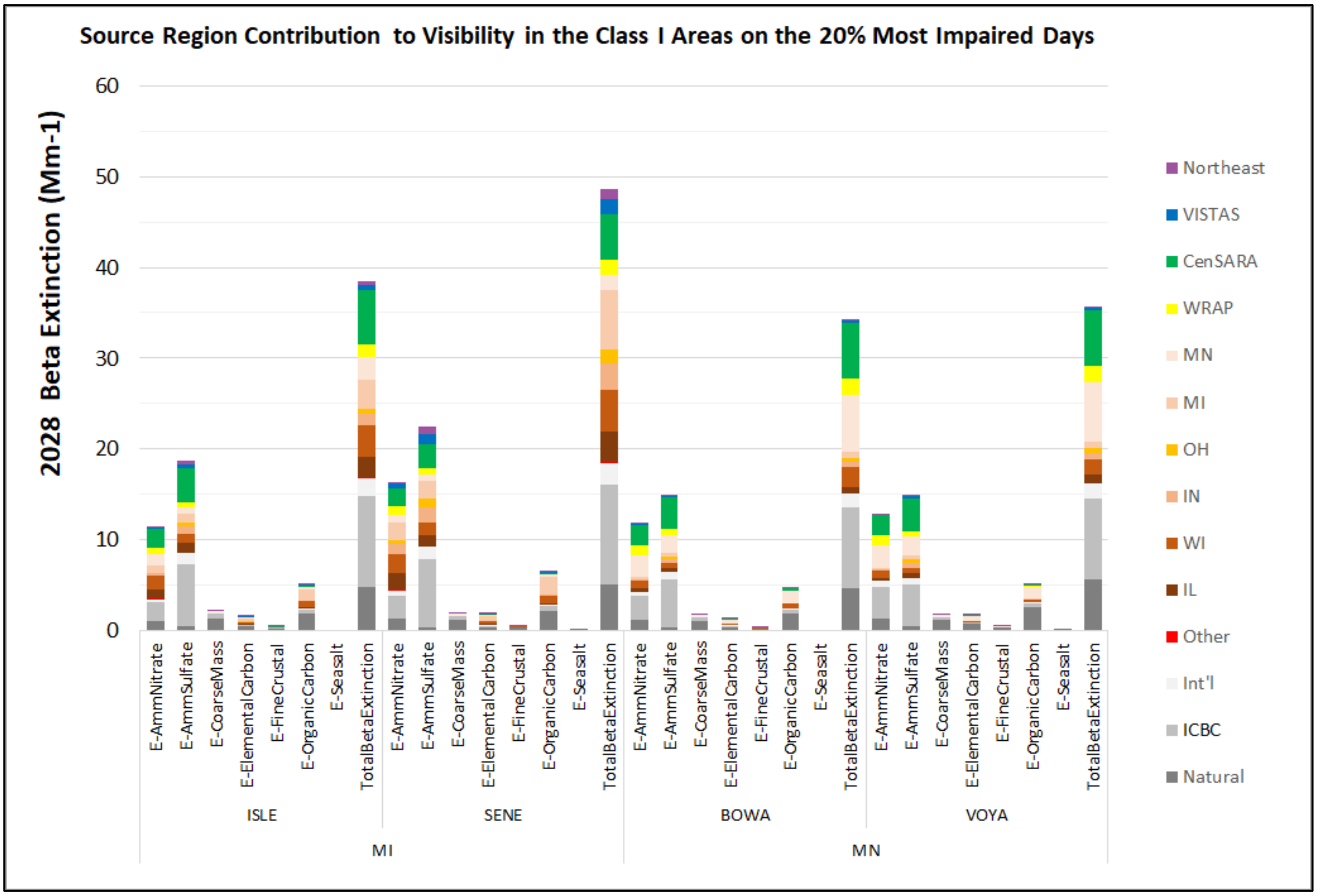


Figure 8-15. PM species tracer contributions to b_{ext} on the 20% most impaired days at the LADCO Class I areas (CAMx 2028_{2011})

Table 8-4. Speciated 2028_{2011} tracer contributions on the 20% most impaired days at the LADCO-region Class I areas

Area	Tracer	Natural	ICBC	Int'l	Other	IL	WI	IN	OH	MI	MN	WRAP	CenSARA	SE	NE	Total
ISLE	Total beta Ext	4.8	10.0	2.0	0.1	2.3	3.5	1.2	0.6	3.3	2.4	1.5	6.0	0.6	0.4	38.5
	NO_3	1.1	2.0	0.4	0.1	1.1	1.5	0.3	0.1	0.7	1.3	0.8	2.0	0.1	0.0	11.3
	SO_4	0.4	6.9	1.3	0.0	1.0	1.0	0.8	0.5	1.0	0.7	0.6	3.7	0.5	0.4	18.7
	CM	1.4	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
	EC	0.5	0.1	0.1	0.0	0.1	0.2	0.0	0.0	0.3	0.1	0.0	0.1	0.0	0.0	1.6
	FCRS	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	OC	1.9	0.4	0.1	0.0	0.1	0.7	0.0	0.0	1.2	0.3	0.0	0.1	0.0	0.0	5.1
	SS	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
SENE	Total beta Ext	5.1	11.1	2.4	0.1	3.4	4.5	2.9	1.5	6.5	1.7	1.7	5.0	1.7	1.2	48.7
	NO_3	1.3	2.5	0.6	0.1	1.8	2.1	1.1	0.4	2.0	0.8	0.9	1.9	0.5	0.2	16.4
	SO_4	0.4	7.5	1.3	0.0	1.3	1.3	1.7	1.0	2.0	0.6	0.7	2.8	1.0	0.9	22.5
	CM	1.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
	EC	0.4	0.1	0.1	0.0	0.1	0.2	0.1	0.0	0.5	0.1	0.0	0.1	0.0	0.0	1.9
	FCRS	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	OC	2.2	0.5	0.2	0.0	0.1	0.8	0.1	0.1	1.9	0.2	0.1	0.2	0.1	0.1	6.5
	SS	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
BOWA	Total beta Ext	4.6	8.9	1.5	0.0	0.8	2.2	0.5	0.4	0.8	6.2	1.8	6.0	0.3	0.2	34.3
	NO_3	1.2	2.6	0.4	0.0	0.4	0.9	0.1	0.0	0.3	2.3	1.1	2.3	0.0	0.0	11.7
	SO_4	0.4	5.3	0.8	0.0	0.3	0.7	0.4	0.3	0.4	1.9	0.6	3.5	0.2	0.2	15.0
	CM	1.1	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	1.7
	EC	0.4	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.5	0.0	0.1	0.0	0.0	1.4
	FCRS	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.4
	OC	1.9	0.4	0.1	0.0	0.0	0.5	0.0	0.0	0.1	1.3	0.1	0.2	0.0	0.0	4.6
	SS	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
VOYA	Total beta Ext	5.7	8.9	1.6	0.0	1.0	1.7	0.6	0.5	0.7	6.5	1.8	6.0	0.4	0.2	35.7
	NO_3	1.3	3.5	0.6	0.0	0.4	0.8	0.1	0.0	0.2	2.4	1.2	2.2	0.0	0.0	12.8
	SO_4	0.5	4.6	0.7	0.0	0.5	0.5	0.5	0.4	0.4	2.1	0.6	3.6	0.3	0.2	15.0
	CM	1.2	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	1.8
	EC	0.8	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.5	0.0	0.1	0.0	0.0	1.7
	FCRS	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.6
	OC	2.7	0.3	0.1	0.0	0.0	0.3	0.0	0.0	0.1	1.3	0.1	0.2	0.0	0.0	5.1
	SS	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2

8.3 2016 Platform Results

This section presents the results from the LADCO CAMx 2016-based 2028 PSAT configuration that are included in the spreadsheets described in the previous section.

8.3.1 Source Region Tracer Results

The LADCO CAMx 2028_{2016} PSAT modeling estimated the state, Indiana point source, biogenic, initial and boundary condition (ICBC), and international (Canada and Mexico) anthropogenic emissions source contributions to visibility in the U.S. Class I areas (Table 8-5 and Figure 8-16). LADCO redefined the tracers for the 2028_{2016} simulation to support analyses requested by our member states, and to eliminate tracers that had a small (<1 Mm^{-1}) estimated impact on visibility in the 2028_{2011} simulation. In particular, the 2016-based simulation excluded tracers for some of the states surrounding the LADCO region, and included tracers for specific point sources and sectors in Indiana. The 2028_{2016} simulation results include an estimated OC contribution to beta light extinction because the 2028_{2016} did not include the CAMx organic aerosol tracer. LADCO calculated the species "OC estimated" as the difference of total beta extinction from the core CAMx model and the sum of all of the PSAT tracers (including Rayleigh).

CAMx estimated the average light extinction in 2028 across all of the LADCO region Class I areas to be about 47 Mm^{-1}. CAMx estimated that about 25.5% of the extinction is due to Rayleigh scattering, 22% from ICBC (almost entirely from the model boundary conditions), 3.5-10.5% from the residing state, and about 4.6% from the international anthropogenic emissions, mostly from Canada. The average biogenic contribution of 3% does not include the contribution from organic carbon aerosols as these species were not explicitly tracked in this simulation. The relative contribution from biogenics to light extinction at the LADCO Class I areas is at least double the 2028_{2016} estimate as biogenic emissions are the primary source of organic aerosols. The majority of the remainder of the light extinction contribution comes from other states.

Figure 8-16 illustrates the results in Table 8-5 as a stacked bar plot. An aggregation of the PSAT source region tags to regional planning organization (RPO) area for the LADCO Class I areas is shown in Figure 8-17.

Table 8-5. 2028$_{2016}$ tracer contributions to b_{ext} on the most impaired days at the LADCO Class I areas

Source region tags	Source contributions to 2028 visibility at IMPROVE Sites (Mm^{-1})					Percent source contributions to 2028 visibility at IMPROVE Sites (%)			
IMPROVE Sites	ISLE1	SENE1	BOWA1	VOYA2		ISLE1	SENE1	BOWA1	VOYA2
Total Bext	48.6	57.4	40.5	41.0					
Rayleigh	12.0	12.0	11.0	12.0		24.7%	20.9%	27.2%	29.2%
Sea salt (SS)	0.3	0.2	0.2	0.3		0.5%	0.4%	0.5%	0.7%
Biogenic	1.4	1.8	1.2	1.3		2.9%	3.1%	2.9%	3.1%
ICBC	10.5	9.9	9.7	10.0		21.5%	17.2%	23.9%	24.4%
OC Estimated	4.2	5.1	3.6	3.5		8.6%	8.9%	8.9%	8.6%
Fire	0.9	0.9	0.9	0.4		1.9%	1.5%	2.1%	0.9%
Int'l anthropogenic	1.7	2.7	1.7	2.3		3.5%	4.8%	4.3%	5.7%
Offshore	0.2	0.2	0.1	0.1		0.5%	0.4%	0.1%	0.1%
West	1.6	1.9	1.9	1.8		3.4%	3.2%	4.6%	4.4%
Northeast	0.1	0.3	0.1	0.1		0.2%	0.5%	0.2%	0.2%
Southeast	0.4	1.3	0.2	0.2		0.8%	2.2%	0.6%	0.5%
CenSARA Other	2.4	1.8	1.9	1.5		4.9%	3.2%	4.6%	3.6%
IA	1.4	1.5	0.9	0.9		2.9%	2.6%	2.3%	2.1%
MO	1.4	1.7	0.8	0.6		3.0%	3.0%	2.1%	1.6%
TX	0.6	0.3	0.3	0.3		1.1%	0.6%	0.8%	0.7%
IL	2.0	3.6	0.6	0.4		4.0%	6.3%	1.6%	1.0%
WI	2.3	3.5	0.9	0.4		4.8%	6.2%	2.3%	1.0%
MI	1.7	3.4	0.1	0.2		3.5%	6.0%	0.3%	0.5%
OH	0.2	1.2	0.2	0.2		0.4%	2.0%	0.4%	0.5%
MN	2.4	1.7	3.9	4.4		5.0%	3.0%	9.6%	10.6%
IN (Total)	0.9	2.3	0.2	0.2		1.9%	4.0%	0.6%	0.5%
IN (Nonpoint)	0.3	0.7	0.1	0.1		0.6%	1.2%	0.2%	0.2%
IN (Rockport EGU)	0.0	0.1	0.0	0.0		0.1%	0.1%	0.0%	0.0%
IN (Gibson EGU)	0.0	0.1	0.0	0.0		0.1%	0.1%	0.0%	0.0%
IN (other EGU)	0.2	0.5	0.0	0.0		0.4%	0.8%	0.1%	0.1%
IN (Cement)	0.0	0.0	0.0	0.0		0.0%	0.1%	0.0%	0.0%
IN (Iron & Steel)	0.3	0.7	0.0	0.1		0.6%	1.2%	0.1%	0.1%
IN (Plastics & Resins)	0.0	0.0	0.0	0.0		0.0%	0.1%	0.0%	0.0%
IN (Aluminum)	0.0	0.0	0.0	0.0		0.0%	0.0%	0.0%	0.0%
IN (Other Point)	0.1	0.2	0.0	0.0		0.2%	0.4%	0.1%	0.0%
Other Anthro	0.0	0.0	0.0	0.0		0.0%	0.0%	0.0%	0.0%
Aggregated by RPO									
Natural	2.3	2.7	2.0	1.6		5%	5%	5%	4%
LADCO	9.6	15.7	6.0	5.8		20%	27%	15%	14%
WRAP	1.6	1.9	1.9	1.8		3%	3%	5%	4%
CenSARA	5.8	5.4	4.0	3.3		12%	9%	10%	8%
VISTAS	0.4	1.3	0.2	0.2		1%	2%	1%	0%

Note: Natural (Sea Salt, Fire, Biogenic); LADCO (MN, MI, WI, IL, IN, OH); WRAP (ND, SD, West); CenSARA (IA, MO, AR, LA, TX, OK, KS, Northeast); VISTAS (WY, KY, Southeast)

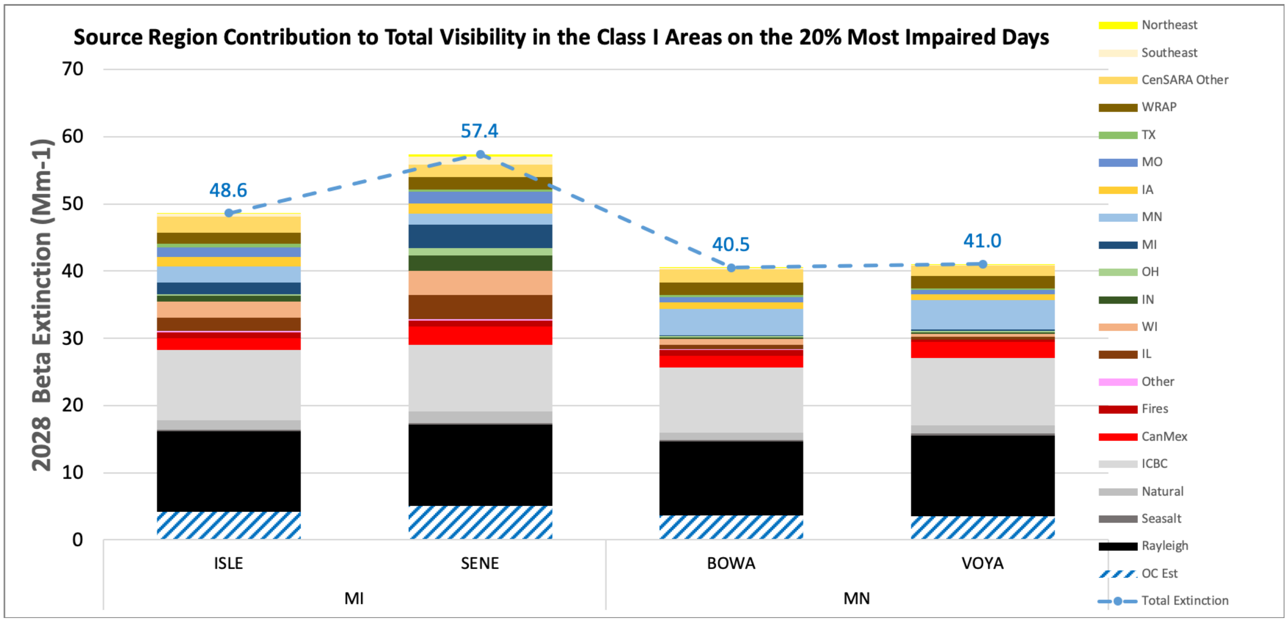


Figure 8-16. State and regional 2028_{2016} tracer contributions to b_{ext} on the 20% most impaired days at the LADCO region class I areas

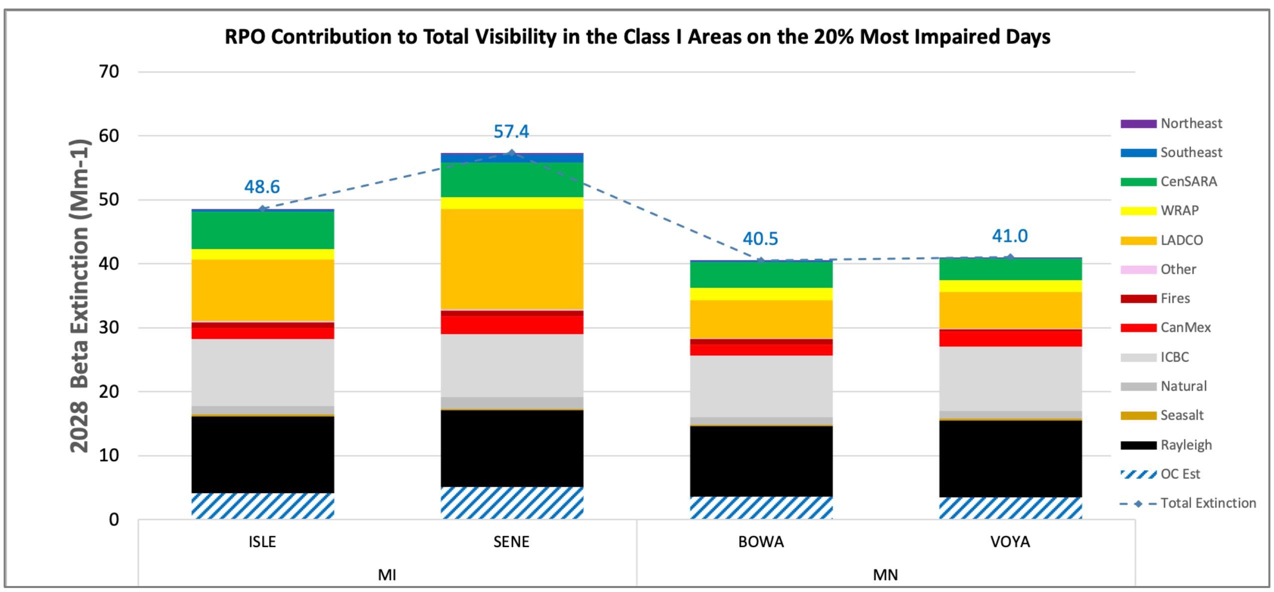


Figure 8-17. RPO 2028_{2016} tracer contributions to b_{ext} on the 20% most impaired days at the LADCO region class I areas

8.3.2 Speciated PM Tracer Results

The PSAT results can also be used to quantify how much each PM species contributes to visibility conditions at the receptors. Figure 8-18 through Figure 8-21 are examples of PSAT tracer footprint plots from LADCO CAMx 2028_{2016}. These plots show the maximum gridded concentrations of particulate nitrate and sulfate tracers on the 20% most impaired days at different Class I areas in the LADCO. These plots shows the maximum area of impact of each source region on sulfate and nitrate concentrations during the 20% most impaired days at the different Class I areas. Although PM concentrations do not linearly correspond with visibility impairment, they are a good qualitative surrogate for examining the linkages between emissions sources and downwind visibility impairment.

Figure 8-20 and Figure 8-21 show the maximum nitrate and sulfate tracer forecast (2028_{2016}) concentrations from sources in Minnesota during the 20% most impaired days at the Boundary Waters Canoe Area (BOWA). LADCO estimated that on the 20% most impaired days at BOWA[34] in 2028, about 0.5-1.5 ug/m^3 nitrate and about 0.5-1.0 ug/m^3 sulfate concentrations will be attributed from emissions sources in Minnesota. Figure 8-18 and Figure 8-19 show that the LADCO 2028_{2016} CAMx simulation estimated that a similar amount of nitrate and sulfate at BOWA originate from Canadian sources as Minnesota sources.

As with the 2011-based 2028 modeling, LADCO generated footprint plots for all of the Class I areas in and around the LADCO region from our 2016-based 2028 CAMx simulation. The plots are available as an electronic docket to this TSD and can be found on the LADCO website through the following link:

LADCO 2016-based 2028 PM tracer footprint plots

[34] The tracer footprint plots use the 20% most impaired days from the base year from which the modeling is projected (i.e., 2011 or 2016)

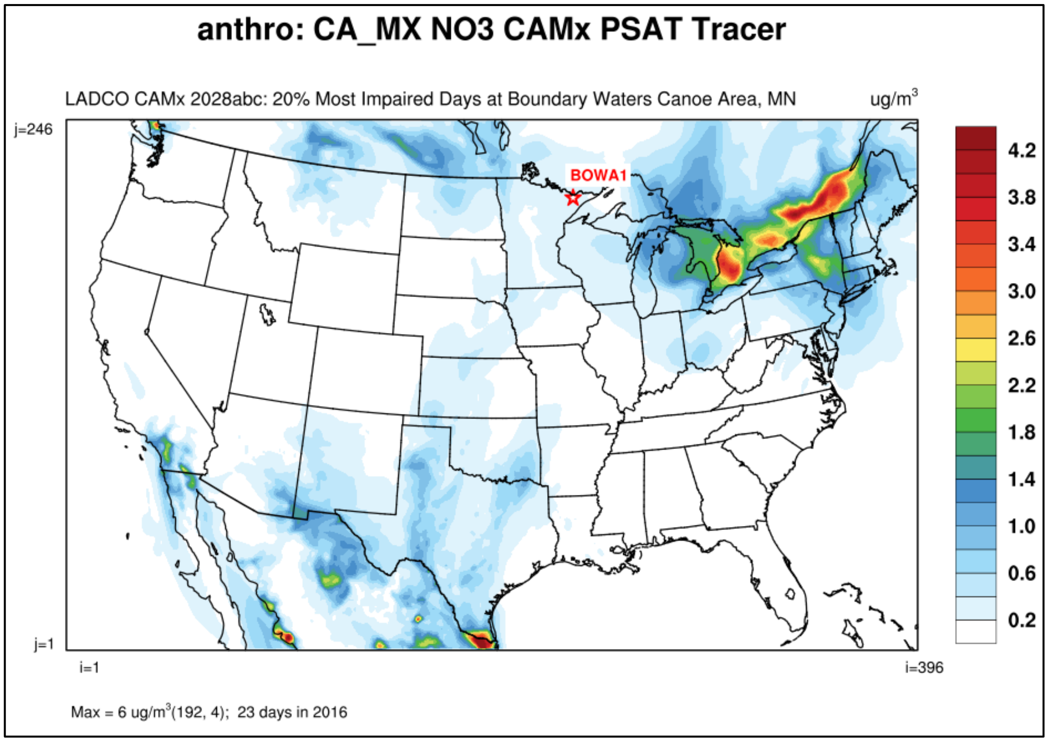


Figure 8-18. Maximum 2028_{2016} nitrate tracer concentration from Canada and Mexico sources on the 20% most impaired days at Boundary Waters, MN

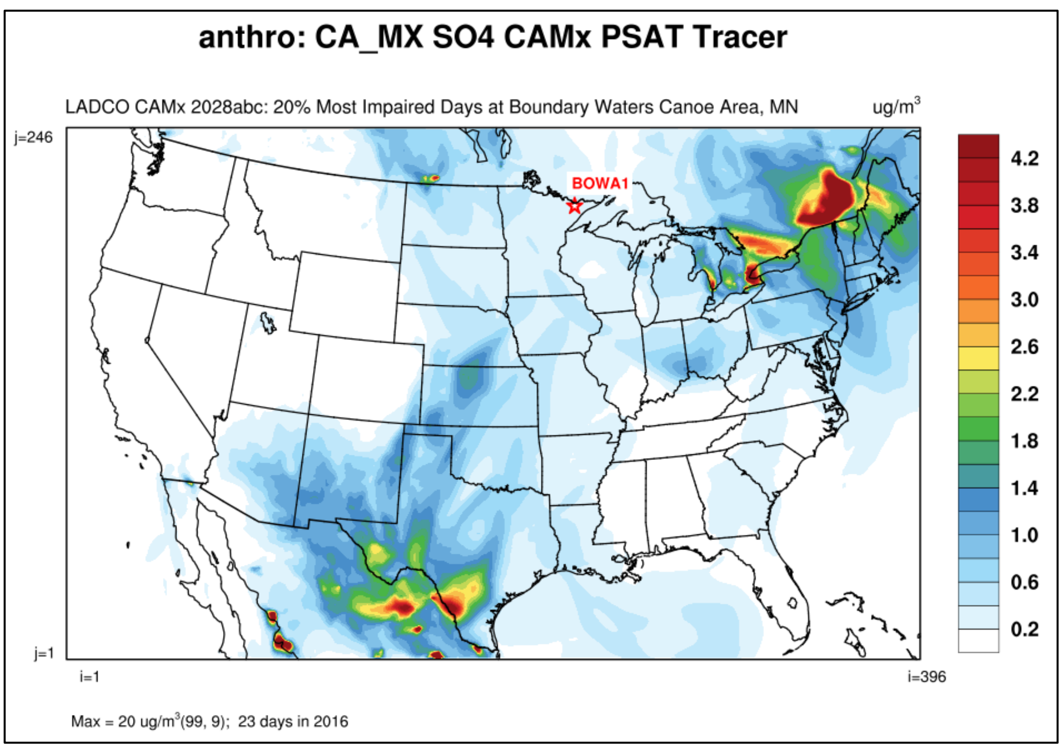


Figure 8-19. Maximum 2028_{2016} sulfate tracer concentration from Canada and Mexico sources on the 20% most impaired days at Boundary Waters, MN

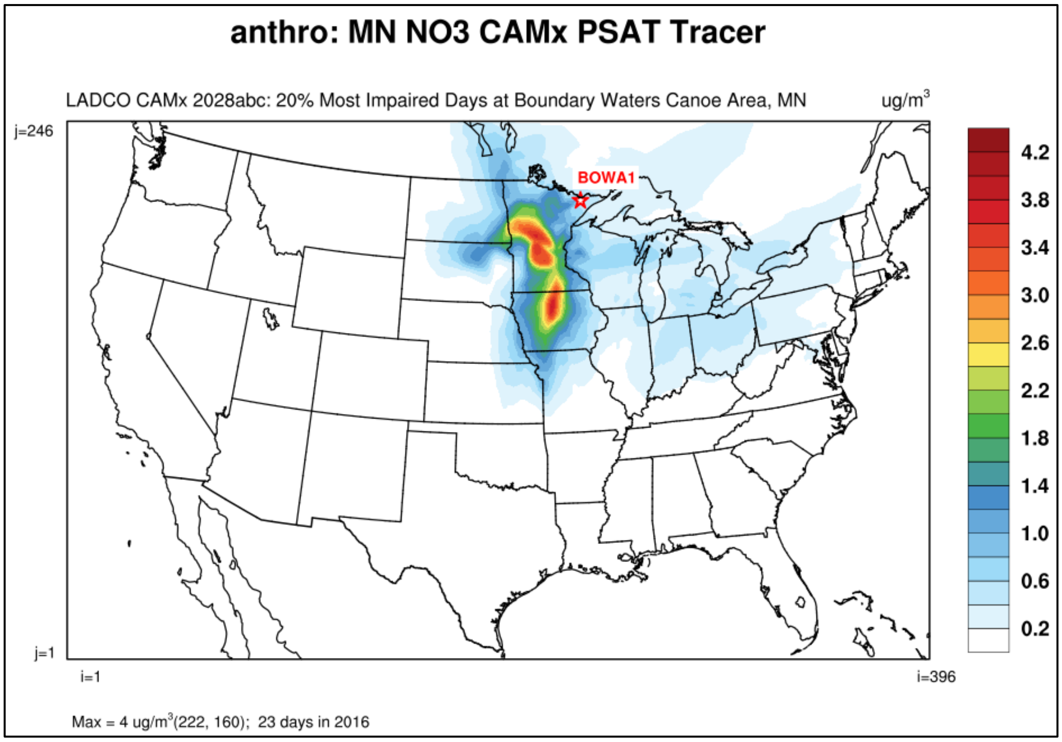


Figure 8-20. Maximum 2028_{2016} nitrate tracer concentration from MN sources on the 20% most impaired days at Boundary Waters, MN

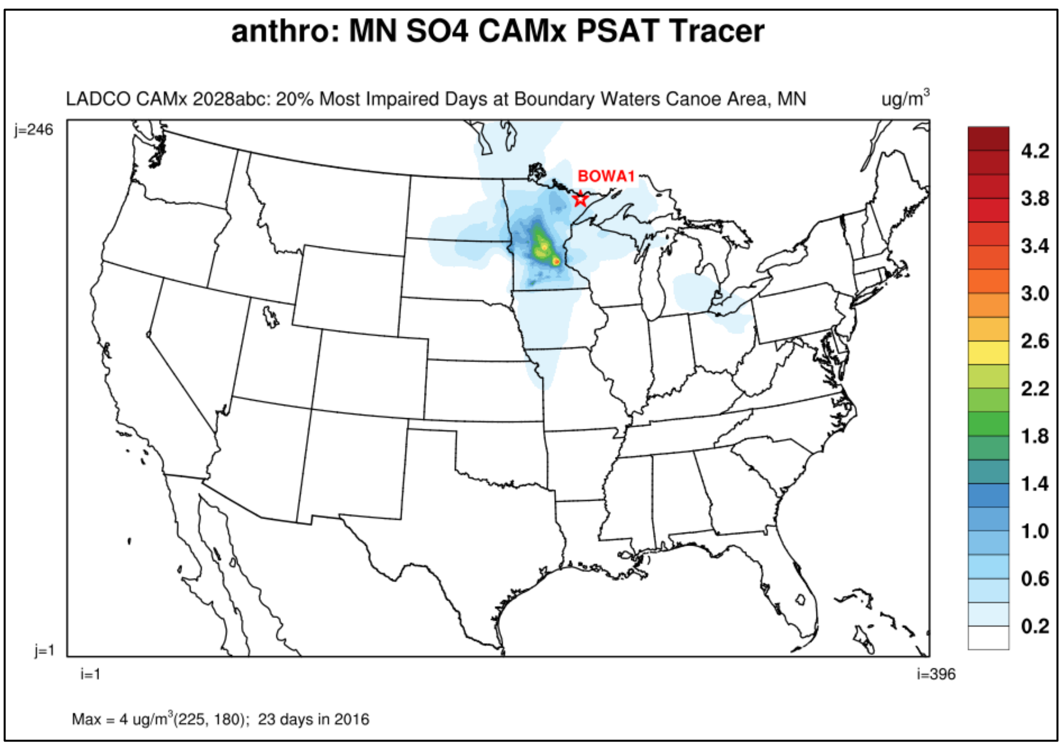


Figure 8-21. Maximum 2028_{2016} sulfate tracer concentration from MN sources on the 20% most impaired days at Boundary Waters, MN

LADCO also used the CAMx PSAT results to quantify the light extinction at Class I areas by $PM_{2.5}$ composition in 2028. LADCO post-processed our CAMx 2028_{2016} modeling results to estimate individual $PM_{2.5}$ species contributions to total light extinction on the 20% most impaired days at the Class I areas. The speciated tracer result for the LADCO region Class I areas are shown in Table 8-6 and in Figure 8-15.

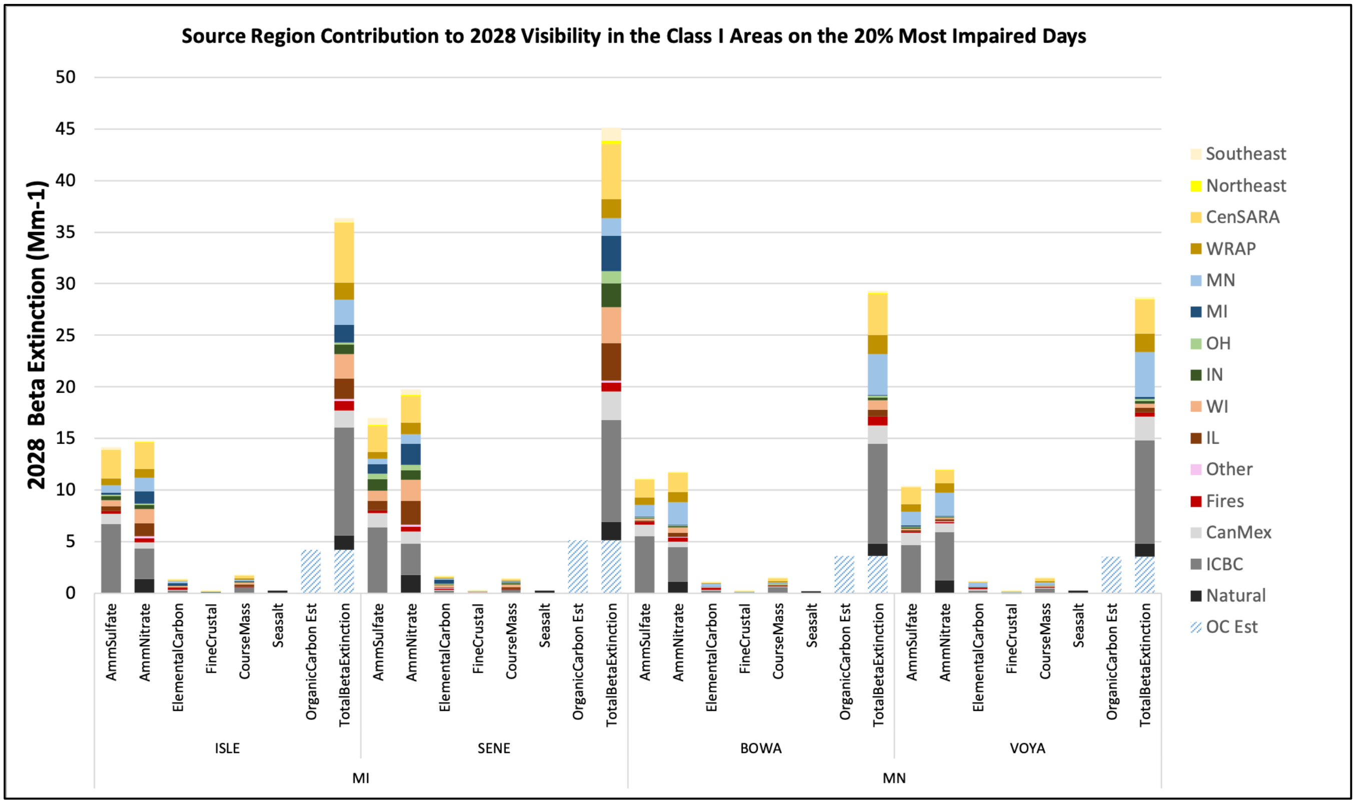


Figure 8-22. PM species tracer contributions to b_{ext} on the 20% most impaired days in 2028 at the LADCO Class I areas (CAMx 2028_{2016})

Table 8-6. Speciated 2028_{2016} tracer contributions on the 20% most impaired days at the LADCO-region Class I areas

Area	Tracer	OC_{est}	Natural	ICBC	Int'l	Fires	Other	IL	WI	IN	OH	MI	MN	WRAP	Cen	SE	NE	Total
ISLE	Total beta Ext	4.2	1.4	10.5	1.7	0.9	0.2	2.0	2.3	0.9	0.2	1.7	2.4	1.6	5.8	0.4	0.1	36.4
	NO_3	0.0	1.4	3.0	0.6	0.4	0.2	1.3	1.3	0.4	0.1	1.2	1.4	0.8	2.6	0.1	0.1	14.8
	SO_4	0.0	0.0	6.7	1.0	0.3	0.0	0.4	0.6	0.4	0.1	0.2	0.7	0.6	2.8	0.2	0.0	14.1
	CM	0.0	0.0	0.6	0.1	0.0	0.0	0.2	0.2	0.0	0.0	0.1	0.1	0.1	0.3	0.0	0.0	1.7
	EC	0.0	0.0	0.3	0.1	0.2	0.0	0.1	0.1	0.0	0.0	0.2	0.2	0.0	0.1	0.0	0.0	1.3
	FCRS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	OC	4.2	0.0	0.0	0.0	0.0	0.0			0.0					0.0	0.0	0.0	4.2
	SS		0.3															0.3
SENE	Total beta Ext	5.1	1.8	9.9	2.7	0.9	0.2	3.6	3.5	2.3	1.2	3.4	1.7	1.9	5.4	1.3	0.3	45.1
	NO_3	0.0	1.8	3.0	1.2	0.4	0.2	2.3	2.1	1.0	0.5	2.0	1.0	1.1	2.6	0.5	0.2	19.8
	SO_4	0.0	0.0	6.3	1.4	0.2	0.0	0.9	1.0	1.1	0.5	0.9	0.5	0.7	2.5	0.7	0.1	17.0
	CM	0.0	0.0	0.3	0.0	0.0	0.0	0.2	0.2	0.1	0.1	0.1	0.0	0.1	0.2	0.0	0.0	1.4
	EC	0.0	0.0	0.2	0.1	0.2	0.0	0.1	0.2	0.1	0.0	0.4	0.1	0.0	0.1	0.0	0.0	1.6
	FCRS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	OC	5.1	0.0	0.0	0.0	0.0	0.0			0.0					0.0	0.0	0.0	5.1
	SS		0.2															0.2
BOWA	Total beta Ext	3.6	1.2	9.7	1.7	0.9	0.1	0.6	0.9	0.2	0.2	0.1	3.9	1.9	4.0	0.2	0.1	29.3
	NO_3	0.0	1.1	3.3	0.5	0.4	0.1	0.4	0.5	0.1	0.1	0.1	2.2	1.0	1.9	0.1	0.0	11.8
	SO_4	0.0	0.0	5.5	1.1	0.3	0.0	0.1	0.2	0.1	0.1	0.0	1.1	0.7	1.7	0.1	0.0	11.2
	CM	0.0	0.0	0.6	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.2	0.1	0.3	0.0	0.0	1.5
	EC	0.0	0.0	0.3	0.1	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.3	0.0	0.1	0.0	0.0	1.1
	FCRS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2
	OC	3.6	0.0	0.0	0.0	0.0	0.0			0.0					0.0	0.0	0.0	3.6
	SS		0.2															0.2
VOYA	Total beta Ext	3.5	1.3	10.0	2.3	0.4	0.1	0.4	0.4	0.2	0.2	0.2	4.4	1.8	3.3	0.2	0.1	28.7
	NO_3	0.0	1.2	4.7	0.9	0.1	0.0	0.2	0.2	0.1	0.1	0.1	2.2	0.9	1.3	0.1	0.0	12.0
	SO_4	0.0	0.0	4.6	1.2	0.1	0.0	0.1	0.1	0.1	0.1	0.1	1.3	0.7	1.6	0.1	0.0	10.4
	CM	0.0	0.0	0.4	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.3	0.1	0.3	0.0	0.0	1.4
	EC	0.0	0.0	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.1	0.0	0.0	1.1
	FCRS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2
	OC	3.5	0.0	0.0	0.0	0.0	0.0			0.0					0.0	0.0	0.0	3.5
	SS		0.3															0.3

9 Conclusions and Significant Findings

LADCO presents in this TSD the results from two regional air quality modeling platforms for quantifying and evaluating future year haze conditions pursuant to tracking progress during the second planning period for the Regional Haze Rule.

Significant findings in this report include:

Trends in PM Concentrations and Regional Haze (Section 2)

- $PM_{2.5}$ design values at all monitors in the LADCO region are currently below the levels of both $PM_{2.5}$ NAAQS. In particular, the 2019 24-hour DVs are at least five $\mu g/m^3$ below the level of the NAAQS. The highest concentrations in the LADCO region are in the urban areas, and the lowest concentrations are in the far northern parts of the region, including near LADCO's Class I areas.
- Both the annual and 24-hour $PM_{2.5}$ design values for the LADCO states decreased by 33% to 51% between 2002 and 2019.
- Concentrations of all of the measured $PM_{2.5}$ species have decreased at the regional surface monitors since 2001, with the largest reductions (70%) from ammonium sulfate aerosols and the smallest reductions (7%) from organic carbon.
- From 2000 to 2018, visibility on the most impaired days at the LADCO region Class I areas improved by 18% to 26%. Visibility improvements were even greater on the clearest days, with improvements of 26% to 34%.
- Concentrations of ammonium sulfate have undergone particularly large reductions over the past two decades. As a result, ammonium nitrate and organic carbon have become relatively more important contributors to fine particulate matter and haze in the LADCO region.

Air Quality Modeling (Section 3)

- LADCO used 2011 and 2016 as modeling base years from which to project visibility conditions in 2028. LADCO selected these modeling years because they were available as modeling platforms that included projections to 2028 during the current regional haze implementation period.

Air Quality Modeling Performance Evaluation (Section 6)

- The LADCO CAMx 2011 and 2016 modeling results are comparable to the U.S. EPA 2011 and 2016 modeling platforms that the Agency used for regional haze modeling
- Both of the LADCO base year CAMx simulations achieved either the model performance goals or criteria for most of the $PM_{2.5}$ species in the winter and spring seasons
- The LADCO CAMx simulations generally better estimated $PM_{2.5}$ at the more rural IMPROVE sites compared to the CSN sites (i.e., lower NMB and NME at IMPROVE vs CSN).
- CAMx did not simulate the carbonaceous or organic aerosol well in either of the base years.
- The LADCO CAMx simulations performed relatively well in estimating spring and winter season nitrate and sulfate at the IMPROVE monitors in both 2011 and 2016.

Future Year Haze Projections (Section 7)

- The visibility conditions at the Class I areas in the LADCO region were predicted to improve on average by about 2 dv in 2028 as compared to the 2011 base year, and about 0.8 dv improvement relative to the 2016 base year.
- Predicted 2028 visibility conditions based on the 2016 modeling platform shows that the visibility in the Class I areas in Minnesota and Michigan is about 1.4 dv below the unadjusted glidepath line (i.e., URP). Accounting for the adjustment due to the international contribution, LADCO estimated 2028 visibility on the 20% most impaired days to be about 2.6 dv below the URP line.

2028 Source-Receptor Modeling Results (Section 8)

- LADCO's 2011-based 2028 projection modeling estimated that natural sources such as Rayleigh, sea salt, biogenic and fire emissions will contribute 28-33 % of the light extinction coefficients in the LADCO's Class I areas, while the LADCO and CenSARA RPOs will contribute 23-24% and 8-13% of the extinction, respectively.
- LADCO's 2016-based 2028 projection modeling estimated that natural sources such as Rayleigh, sea salt, biogenic and fire emissions will contribute 28-36 % of the light extinction coefficients in the LADCO's Class I areas, while the LADCO and CenSARA RPOs will contribute 14-27% and 8-13% of the extinction, respectively.

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