Documentation for the EPA's Preliminary 2028 Regional Haze Modeling

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1.0 Background and Caveats

The Regional Haze Rule (RHR) requires a state implementation plan (SIP) that evaluates reasonable progress for implementation periods in approximately 10 year increments. The next regional haze SIP is due in 2021, for the second implementation period which ends in 2028 (period of 2019-2028).[1] The EPA conducted preliminary visibility modeling for 2028 with the intention of informing the regional haze SIP development process.

Based on our analysis of these results, we identified a number of uncertainties and model performance issues that should be addressed in future EPA, state, multistate, or stakeholder modeling that may be used in regional haze SIP development. Despite these uncertainties, the EPA is releasing this information as part of the necessary collaborative work with states, tribes, multi-jurisdictional organizations, and federal land managers. Our goal is that this information, along with future collaborative work, will improve the technical foundation of modeling used in regional haze SIP development. For most Class I areas, we recommend using these preliminary results only as a first step in the process of developing technically sound regional haze modeling for the second implementation period. However, the modeling results for some sites (particularly in the east) may provide a reasonably accurate assessment of 2028 visibility levels and source sector contributions. States should consult with their EPA Regional Office to determine the usefulness of these preliminary model results for any particular Class I area.

1.1 Introduction

In this technical support document (TSD) we describe the air quality modeling performed as a first look at regional haze in 2028. For this assessment, air quality modeling is used to project visibility levels at individual Class I areas (represented by Interagency Monitoring of Protected Visual Environments [IMPROVE] monitoring sites) to 2028 and to estimate emissions sector contributions to 2028 particulate matter (PM) concentrations and visibility. The projected 2028 PM concentrations are converted to light extinction coefficients and then to deciviews and used to evaluate visibility progress as of 2028. In addition, 2028 visibility contribution information by major emissions source sector is calculated using particulate source apportionment technology (PSAT). The sector contribution information can

[1] On January 10, 2017 (82 FR 3078), the EPA revised the Regional Haze Rule to clarify and streamline certain planning requirements for states. The rule also extended the deadline for second implementation period plans by three years, to July 31, 2021. The second implementation period covers 2019 to 2028.

help us to better understand the sources of future visibility impairment (including domestic anthropogenic, domestic natural, and international anthropogenic and natural sources).

The remaining sections of this TSD are as follows. Section 2 describes the air quality modeling platform and the evaluation of model predictions using measured concentrations. Section 3 defines the procedures for projecting regional haze deciview values to 2028. Section 4 describes (1) the PM source contribution (i.e., particulate source apportionment) modeling and (2) the procedures for quantifying contributions to visibility at individual IMPROVE monitoring sites.

2.0 Air Quality Modeling Platform

The EPA used a 2011-based air quality modeling platform which includes emissions, meteorology, and other inputs for 2011 as the base year for the modeling described in this TSD. The 2011 base year emissions were projected to a future year base case scenario, 2028. The 2011 modeling platform and projected 2028 emissions were used to drive the 2011 base year and 2028 base case air quality model simulations. The 2011 base year emissions and methods for projecting these emissions to 2028 are in large part similar to the data and methods used by EPA in the final Cross-State Air Pollution Rule (CSAPR) Update[2] and the subsequent notice of data availability (NODA)[3] to support ozone transport for the 2015 ozone national ambient air quality standard (NAAQS). The 2011 and 2028 emissions used for this regional haze modeling are described in the documents, "Preparation of Emissions Inventories for the Version 6.3, 2011 Emissions Modeling Platform",[4] "Technical Support Document (TSD) Updates to Emissions Inventories for the Version 6.3 2011 Emissions Modeling Platform for the Year 2028",[5] and "EPA Base Case v.5.16 for 2023 Ozone Transport NODA Using IPM Incremental Documentation."[6] The meteorological data and initial and boundary concentrations used for this regional haze assessment, as described below, are the same as those used for the Final CSAPR Update air quality modeling and the 2015 ozone transport NAAQS NODA.

[2] https://www.epa.gov/airmarkets/final-cross-state-air-pollution-rule-update

[3] https://www.epa.gov/airmarkets/notice-data-availability-preliminary-interstate-ozone-transport-modeling-data-2015-ozone

[4] https://www.epa.gov/air-emissions-modeling/2011-version-63-technical-support-document

[5] https://www.epa.gov/air-emissions-modeling/2011-version-63-platform

[6] https://www.epa.gov/airmarkets/epa-base-case-v516-2015-ozone-naaqs-transport-noda-using-ipm-incremental-documentation

2.1 Air Quality Model Configuration

The photochemical model simulations performed for this ozone transport assessment used the Comprehensive Air Quality Model with Extensions (CAMx version 6.32) which is a version of CAMx v6.30 (Ramboll Environ, 2016) with updated Carbon Bond chemistry (CB6r4).[7] CAMx is a three-dimensional grid-based Eulerian air quality model designed to simulate the formation and fate of oxidant precursors, primary and secondary particulate matter concentrations, and deposition over regional and urban spatial scales (e.g., the contiguous U.S.). Consideration of the different processes (e.g., transport and deposition) that affect primary (directly emitted) and secondary (formed by atmospheric processes) pollutants at the regional scale in different locations is fundamental to understanding and assessing the effects of emissions on air quality concentrations.

Figure 2-1 shows the geographic extent of the modeling domain that was used for air quality modeling in this analysis. The domain covers the 48 contiguous states along with the southern portions of Canada and the northern portions of Mexico. As discussed later, the limited coverage of Canada and Mexico is an important consideration when interpreting the modeling results. This modeling domain contains 25 vertical layers with a top at about 17,550 meters, or 50 millibars (mb), and horizontal grid resolution of 12 km x 12 km. The model simulations produce hourly air quality concentrations for each 12 km grid cell across the modeling domain.

CAMx requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded, hourly emissions estimates and meteorological data, and boundary concentrations. Separate emissions inventories were prepared for the 2011 base year and the 2028 base case. All other inputs (i.e., meteorological fields, initial concentrations, and boundary concentrations) were specified for the 2011 base year model application and remained unchanged for the future-year model simulations.[8]

[7] The updates to the Carbon Bond chemical mechanism in CB6r4 are described in a Technical Memorandum “EMAQ4-07_Task7_TechMemo_1Aug16.pdf” which can be found in the docket for the CSAPR Update. CAMx v6.32 is a pre-release version of CAMx v6.40.

[8] The CAMx annual simulations for 2011 and 2028 were each performed using two time segments (January 1 through April 30, 2011 with a 10-day ramp-up period at the end of December 2010 and May 1 through December 31, 2011 with a 10-day ramp-up period at the end of April 2011).

Figure 2-1. *Map of the CAMx modeling domain used for regional haze modeling.*

Table 2-1 below list the three CAMx model runs which were performed for this analysis. There is a 2011 base case model run, a 2028 future base case model run, and a separate 2028 PSAT source apportionment run.

Table 2-1 CAMx model runs for 2011 and 2028.

Scenario Name	Scenario	Description
2011el	2011 base case	Historical base case
2028el	2028 future base case	Future year “on the books” base case
2028el_secsa	2028 PSAT sector source apportionment case	Source apportionment case which produces both 2028 “bulk outputs” and source sector tag outputs

2.2 Meteorological Data for 2011

The 2011 meteorological data for the air quality modeling of 2011 and 2028 were derived from running Version 3.4 of the Weather Research and Forecasting Model (WRF) (Skamarock, et al., 2008). The meteorological outputs from WRF include hourly-varying horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each vertical layer in each grid cell. Selected physics options used in the WRF simulation include Pleim-Xiu land surface model (Xiu and Pleim, 2001; Pleim and Xiu, 2003), Asymmetric Convective Model version 2 planetary boundary layer scheme (Pleim 2007a,b), Kain-Fritsch cumulus parameterization (Kain, 2004) utilizing the moistureadvection trigger (Ma and Tan, 2009), Morrison double moment microphysics (Morrison, et al., 2005; Morrison and Gettelman, 2008), and Rapid Radiative Transfer Model-Global (RRTMG) longwave and shortwave radiation schemes (Iacono, et.al., 2008).

The WRF model simulation was initialized using the 12km North American Model (12NAM) analysis product provided by the National Climatic Data Center (NCDC). Where 12NAM data were unavailable, the 40km Eta Data Assimilation System (EDAS) analysis (ds609.2) from the National Center for Atmospheric Research (NCAR) was used. Analysis nudging for temperature, wind, and moisture was applied above the boundary layer only. The model simulations were conducted in 5.5 day blocks with soil moisture and temperature carried from one block to the next via the "ipxwrf" program (Gilliam and Pleim, 2010). Land use and land cover data were based on the 2006 National Land Cover Database (NLCD2006) data.[9] Sea surface temperatures at 1 km resolution were obtained from the Group for High Resolution Sea Surface Temperatures (GHRSST) (Stammer, et al., 2003). As shown in Table 2-2, the WRF simulations were performed with 35 vertical layers up to 50 mb, with the thinnest layers being nearest the surface to better resolve the planetary boundary layer (PBL). The WRF 35-layer structure was collapsed to 25 layers for the CAMx air quality model simulations, as shown in Table 2-2.

Table 2-2. WRF and CAMx layers and their approximate height above ground level.

CAMx Layers	WRF Layers	Sigma P	Pressure (mb)	Approximate Height (m AGL)
25	35	0.00	50.00	17,556
	34	0.05	97.50	14,780
24	33	0.10	145.00	12,822
	32	0.15	192.50	11,282
23	31	0.20	240.00	10,002
	30	0.25	287.50	8,901
22	29	0.30	335.00	7,932
	28	0.35	382.50	7,064
21	27	0.40	430.00	6,275
	26	0.45	477.50	5,553
20	25	0.50	525.00	4,885
	24	0.55	572.50	4,264
19	23	0.60	620.00	3,683
18	22	0.65	667.50	3,136

[9] The 2006 NLCD data are available at http://www.mrlc.gov/nlcd06_data.php

CAMx Layers	WRF Layers	Sigma P	Pressure (mb)	Approximate Height (m AGL)
17	21	0.70	715.00	2,619
16	20	0.74	753.00	2,226
15	19	0.77	781.50	1,941
14	18	0.80	810.00	1,665
13	17	0.82	829.00	1,485
12	16	0.84	848.00	1,308
11	15	0.86	867.00	1,134
10	14	0.88	886.00	964
9	13	0.90	905.00	797
	12	0.91	914.50	714
8	11	0.92	924.00	632
	10	0.93	933.50	551
7	9	0.94	943.00	470
	8	0.95	952.50	390
6	7	0.96	962.00	311
5	6	0.97	971.50	232
4	5	0.98	981.00	154
	4	0.99	985.75	115
3	3	0.99	990.50	77
2	2	1.00	995.25	38
1	1	1.00	997.63	19

Details of the annual 2011 meteorological model simulation and evaluation are provided in a separate technical support document (US EPA, 2014a) which can be obtained at http://www.epa.gov/ttn/scram/reports/MET_TSD_2011_final_11-26-14.pdf

The meteorological data generated by the WRF simulations were processed using wrfcamx v4.3 (Ramboll Environ, 2014) meteorological data processing program to create model-ready meteorological inputs to CAMx.[10] In running wrfcamx, vertical eddy diffusivities (Kv) were calculated using the Yonsei University (YSU) (Hong and Dudhia, 2006) mixing scheme. We used a minimum Kv of 0.1 m^2/sec except for urban grid cells where the minimum Kv was

[10] The meteorological data used for the preliminary 2015 ozone transport assessment modeling are the same as the meteorological data EPA used for the final CSAPR Update air quality modeling.

reset to 1.0 m^2/sec within the lowest 200 m of the surface in order to enhance mixing associated with the nighttime "urban heat island" effect. In addition, we invoked the subgrid convection and subgrid stratoform cloud options in our wrfcamx run for 2011.

2.3 Initial and Boundary Concentrations

The lateral boundary and initial species concentrations are provided by a three-dimensional global atmospheric chemistry model, GEOS-Chem (Yantosca, 2004) standard version 8-03-02 with 8-02-01 chemistry. The global GEOS-Chem model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS-5; additional information available at: http://gmao.gsfc.nasa.gov/GEOS/ and http://wiki.seas.harvard.edu/geos-chem/index.php/GEOS-5). This model was run for 2011 with a grid resolution of 2.0 degrees x 2.5 degrees (latitude-longitude). The predictions were used to provide one-way dynamic boundary concentrations at one-hour intervals and an initial concentration field for the CAMx simulations. The 2011 boundary concentrations from GEOS-Chem were used for the 2011 and 2028 model simulations. The procedures for translating GEOS-Chem predictions to initial and boundary concentrations are described elsewhere (Henderson, 2014). More information about the GEOS-Chem model and other applications using this tool is available at: http://www-as.harvard.edu/chemistry/trop/geos.

2.4 Emissions Inventories

CAMx requires detailed emissions inventories containing temporally allocated (i.e., hourly) emissions for each grid-cell in the modeling domain for a large number of chemical species that act as primary pollutants and precursors to secondary pollutants. Annual emission inventories for 2011 and 2028 were preprocessed into CAMx-ready inputs using the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system (Houyoux et al., 2000).[11]

The emissions data in the 2011 platform are primarily based on the 2011NEIv2 for point sources, nonpoint sources, commercial marine vessels (CMV), nonroad mobile sources and fires. The onroad mobile source emissions are similar to those in the 2011NEIv2, but were generated using the released 2014a version of the Motor Vehicle Emissions Simulator (MOVES2014a). The 2011 emissions were also projected to 2028 using various sector dependent methodologies. Onroad and nonroad mobile source emissions were created for 2028 using the MOVES and NONROAD models, respectively. Electric generating unit (EGU)

[11] The SMOKE output emissions case name for the 2011 base year is "2011el_cb6v2_v6_11g" and the emissions case name for the 2023 base case is "2023el_cb6v2_v6_11g".

emissions for 2028 were derived from the Integrated Planning Model (IPM v.5.16).[12] Fugitive dust emissions from anthropogenic sources (i.e., agricultural tilling and unpaved roads) are included in the nonpoint sector of the inventory, but wind-blown dust from natural sources is not accounted for in the inventory. Detailed information on the emissions inventories used as input to the 2011 and 2028 CAMx model simulations can be found in the emissions inventory technical support documents identified in Section 2.0.

2.5 Air Quality Model Evaluation

An operational model performance evaluation was performed for particulate matter ($PM_{2.5}$ species components and coarse PM) and regional haze to examine the ability of the CAMx v6.32 modeling system to simulate 2011 measured concentrations. This evaluation focused on graphical analyses and statistical metrics of model predictions versus observations. Regional statistics and summaries are presented by the NOAA Climate Regions shown in Figure 2-2 below. Details on the evaluation methodology, the calculation of performance statistics, and results are provided in Appendix A.

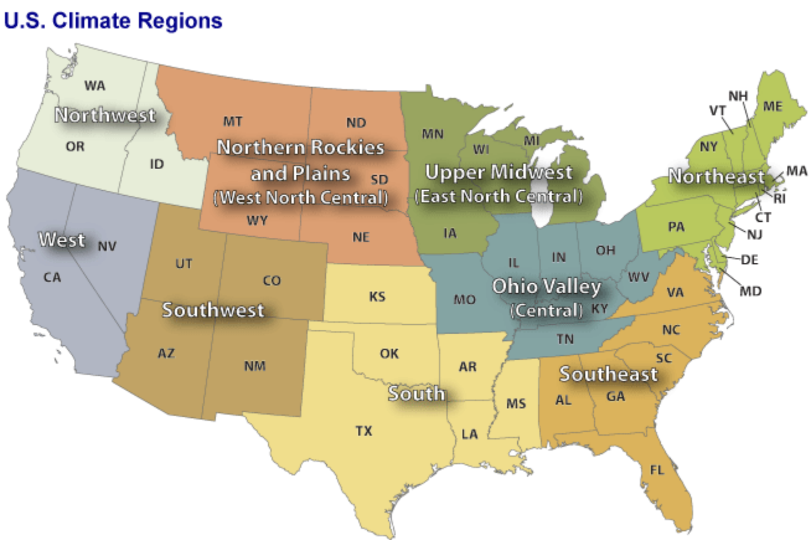

***Figure 2-2**. Climate regions used for aggregating model performance.*

Source: https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php

[12] The 2028 EGU emissions (from IPM) were based on a model run from 2016, which assumed that the Clean Power Plan (CPP) and Texas regional haze FIP were in place. See https://www.epa.gov/airmarkets/epas-power-sector-modeling-support-notice-data-availability-preliminary-interstate-ozone.

The model evaluation was focused on the ability of the model to predict visibility-reducing PM at Class I areas (represented by IMPROVE monitoring sites). The analysis looked at monthly and seasonal average PM species component performance at IMPROVE and other PM monitoring networks, and performance on the 20% most impaired (and 20% clearest) days[13] at individual IMPROVE sites. This provides a comprehensive assessment of the components that make up visibility performance.

The measured concentrations of PM components such as sulfate and nitrate on the 20% most impaired days at many Class I areas in the West are extremely small. Numerous Western Class I areas have average sulfate and nitrate observations (on the 20% most impaired days) of less than 1 $\mu g/m^3$. This makes it challenging to correctly model observed visibility. Assumptions regarding particular emissions categories and boundary conditions can have a large impact on model performance. Even when model performance appears to be accurate, it is difficult (without further modeling and analysis) to determine if we are getting the right answer for the right reasons (for example, when the extinction is dominated by modeled boundary conditions).

Overall, the visibility performance for 2011 was mixed. In different parts of the country, varying PM components contribute to visibility impairment, which also varies by season. The modeling system was generally able to correctly simulate the relatively high sulfate contributions to visibility impairment in the Northeast, Upper Midwest, Ohio Valley, and Southeast, but sulfate concentrations (and extinction levels) in those regions were also generally underpredicted. In the Northern Rockies, Northwest, Southwest, and West, sulfate is often the largest contributor to visibility impairment, but nitrate, coarse mass, and organic carbon can also be important contributors. The modeling system generally underpredicted sulfate on the 20% most impaired days across the domain, with an especially large underprediction in the Southwest. Nitrate on the 20% most impaired days was underpredicted in the southern portion of the domain, again, especially in the Southwest. However, nitrate on the 20% most impaired days was overpredicted in the Northwest and Northern Rockies regions. Coarse mass was underpredicted in many areas of the Southwest and West, where it can be an important contributor to visibility impairment. Organic carbon performance was mixed, with large underprediction and overprediction biases in most parts of the country.

Appendix A contains more detailed maps, tables, figures, and descriptions of model performance including individual IMPROVE site information. Performance issues seen in the 2011 operational performance evaluation, combined with the 2028 source apportionment

[13] The values for the 20% most impaired and clearest days are calculated according to the draft recommended method in the draft EPA guidance document “Draft Guidance for the Second Implementation Period of the Regional Haze Rule” posted at https://www.epa.gov/visibility/regional-haze-guidance-technical-support-document-and-data-file.

results (see section 4) indicate a large amount of uncertainty in the model results at many Class I areas (especially in the western U.S.). Improvements in emissions inputs, boundary conditions, and model chemistry may help improve model performance, particularly in the Northern Rockies, Northwest, West, and the Southwest regions.

3.0 Projection of Future Year 2028 Visibility

The PM predictions from the 2011 and 2028 CAMx model simulations were used to project 2009-2013 IMPROVE visibility data to 2028 following the approach described in EPA's ozone, $PM_{2.5}$ and regional haze modeling guidance (US EPA, 2014b).[14] The guidance describes the recommended modeling analysis used to help set reasonable progress goals (RPGs) that reflect emissions controls in a regional haze SIP.

3.1 Regional Haze Rule Requirement

As required by the Regional Haze Rule (RHR) RPGs must provide for an improvement in visibility for the 20 percent most anthropogenically impaired days relative to baseline visibility conditions and ensure no degradation in visibility for the 20 percent clearest days relative to baseline visibility conditions.[15] The baseline for each Class I area is the average visibility (in deciviews) for the years 2000 through 2004.[16] The visibility conditions in these years are the benchmark for the "provide for an improvement" and "no degradation" requirements. In addition, states are required to determine the rate of improvement in visibility needed to reach natural conditions by 2064 for the 20 percent most anthropogenically impaired days.[17] A line drawn between the end of the 2000-2004 baseline period and 2064 (dv/year) shows a uniform rate of progress (URP) between these two points. This "glidepath" is the amount of visibility improvement needed in each implementation period, starting from the baseline period, to stay on a linear path towards visibility improvement to natural conditions by 2064. The glidepath represents a linear or uniform rate of progress. This is a framework for consideration but there is no requirement to be on or below the glidepath. An example glidepath plot is shown in Figure 2-3.

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[14] The EPA's regional haze (and ozone/$PM_{2.5}$) modeling guidance is referred to as "the modeling guidance" in the remainder of this document.

[15] 40 CFR 51.308(f)(3)(i).

[16] 40 CFR 51.308(f)(1) and definitions in 51.301.

[17] 40 CFR 51.308(f)(1).

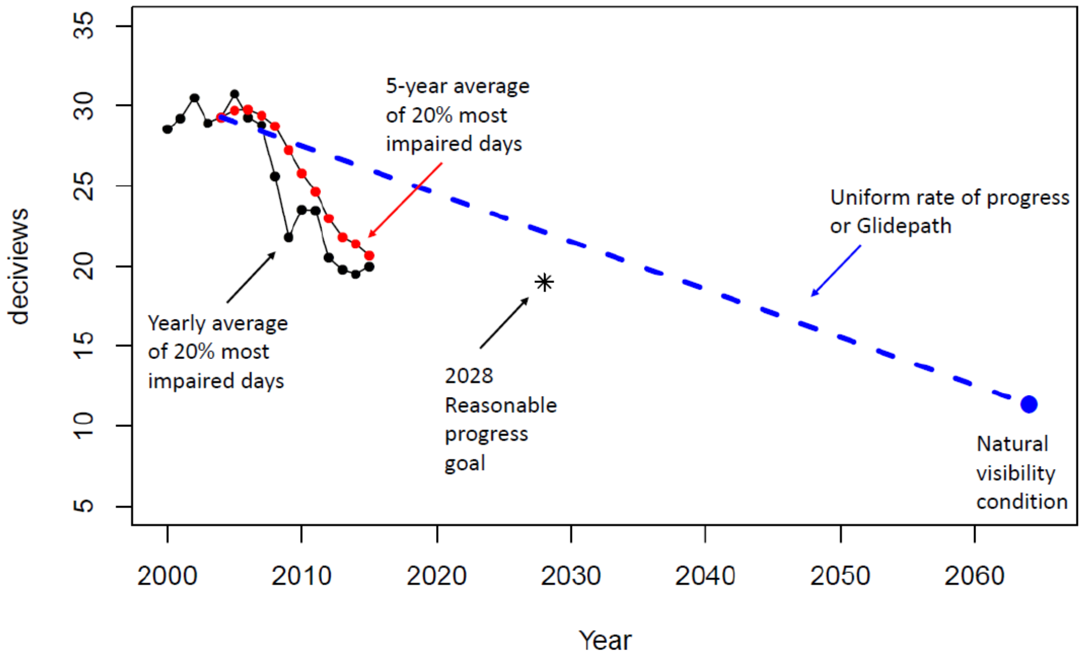

***Figure 2-3** Example Glidepath Plot.*

The RHR requires states to submit an implementation plan that evaluates reasonable progress for implementation periods in approximately ten year increments. The next regional haze SIP is due in 2021, for the implementation period which ends in 2028 (period of 2019-2028). Therefore, modeling was used to project visibility to 2028 using a 2028 emissions inventory with "on-the-books" controls. The EPA Software for Model Attainment Test-Community Edition (SMAT-CE) tool was used to calculate 2028 deciview values on the 20% most impaired and 20% clearest days at each Class I Area (IMPROVE site).[18] SMAT-CE is an EPA software tool which implements the procedures in the modeling guidance[19] to project visibility to a future year.[20]

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[18] The base year (2009-2013) IMPROVE data for the 20% most impaired and 20% clearest days was calculated based on the draft EPA method described in "Draft Guidance for the Second Implementation Period of the Regional Haze Rule."

[19] The procedures in the modeling guidance were followed except we used the "20% most impaired days" instead of the "20% worst days". The draft guidance is in the process of being updated to refer to the 20% most impaired days (to reflect the revised regional haze rule).

[20] A beta version of SMAT-CE is available here: https://www.epa.gov/scram/photochemical-modeling-tools

3.2 Calculation of 2028 Visibility

The visibility projections follow the procedures in section 4.8 of the modeling guidance. Based on the recommendation in the modeling guidance, the observed base period visibility data is linked to the base modeling year. This is the 5-year ambient data base period centered about the base modeling year. In this case, for a base modeling year of 2011, the ambient IMPROVE data should be from the 2009-2013 period.[21]

The visibility calculations use the "revised" IMPROVE equation (Hand, 2006); (Pitchford, 2007), which has replaced the original IMPROVE equation and has been used in most regional haze SIPs over the last 10 years. The IMPROVE equation (or algorithm) uses PM species concentrations and relative humidity data to calculate visibility impairment or beta extinction (bext) in units of extinction (expressed in inverse megameters (Mm^{-1}) as follows:

bext = 2.2 x $f_S(RH)$ x [Small Sulfate] + 4.8 x $f_L(RH)$ x [Large Sulfate]
+ 2.4 x $f_S(RH)$ x [Small Nitrate] + 5.1 x $f_L(RH)$ x [Large Nitrate]
+ 2.8 x {Small Organic Mass] + 6.1 x [Large Organic Mass]
+ 10 x [Elemental Carbon]
+ 1 x [Fine Soil]
+ 1.7 x $f_{ss}(RH)$ x [Sea Salt]
+ 0.6 x [Coarse Mass]
+ Rayleigh Scattering (site specific)

The total sulfate, nitrate, and organic carbon compound concentrations are each split into two fractions, representing small and large size distributions of those components. Site-specific Rayleigh scattering is calculated based on the elevation and annual average temperature of each IMPROVE monitoring site. See (Hand, 2006) for more details.

The 2028 future year visibility on the 20% most impaired days[22] and 20% clearest days at each

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[21] The *baseline period* for the regional haze program continues to be 2000-2004, and the uniform rate of progress is calculated using that historical data. However, the modeled visibility projections should use ambient data from a 5-year *base period* that corresponds to the modeled base year meteorological and emissions data. Also, unlike the ozone and $PM_{2.5}$ attainment tests, the calculation is a 5-year mean, where each year counts equally (unlike the 5-year weighted average values for the ozone and $PM_{2.5}$ attainment test).

[22] Note that the modeling guidance refers to the 20% worst days and 20% best days, which are not based on the anthropogenic impairment. However, the procedures for processing model results to calculate future year visibility are the same for total impairment and anthropogenic impairment. Future updates to the guidance will refer to the "most impaired" and "clearest" days.

Class I area is estimated by using the observed IMPROVE data (2009-2013) and the relative *percent modeled* change in PM species between 2011 and 2028. The process is described in the following six steps (see the modeling guidance for a more detailed description and examples).

1) For each Class I area (IMPROVE site), estimate anthropogenic impairment on each day using observed speciated $PM_{2.5}$ data plus PM_{10} data (and other information) for each of the 5 years comprising the base period (2009-2013 in this case) and rank the days on this indicator.[23] This ranking will determine the 20 percent most anthropogenically impaired days. For each Class I area, also rank observed visibility (in deciviews) on each day using observed speciated $PM_{2.5}$ data plus PM_{10} data for each of the 5 years comprising the base period. This ranking will determine the 20 percent clearest days.
2) For each of the 5 years comprising the base period, calculate the mean deciviews for the 20 percent most anthropogenically impaired days and 20 percent clearest days. For each Class I area, calculate the 5 year mean deciviews for most impaired and clearest days from the 5 year-specific values.
3) Use an air quality model to simulate air quality with base period (2011) emissions and future year (2028) emissions. Use the resulting information to develop site-specific relative response factors (RRFs) for each component of PM identified in the "revised" IMPROVE equation.[24] The RRFs are an average percent change in species concentrations based on the *measured* 20% most impaired and 20% clearest days from 2011 (the calendar days identified from the IMPROVE data above are matched to the same modeled days).
4) Multiply the species-specific RRFs by the measured daily species concentration data during the 2009-2013 base period (for each day in the measured 20% most impaired day set and each day in the 20% clearest day set), for each site. This results in daily future year 2028 PM species concentration data.
5) Using the results in Step 4 and the IMPROVE algorithm, calculate the future daily extinction coefficients for the previously identified 20 percent most impaired days and 20 percent clearest days in each of the five base years.
6) Calculate daily deciview values (from total daily extinction) and then compute the future

[23] The methodology for determining the most anthropogenically impaired days (which includes the explanation of how anthropogenic vs. natural daily light extinction was determined) can be found in section 5 of the draft regional haze guidance published July 8, 2016. [81 FR 44608]. https://www.epa.gov/visibility/draft-guidance-second-implementation-period-regional-haze-rule.

[24] Relative response factors (RRFs) are calculated for sulfate, nitrate, organic carbon mass, elemental carbon, fine soil mass, and coarse mass. Since observed sea salt is primarily from natural sources which are not expected to be year-sensitive, and the modeled sea salt is uncertain, the sea salt RRF for all sites is assumed to be 1.0.

year (2028) average mean deciviews for the 20 percent most impaired days and 20 percent clearest days for each year. Average the five years together to get the final future mean deciview values for the 20 percent most impaired days and 20 percent clearest days.

The SMAT-CE tool outputs individual year and 5-year average base year and future year deciview values on the 20% most impaired days and 20% clearest days. Additional SMAT output variables include the results of intermediate calculations such as species specific extinction values (both base and future year) and species specific RRFs (on the 20% most impaired and clearest days).

Table 3-1 details the settings used for the SMAT runs to generate the 2028 future year deciview projections:

Table 3-1 SMAT settings for 2028 visibility calculations.

SMAT Option	**Setting or File Used**
IMPROVE algorithm	Use new version
Grid cells at monitor or Class I area centroid?	Use grid cells at monitor
IMPROVE data file	ClassIareas_NEWIMPROVEALG_2000to2015_2017april27_IMPAIRMENT.csv[25]
Baseline file	mats_small.PM.12US2.2011el_cb6r4_v6_11g.csv
Forecast file	mats_small.PM.12US2.2028el_cb6r4_v6_11g.csv
Temporal adjustment at monitor	3 x 3
Start monitor year	2009
End monitor year	2013
Base Model year	2011
Minimum years required for a valid monitor	3

[25] The IMPROVE ambient data file has the 20% most impaired days identified as "group 90" days and 20% clearest days identified as "group 10" days. The definition of most impaired days uses the EPA recommended values from the draft regional haze guidance published July 8, 2016. [81 FR 44608]. https://www.epa.gov/visibility/draft-guidance-second-implementation-period-regional-haze-rule. The IMPROVE data file used for this analysis did not include substituted data. It may be possible to project 2028 visibility for several additional IMPROVE sites if substituted data is incorporated into the ambient data file.

Table 3-2 shows the base and future year deciview values on the 20% clearest and most impaired days at each Class I area for the base model period (2009-2013) and future year (2028).[26]

Table 3-2 Base and future year deciview values on the 20% clearest and 20% most impaired days at each Class I area for the base model period (2009-2013) and future year (2028).

Class I Area Site ID	Class I Area Name	IMPROVE Site ID	Base Year (2009-2013) 20% Clearest Days (dv)	Future Year (2028) 20% Clearest Days (dv)	Base Year (2009-2013) 20% Most Impaired Days (dv)	Future Year (2028) 20% Most Impaired Days (dv)
ACAD	Acadia NP	ACAD1	7.02	6.73	16.84	14.7
AGTI	Agua Tibia Wilderness	AGTI1	6.45	6.23	17.66	15.34
ALLA	Alpine Lake Wilderness	SNPA1	3.89	3.44	13.75	12.49
ANAC	Anaconda-Pintler Wilderness	SULA1	1.85	1.73	8.75	8.48
ANAD	Ansel Adams Wilderness (Minarets)	KAIS1	1.52	1.37	11.69	10.55
ARCH	Arches NP	CANY1	3.04	2.83	8.26	7.46
BADL	Badlands NP	BADL1	5.78	5.42	14.33	12.68
BAND	Bandelier NM	BAND1	3.99	3.96	9.17	8.72
BIBE	Big Bend NP	BIBE1	5.65	5.59	14.37	13.93
BLCA	Black Canyon of the Gunnison NM	WEMI1	2.07	1.87	6.83	6.38
BOAP	Bosque del Apache	BOAP1	5.72	5.71	11.19	10.69
BOMA	Bob Marshall Wilderness	MONT1	2.73	2.53	9.83	9.61
BOWA	Boundary Waters Canoe Area	BOWA1	4.86	4.72	16.43	13.81
BRCA	Bryce Canyon NP	BRCA1	1.77	1.64	7.47	7.14
BRET	Breton	BRIS1	13.81	12.29	22.49	18.45
BRID	Bridger Wilderness	BRID1	1.01	0.88	6.91	6.41
BRIG	Brigantine	BRIG1	12.25	10.73	22.26	18.66
CABI	Cabinet Mountains Wilderness	CABI1	2.49	2.11	10.1	9.58
CACR	Caney Creek Wilderness	CACR1	9.74	8.67	20.87	18.51
CANY	Canyonlands NP	CANY1	3.04	2.83	8.26	7.46
CAPI	Capitol Reef NP	CAPI1	2.61	2.41	8.05	7.42
CARI	Caribou Wilderness	LAVO1	2.03	1.89	10.08	9.57

[26] The 2028 results are calculated for 136 Class I areas which are represented by 94 IMPROVE sites. Results are not shown for Class I areas which are outside of the modeling domain (outside of the contiguous U.S.), and for Class I areas which did not have complete IMPROVE data in 2011, or did not have at least 3 years of complete IMPROVE data in the 2009-2013 period.

Class I Area Site ID	Class I Area Name	IMPROVE Site ID	Base Year (2009-2013) 20% Clearest Days (dv)	Future Year (2028) 20% Clearest Days (dv)	Base Year (2009-2013) 20% Most Impaired Days (dv)	Future Year (2028) 20% Most Impaired Days (dv)
CAVE	Carlsbad Caverns NP	GUMO1	5.25	4.95	12.81	11.97
CHAS	Chassahowitzka	CHAS1	13.76	12.73	19.94	17.14
CHIR	Chiricahua NM	CHIR1	4.13	3.87	9.99	9.38
CHIW	Chiricahua Wilderness	CHIR1	4.13	3.87	9.99	9.38
COHU	Cohutta Wilderness	COHU1	10.94	9.11	21.19	15.15
CRLA	Crater Lake NP	CRLA1	1.36	1.25	8.84	8.62
CRMO	Craters of the Moon NM	CRMO1	3.06	2.78	10.44	9.04
DESO	Desolation Wilderness	BLIS1	1.86	1.68	9.4	8.79
DIPE	Diamond Peak Wilderness	CRLA1	1.36	1.25	8.84	8.62
DOME	Dome Land Wilderness	DOME1	4.52	4.25	16.01	14.32
DOSO	Dolly Sods Wilderness	DOSO1	9.03	7.18	21.59	15.11
EACA	Eagle Cap Wilderness	STAR1	2.96	2.75	11.92	10.99
EANE	Eagles Nest Wilderness	WHRI1	-0.09	-0.21	5.71	5.19
EMIG	Emigrant Wilderness	YOSE1	2.62	2.49	12.31	11.28
EVER	Everglades NP	EVER1	11.23	10.66	16.3	15.56
FITZ	Fitzpatrick Wilderness	BRID1	1.01	0.88	6.91	6.41
FLTO	Flat Tops Wilderness	WHRI1	-0.09	-0.21	5.71	5.19
GALI	Galiuro Wilderness	CHIR1	4.13	3.87	9.99	9.38
GEMO	Gearhart Mountain Wilderness	CRLA1	1.36	1.25	8.84	8.62
GLAC	Glacier NP	GLAC1	5.4	4.96	13.89	13.42
GLPE	Glacier Peak Wilderness	NOCA1	2.71	2.52	10.99	10.38
GORO	Goat Rocks Wilderness	WHPA1	1.1	1.01	9.06	8.57
GRCA	Grand Canyon NP	GRCA2	1.83	1.56	7.53	7.48
GRGU	Great Gulf Wilderness	GRGU1	5.87	5.34	15.43	12.41
GRSA	Great Sand Dunes NM	GRSA1	3.81	3.68	8.78	8.24
GRSM	Great Smoky Mountains NP	GRSM1	10.63	9.05	21.39	15.63
GRTE	Grand Teton NP	YELL2	1.51	1.28	7.41	6.94
GUMO	Guadalupe Mountains NP	GUMO1	5.25	4.95	12.81	11.97
HECA	Hells Canyon Wilderness	HECA1	4.12	3.85	13.47	12.06
HEGL	Hercules-Glades Wilderness	HEGL1	10.96	9.64	21.63	18.9
HOOV	Hoover Wilderness	HOOV1	1.12	1.04	7.69	7.24
ISLE	Isle Royale NP	ISLE1	5.4	5.22	17.63	15.06
JARB	Jarbidge Wilderness	JARB1	1.88	1.82	7.73	7.52
JARI	James River Face Wilderness	JARI1	11.79	9.58	21.37	16.03
JOMU	John Muir Wilderness	KAIS1	1.52	1.37	11.69	10.55
JOSH	Joshua Tree NM	JOSH1	4.27	4.2	13.61	12.13

Class I Area Site ID	Class I Area Name	IMPROVE Site ID	Base Year (2009-2013) 20% Clearest Days (dv)	Future Year (2028) 20% Clearest Days (dv)	Base Year (2009-2013) 20% Most Impaired Days (dv)	Future Year (2028) 20% Most Impaired Days (dv)
JOYC	Joyce-Kilmer-Slickrock Wilderness	GRSM1	10.63	9.05	21.39	15.63
KAIS	Kaiser Wilderness	KAIS1	1.52	1.37	11.69	10.55
KALM	Kalmiopsis Wilderness	KALM1	6.01	5.84	12.62	12.23
KICA	Kings Canyon NP	SEQU1	6.87	6.21	19.95	16.36
LABE	Lava Beds NM	LABE1	2.71	2.56	9.87	9.53
LAGA	La Garita Wilderness	WEMI1	2.07	1.87	6.83	6.38
LAVO	Lassen Volcanic NP	LAVO1	2.03	1.89	10.08	9.57
LIGO	Linville Gorge Wilderness	LIGO1	9.7	7.88	20.39	14.62
LYBR	Lye Brook Wilderness	LYEB1	4.89	4.16	18.06	14.15
MABE	Maroon Bells-Snowmass Wilderness	WHRI1	-0.09	-0.21	5.71	5.19
MACA	Mammoth Cave NP	MACA1	13.69	11.72	24.04	20.01
MAMO	Marble Mountain Wilderness	TRIN1	2.55	2.38	10.77	10.18
MAZA	Mazatzal Wilderness	IKBA1	4.38	4.13	9.96	8.96
MELA	Medicine Lake	MELA1	6.56	6.3	16.59	15.5
MEVE	Mesa Verde NP	MEVE1	2.96	2.66	7.92	7.33
MIMO	Mission Mountains Wilderness	MONT1	2.73	2.53	9.83	9.61
MING	Mingo	MING1	12.47	10.98	22.7	19.74
MOHO	Mount Hood Wilderness	MOHO1	1.3	1.22	10.12	9.27
MOJE	Mount Jefferson Wilderness	THSI1	2.63	2.54	11.45	10.96
MOKE	Mokelumne Wilderness	BLIS1	1.86	1.68	9.4	8.79
MOLA	Mountain Lakes Wilderness	CRLA1	1.36	1.25	8.84	8.62
MOOS	Moosehorn	MOOS1	6.71	6.61	15.8	13.9
MORA	Mount Rainier NP	MORA1	3.95	3.71	14.19	13.14
MOWA	Mount Washington Wilderness	THSI1	2.63	2.54	11.45	10.96
MOZI	Mount Zirkel Wilderness	MOZI1	0.44	0.3	6.05	5.49
NOCA	North Cascades NP	NOCA1	2.71	2.52	10.99	10.38
OKEF	Okefenokee	OKEF1	13.34	11.98	20.7	17.34
OLYM	Olympic NP	OLYM1	3.73	3.45	13.22	12.42
OTCR	Otter Creek Wilderness	DOSO1	9.03	7.18	21.59	15.11
PASA	Pasayten Wilderness	PASA1	1.9	1.65	9.27	8.8
PECO	Pecos Wilderness	WHPE1	0.57	0.5	6.96	6.42
PEFO	Petrified Forest NP	PEFO1	4.08	3.68	9.17	8.24
PIMO	Pine Mountain Wilderness	IKBA1	4.38	4.13	9.96	8.96

Class I Area Site ID	Class I Area Name	IMPROVE Site ID	Base Year (2009-2013) 20% Clearest Days (dv)	Future Year (2028) 20% Clearest Days (dv)	Base Year (2009-2013) 20% Most Impaired Days (dv)	Future Year (2028) 20% Most Impaired Days (dv)
PINN	Pinnacles NM	PINN1	7.52	7	14.79	13.29
PORE	Point Reyes NS	PORE1	7.76	7.11	17.02	15.45
PRRA	Presidential Range-Dry River Wilderness	GRGU1	5.87	5.34	15.43	12.41
RAFA	San Rafael Wilderness	RAFA1	4.66	4.3	15.05	13.09
RAWA	Rawah Wilderness	MOZI1	0.44	0.3	6.05	5.49
REDR	Red Rock Lakes	YELL2	1.51	1.28	7.41	6.94
REDW	Redwood NP	REDW1	5.23	4.96	13.36	12.81
ROCA	Roosevelt Campobello International Park	MOOS1	6.71	6.61	15.8	13.9
ROMA	Cape Romain	ROMA1	13.59	12.06	21.48	17.35
ROMO	Rocky Mountain NP	ROMO1	1.6	1.44	9.21	8.2
SACR	Salt Creek	SACR1	7.37	7.55	15.31	14.69
SAGO	San Gorgonio Wilderness	SAGO1	3.38	3.21	15.74	13.28
SAJA	San Jacinto Wilderness	SAGO1	3.38	3.21	15.74	13.28
SAMA	St. Marks	SAMA1	13.33	11.93	20.11	16.85
SAPE	San Pedro Parks Wilderness	SAPE1	1.22	1.07	6.82	6.35
SAWT	Sawtooth Wilderness	SAWT1	3.3	3.13	8.71	8.5
SCAP	Scapegoat Wilderness	MONT1	2.73	2.53	9.83	9.61
SELW	Selway-Bitterroot Wilderness	SULA1	1.85	1.73	8.75	8.48
SENE	Seney	SENE1	5.51	5.29	19.84	16.87
SEQU	Sequoia NP	SEQU1	6.87	6.21	19.95	16.36
SHEN	Shenandoah NP	SHEN1	8.6	6.79	20.72	14.26
SIPS	Sipsey Wilderness	SIPS1	12.84	11.2	21.67	17.64
SOWA	South Warner Wilderness	LABE1	2.71	2.56	9.87	9.53
STMO	Strawberry Mountain Wilderness	STAR1	2.96	2.75	11.92	10.99
SUPE	Superstition Wilderness	TONT1	5.19	4.79	11.04	10.16
SWAN	Swanquarter	SWAN1	11.76	10.68	19.76	15.32
SYCA	Sycamore Canyon Wilderness	SYCA2	5.05	4.55	11.47	10.81
TETO	Teton Wilderness	YELL2	1.51	1.28	7.41	6.94
THIS	Three Sisters Wilderness	THSI1	2.63	2.54	11.45	10.96
THLA	Thousand Lakes Wilderness	LAVO1	2.03	1.89	10.08	9.57
THRO	Theodore Roosevelt NP	THRO1	6.38	6.02	15.71	14.42
ULBE	UL Bend	ULBE1	4.03	3.86	11.9	11.15
UPBU	Upper Buffalo Wilderness	UPBU1	9.95	8.78	20.52	18.08

Class I Area Site ID	Class I Area Name	IMPROVE Site ID	Base Year (2009-2013) 20% Clearest Days (dv)	Future Year (2028) 20% Clearest Days (dv)	Base Year (2009-2013) 20% Most Impaired Days (dv)	Future Year (2028) 20% Most Impaired Days (dv)
VENT	Ventana Wilderness	PINN1	7.52	7	14.79	13.29
WEEL	West Elk Wilderness	WHRI1	-0.09	-0.21	5.71	5.19
WEMI	Weminuche Wilderness	WEMI1	2.07	1.87	6.83	6.38
WHIT	White Mountain Wilderness	WHIT1	3.34	3.25	10.58	9.98
WHPA	Mount Adams Wilderness	WHPA1	1.1	1.01	9.06	8.57
WHPE	Wheeler Peak Wilderness	WHPE1	0.57	0.5	6.96	6.42
WICA	Wind Cave NP	WICA1	3.99	3.75	12.31	10.87
WIMO	Wichita Mountains	WIMO1	9.22	8.55	20.32	17.94
WOLF	Wolf Island	OKEF1	13.34	11.98	20.7	17.34
YELL	Yellowstone NP	YELL2	1.51	1.28	7.41	6.94
YOBO	Yolla Bolly Middle Eel Wilderness	TRIN1	2.55	2.38	10.77	10.18
YOSE	Yosemite NP	YOSE1	2.62	2.49	12.31	11.28

Figure 3-1 shows the predicted change in deciviews at each Class I area (IMPROVE site) on the 20% most impaired days between 2011 and 2028 (2028 deciviews minus 2011 deciviews). The visibility improvement in the east is generally large, in the range of a 2-6 deciview improvement. Most sites in the west show a relatively small deciview improvement of less than 2 deciviews. There are 35 Class I areas in the west with a projected deciview improvement of less than 0.5 deciviews.

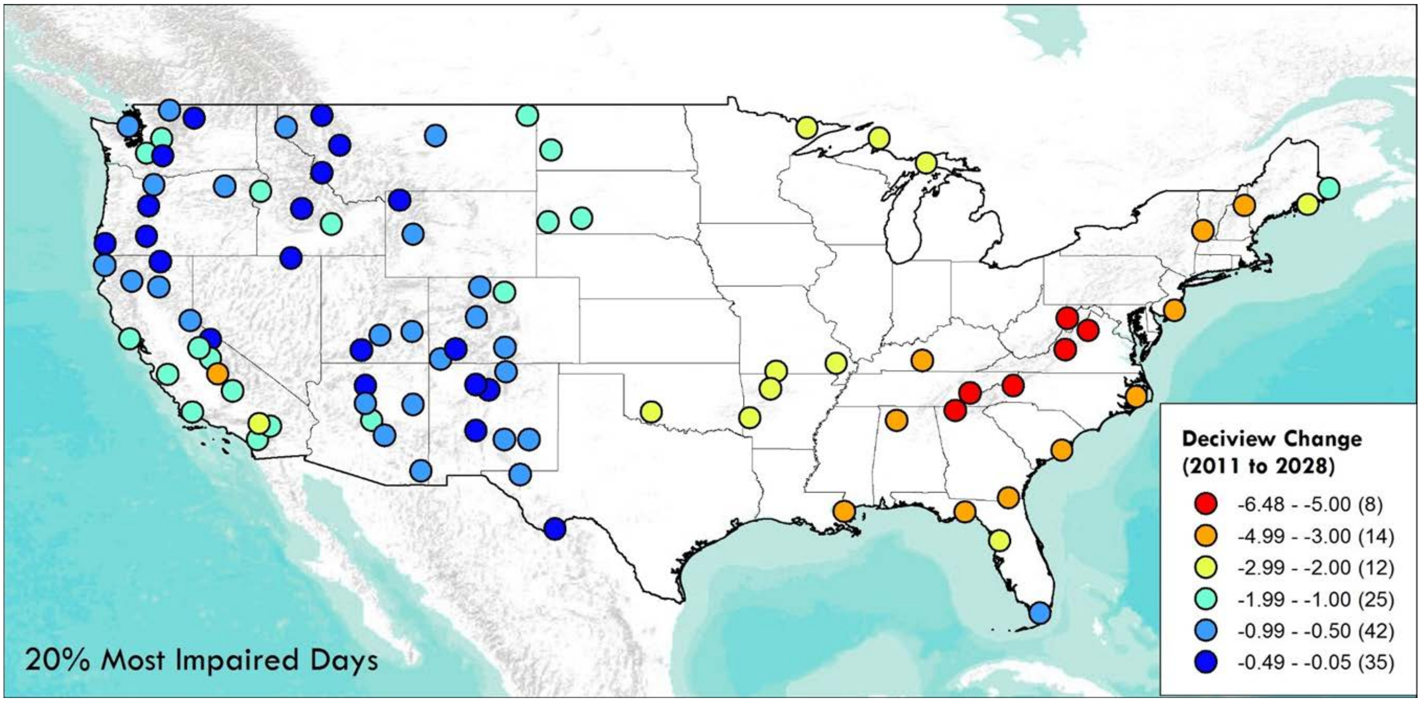

***Figure 3-1**- Change in deciviews at IMPROVE sites[27] between 2011 and 2028 (2028 – 2011).*

3.3 Comparison to Regional Haze "Glidepath"

The future year 2028 deciview projections can be compared to the unadjusted visibility "glidepath" at each Class I area, as defined above.[28] The unadjusted "glidepath" represents the amount of visibility improvement needed in each implementation period, starting from the baseline 2000-2004 period, to stay on a linear path to natural visibility conditions by 2064. Visibility on the 20% most impaired days is compared to the relevant value of the glidepath, in this case for a future year of 2028. Since the glidepath is a linear path between 2004 and 2064, a glidepath value (in deciviews) can be calculated for any future year, using a simple equation. The following formula was used to calculate the 2028 glidepath value:

[27] The map shows results at IMPROVE sites. Note that many IMPROVE sites represent more than one Class I area.

[28] The projected 2028 visibility level is compared to the "unadjusted" glidepath for each Class I area because we expect stakeholders to be interested in this comparison. No adjustments have been made for impacts from international anthropogenic sources or wildland prescribed fires, as would be an option under the Regional Haze Rule. The relevance of this comparison to SIP development is beyond the scope of this modeling. See 40 CFR 51.308(f)(3)(ii) and (iii) for more information.

Glidepath$_{2028}$= Baseline avg deciview – (((Baseline avg deciview – Natural conditions)/60)*24)

Where

> **Baseline avg deciview** = average observed deciview value on the 20% most impaired days for 2000-2004 (in dv)
>
> **Natural conditions**= Natural conditions on the 20% most impaired days at the Class I area (in dv)

Table 3-3 shows the 2028 glidepath values (in dv) at each Class I area, including the data needed to calculate the glidepath (natural conditions and the 2000-2004 baseline deciview values).[29] The observed 2009-2013 values and projected 2028 values are repeated from Table 3-2.

Table 3-3 Natural conditions, 2000-2004 baseline visibility, observed 2009-2013 visibility, 2028 projected visibility, and 2028 glidepath values (all in deciviews).

Class I Area ID	Class I Area Name	State	IMPROVE Site ID	Natural Conditions 20% Most Impaired Days (dv)	Observed 00-04 Baseline 20% Most Impaired Days(dv)	Observed 09-13 Impairment 20% Most Impaired Days(dv)	Projected 2028 Impairment 20% Most Impaired Days(dv)	2028 Glidepath 20% Most Impaired Days(dv)
ACAD	Acadia NP	ME	ACAD1	10.39	22.01	16.84	14.70	17.36
AGTI	Agua Tibia Wilderness	CA	AGTI1	7.63	21.62	17.66	15.34	16.03
ALLA	Alpine Lake Wilderness	WA	SNPA1	7.25	15.37	13.75	12.49	12.12
ANAC	Anaconda-Pintler Wilderness	MT	SULA1	5.48	10.06	8.75	8.48	8.23
ANAD	Ansel Adams Wilderness (Minarets)	CA	KAIS1	5.98	N/A	11.69	10.55	N/A
ARCH	Arches NP	UT	CANY1	4.11	8.79	8.26	7.46	6.92
BADL	Badlands NP	SD	BADL1	6.09	14.98	14.33	12.68	11.42
BAND	Bandelier NM	NM	BAND1	4.59	9.70	9.17	8.72	7.65
BIBE	Big Bend NP	TX	BIBE1	5.33	15.57	14.37	13.93	11.47
BLCA	Black Canyon of the Gunnison NM	CO	WEMI1	3.98	7.81	6.83	6.38	6.28

[29] The values for the 20% most impaired and clearest days and natural conditions are calculated according to the draft recommended method in the draft EPA guidance document "Draft Guidance for the Second Implementation Period of the Regional Haze Rule" posted at https://www.epa.gov/visibility/regional-haze-guidance-technical-support-document-and-data-file.

Class I Area ID	Class I Area Name	State	IMPROVE Site ID	Natural Conditions 20% Most Impaired Days (dv)	Observed 00-04 Baseline 20% Most Impaired Days(dv)	Observed 09-13 Impairment 20% Most Impaired Days(dv)	Projected 2028 Impairment 20% Most Impaired Days(dv)	2028 Glidepath 20% Most Impaired Days(dv)
BOAP	Bosque del Apache	NM	BOAP1	5.36	11.61	11.19	10.69	9.11
BOMA	Bob Marshall Wilderness	MT	MONT1	5.43	10.84	9.83	9.61	8.68
BOWA	Boundary Waters Canoe Area	MN	BOWA1	9.11	N/A	16.43	13.81	N/A
BRCA	Bryce Canyon NP	UT	BRCA1	4.08	8.42	7.47	7.14	6.68
BRET	Breton	LA	BRIS1	9.28	N/A	22.49	18.45	N/A
BRID	Bridger Wilderness	WY	BRID1	3.90	7.96	6.91	6.41	6.34
BRIG	Brigantine	NJ	BRIG1	10.69	27.43	22.26	18.66	20.74
CABI	Cabinet Mountains Wilderness	MT	CABI1	5.65	10.73	10.10	9.58	8.70
CACR	Caney Creek Wilderness	AR	CACR1	9.47	23.99	20.87	18.51	18.18
CANY	Canyonlands NP	UT	CANY1	4.11	8.79	8.26	7.46	6.92
CAPI	Capitol Reef NP	UT	CAPI1	4.13	N/A	8.05	7.42	N/A
CARI	Caribou Wilderness	CA	LAVO1	6.14	11.50	10.08	9.57	9.36
CAVE	Carlsbad Caverns NP	TX	GUMO1	4.83	14.60	12.81	11.97	10.69
CHAS	Chassahowitzka	FL	CHAS1	8.97	24.62	19.94	17.14	18.36
CHIR	Chiricahua NM	AZ	CHIR1	4.93	10.50	9.99	9.38	8.27
CHIW	Chiricahua Wilderness	AZ	CHIR1	4.93	10.50	9.99	9.38	8.27
COHU	Cohutta Wilderness	GA	COHU1	9.52	N/A	21.19	15.15	N/A
CRLA	Crater Lake NP	OR	CRLA1	5.22	9.36	8.84	8.62	7.70
CRMO	Craters of the Moon NM	ID	CRMO1	4.97	11.91	10.44	9.04	9.13
DESO	Desolation Wilderness	CA	BLIS1	4.91	10.06	9.40	8.79	8.00
DIPE	Diamond Peak Wilderness	OR	CRLA1	5.22	9.36	8.84	8.62	7.70
DOME	Dome Land Wilderness	CA	DOME1	6.18	17.20	16.01	14.32	12.79
DOSO	Dolly Sods Wilderness	WV	DOSO1	8.92	28.29	21.59	15.11	20.54
EACA	Eagle Cap Wilderness	OR	STAR1	6.59	14.53	11.92	10.99	11.35
EANE	Eagles Nest Wilderness	CO	WHRI1	3.02	6.30	5.71	5.19	4.99
EMIG	Emigrant Wilderness	CA	YOSE1	6.29	13.52	12.31	11.28	10.63
EVER	Everglades NP	FL	EVER1	8.34	19.54	16.30	15.56	15.06
FITZ	Fitzpatrick Wilderness	WY	BRID1	3.90	7.96	6.91	6.41	6.34

Class I Area ID	Class I Area Name	State	IMPROVE Site ID	Natural Conditions 20% Most Impaired Days (dv)	Observed 00-04 Baseline 20% Most Impaired Days(dv)	Observed 09-13 Impairment 20% Most Impaired Days(dv)	Projected 2028 Impairment 20% Most Impaired Days(dv)	2028 Glidepath 20% Most Impaired Days(dv)
FLTO	Flat Tops Wilderness	CO	WHRI1	3.02	6.30	5.71	5.19	4.99
GALI	Galiuro Wilderness	AZ	CHIR1	4.93	10.50	9.99	9.38	8.27
GEMO	Gearhart Mountain Wilderness	OR	CRLA1	5.22	9.36	8.84	8.62	7.70
GLAC	Glacier NP	MT	GLAC1	6.99	16.19	13.89	13.42	12.51
GLPE	Glacier Peak Wilderness	WA	NOCA1	6.79	N/A	10.99	10.38	N/A
GORO	Goat Rocks Wilderness	WA	WHPA1	6.15	10.48	9.06	8.57	8.75
GRCA	Grand Canyon NP	AZ	GRCA2	4.18	7.94	7.53	7.48	6.44
GRGU	Great Gulf Wilderness	NH	GRGU1	9.78	21.93	15.43	12.41	17.07
GRSA	Great Sand Dunes NM	CO	GRSA1	4.45	9.66	8.78	8.24	7.58
GRSM	Great Smoky Mountains NP	TN	GRSM1	10.05	29.16	21.39	15.63	21.51
GRTE	Grand Teton NP	WY	YELL2	3.98	8.30	7.41	6.94	6.57
GUMO	Guadalupe Mountains NP	TX	GUMO1	4.83	14.60	12.81	11.97	10.69
HECA	Hells Canyon Wilderness	OR	HECA1	6.57	16.51	13.47	12.06	12.53
HEGL	Hercules-Glades Wilderness	MO	HEGL1	9.30	25.17	21.63	18.90	18.82
HOOV	Hoover Wilderness	CA	HOOV1	4.91	8.97	7.69	7.24	7.35
ISLE	Isle Royale NP	MI	ISLE1	10.15	19.53	17.63	15.06	15.78
JARB	Jarbidge Wilderness	NV	JARB1	5.23	8.73	7.73	7.52	7.33
JARI	James River Face Wilderness	VA	JARI1	9.48	28.08	21.37	16.03	20.64
JOMU	John Muir Wilderness	CA	KAIS1	5.98	N/A	11.69	10.55	N/A
JOSH	Joshua Tree NM	CA	JOSH1	6.09	17.74	13.61	12.13	13.08
JOYC	Joyce-Kilmer-Slickrock Wilderness	TN	GRSM1	10.05	29.16	21.39	15.63	21.51
KAIS	Kaiser Wilderness	CA	KAIS1	5.98	N/A	11.69	10.55	N/A
KALM	Kalmiopsis Wilderness	OR	KALM1	7.80	13.35	12.62	12.23	11.13
KICA	Kings Canyon NP	CA	SEQU1	6.29	23.23	19.95	16.36	16.45
LABE	Lava Beds NM	CA	LABE1	6.16	11.29	9.87	9.53	9.24
LAGA	La Garita Wilderness	CO	WEMI1	3.98	7.81	6.83	6.38	6.28
LAVO	Lassen Volcanic NP	CA	LAVO1	6.14	11.50	10.08	9.57	9.36

Class I Area ID	Class I Area Name	State	IMPROVE Site ID	Natural Conditions 20% Most Impaired Days (dv)	Observed 00-04 Baseline 20% Most Impaired Days(dv)	Observed 09-13 Impairment 20% Most Impaired Days(dv)	Projected 2028 Impairment 20% Most Impaired Days(dv)	2028 Glidepath 20% Most Impaired Days(dv)
LIGO	Linville Gorge Wilderness	NC	LIGO1	9.70	28.05	20.39	14.62	20.71
LYBR	Lye Brook Wilderness	VT	LYEB1	10.23	23.57	18.06	14.18	18.23
MABE	Maroon Bells-Snowmass Wilderness	CO	WHRI1	3.02	6.30	5.71	5.19	4.99
MACA	Mammoth Cave NP	KY	MACA1	9.79	29.83	24.04	20.01	21.81
MAMO	Marble Mountain Wilderness	CA	TRIN1	6.24	11.97	10.77	10.18	9.67
MAZA	Mazatzal Wilderness	AZ	IKBA1	5.22	11.19	9.96	8.96	8.80
MELA	Medicine Lake	MT	MELA1	5.95	16.63	16.59	15.50	12.36
MEVE	Mesa Verde NP	CO	MEVE1	4.20	9.22	7.92	7.33	7.22
MIMO	Mission Mountains Wilderness	MT	MONT1	5.43	10.84	9.83	9.61	8.68
MING	Mingo	MO	MING1	9.28	N/A	22.70	19.74	N/A
MOHO	Mount Hood Wilderness	OR	MOHO1	6.60	12.10	10.12	9.27	9.90
MOJE	Mount Jefferson Wilderness	OR	THSI1	7.30	12.80	11.45	10.96	10.60
MOKE	Mokelumne Wilderness	CA	BLIS1	4.91	10.06	9.40	8.79	8.00
MOLA	Mountain Lakes Wilderness	OR	CRLA1	5.22	9.36	8.84	8.62	7.70
MOOS	Moosehorn	ME	MOOS1	9.97	20.66	15.80	13.90	16.38
MORA	Mount Rainier NP	WA	MORA1	7.66	16.53	14.19	13.14	12.98
MOWA	Mount Washington Wilderness	OR	THSI1	7.30	12.80	11.45	10.96	10.60
MOZI	Mount Zirkel Wilderness	CO	MOZI1	3.16	7.29	6.05	5.49	5.64
NOCA	North Cascades NP	WA	NOCA1	6.79	N/A	10.99	10.38	N/A
OKEF	Okefenokee	GA	OKEF1	9.47	25.34	20.70	17.34	18.99
OLYM	Olympic NP	WA	OLYM1	6.88	14.93	13.22	12.42	11.71
OTCR	Otter Creek Wilderness	WV	DOSO1	8.92	28.29	21.59	15.11	20.54
PASA	Pasayten Wilderness	WA	PASA1	5.97	10.41	9.27	8.80	8.63
PECO	Pecos Wilderness	NM	WHPE1	3.53	7.35	6.96	6.42	5.83
PEFO	Petrified Forest NP	AZ	PEFO1	4.21	9.82	9.17	8.24	7.57
PIMO	Pine Mountain Wilderness	AZ	IKBA1	5.22	11.19	9.96	8.96	8.80

Class I Area ID	Class I Area Name	State	IMPROVE Site ID	Natural Conditions 20% Most Impaired Days (dv)	Observed 00-04 Baseline 20% Most Impaired Days(dv)	Observed 09-13 Impairment 20% Most Impaired Days(dv)	Projected 2028 Impairment 20% Most Impaired Days(dv)	2028 Glidepath 20% Most Impaired Days(dv)
PINN	Pinnacles NM	CA	PINN1	6.96	17.02	14.79	13.29	12.99
PORE	Point Reyes NS	CA	PORE1	9.75	19.38	17.02	15.45	15.53
PRRA	Presidential Range-Dry River Wilderness	NH	GRGU1	9.78	21.93	15.43	12.41	17.07
RAFA	San Rafael Wilderness	CA	RAFA1	6.85	N/A	15.05	13.09	N/A
RAWA	Rawah Wilderness	CO	MOZI1	3.16	7.29	6.05	5.49	5.64
REDR	Red Rock Lakes	WY	YELL2	3.98	8.30	7.41	6.94	6.57
REDW	Redwood NP	CA	REDW1	8.54	13.64	13.36	12.81	11.60
ROCA	Roosevelt Campobello International Park	ME	MOOS1	9.97	20.66	15.80	13.90	16.38
ROMA	Cape Romain	SC	ROMA1	9.79	25.25	21.48	17.35	19.07
ROMO	Rocky Mountain NP	CO	ROMO1	4.93	11.12	9.21	8.20	8.64
SACR	Salt Creek	NM	SACR1	5.50	16.54	15.31	14.69	12.12
SAGO	San Gorgonio Wilderness	CA	SAGO1	6.19	20.43	15.74	13.28	14.74
SAJA	San Jacinto Wilderness	CA	SAGO1	6.19	20.43	15.74	13.28	14.74
SAMA	St. Marks	FL	SAMA1	9.19	N/A	20.11	16.85	N/A
SAPE	San Pedro Parks Wilderness	NM	SAPE1	3.36	7.66	6.82	6.35	5.94
SAWT	Sawtooth Wilderness	ID	SAWT1	4.67	9.62	8.71	8.50	7.64
SCAP	Scapegoat Wilderness	MT	MONT1	5.43	10.84	9.83	9.61	8.68
SELW	Selway-Bitterroot Wilderness	MT	SULA1	5.48	10.06	8.75	8.48	8.23
SENE	Seney	MI	SENE1	11.11	23.62	19.84	16.87	18.62
SEQU	Sequoia NP	CA	SEQU1	6.29	23.23	19.95	16.36	16.45
SHEN	Shenandoah NP	VA	SHEN1	9.52	28.32	20.72	14.26	20.80
SIPS	Sipsey Wilderness	AL	SIPS1	9.55	27.71	21.67	17.64	20.44
SOWA	South Warner Wilderness	CA	LABE1	6.16	11.29	9.87	9.53	9.24
STMO	Strawberry Mountain Wilderness	OR	STAR1	6.59	14.53	11.92	10.99	11.35
SUPE	Superstition Wilderness	AZ	TONT1	5.06	11.34	11.04	10.16	8.83
SWAN	Swanquarter	NC	SWAN1	9.79	N/A	19.76	15.32	N/A
SYCA	Sycamore Canyon Wilderness	AZ	SYCA2	4.68	12.16	11.47	10.81	9.17

Class I Area ID	Class I Area Name	State	IMPROVE Site ID	Natural Conditions 20% Most Impaired Days (dv)	Observed 00-04 Baseline 20% Most Impaired Days(dv)	Observed 09-13 Impairment 20% Most Impaired Days(dv)	Projected 2028 Impairment 20% Most Impaired Days(dv)	2028 Glidepath 20% Most Impaired Days(dv)
TETO	Teton Wilderness	WY	YELL2	3.98	8.30	7.41	6.94	6.57
THIS	Three Sisters Wilderness	OR	THSI1	7.30	12.80	11.45	10.96	10.60
THLA	Thousand Lakes Wilderness	CA	LAVO1	6.14	11.50	10.08	9.57	9.36
THRO	Theodore Roosevelt NP	ND	THRO1	5.96	16.35	15.71	14.42	12.19
ULBE	UL Bend	MT	ULBE1	5.87	12.76	11.90	11.15	10.00
UPBU	Upper Buffalo Wilderness	AR	UPBU1	9.43	24.25	20.52	18.08	18.32
VENT	Ventana Wilderness	CA	PINN1	6.96	17.02	14.79	13.29	12.99
WEEL	West Elk Wilderness	CO	WHRI1	3.02	6.30	5.71	5.19	4.99
WEMI	Weminuche Wilderness	CO	WEMI1	3.98	7.81	6.83	6.38	6.28
WHIT	White Mountain Wilderness	NM	WHIT1	4.89	11.31	10.58	9.98	8.74
WHPA	Mount Adams Wilderness	WA	WHPA1	6.15	10.48	9.06	8.57	8.75
WHPE	Wheeler Peak Wilderness	NM	WHPE1	3.53	7.35	6.96	6.42	5.83
WICA	Wind Cave NP	SD	WICA1	5.64	13.09	12.31	10.87	10.11
WIMO	Wichita Mountains	OK	WIMO1	6.92	22.15	20.32	17.94	16.06
WOLF	Wolf Island	GA	OKEF1	9.47	25.34	20.70	17.34	18.99
YELL	Yellowstone NP	WY	YELL2	3.98	8.30	7.41	6.94	6.57
YOBO	Yolla Bolly Middle Eel Wilderness	CA	TRIN1	6.24	11.97	10.77	10.18	9.67
YOSE	Yosemite NP	CA	YOSE1	6.29	13.52	12.31	11.28	10.63

The 2028 future year projected deciview values can be compared to the unadjusted glidepath for 2028 to determine if the Class I area is projected to be above, below, or on the glidepath. While the RHR requires future year projected visibility impairment be compared to the glidepath, it does not require the RPGs be on or below the glidepath. However, the rule has different requirements depending on whether the projected value (RPG) is above or below the glidepath. See 40 CFR 51.308(f)(3)(ii) and (iii) for more information.

Figure 3-2 below combines 2011 model performance information, a representation of the deviation (in deciviews) from the 2028 glidepath, and an uncertainty calculation. The map includes the 2028 projected deciview deviation from the glidepath (color, blue and red), a qualitative representation of model skill (size of gray color), and whether or not uncertainty, represented by alternative projections, is large enough to potentially change the sign of the glidepath deviation for IMPROVE sites in the lower 48 states (vertical bar). Each component is described in more detail as follows:

- Each colored dot represents the IMPROVE station's deviation from the 2028 glidepath for the top 20% most impaired days (red: above; blue: below). The deviation is calculated as the difference between the RRF projected 2028 values compared to the glidepath as above.
- The size of each colored dot (blue, red) is sized inversely proportional to the root mean square error for averaged extinction by species, as described in Equation 1 (as the blue/red gets smaller, the grey gets larger). RMSE ranks sites by magnitude and composition skill using extinction weighted predictions and observations, and is used in a qualitative sense for comparing model performance across sites.

$$RMSE = \left(\frac{\sum_i (\overline{Y_i} - \overline{O_i})^2}{N_i}\right)^{\frac{1}{2}} \qquad \text{Eq. 1}$$

where

$\overline{Y_i} = 1/N_D \sum_{i \in D} y_{i,d}$

$\overline{O_i} = 1/N_D \sum_{i \in D} o_{i,d}$

$D = \{d$: 20% most impaired days$\}$

$N_D =$ # in D

$i \in \{CM, Crustal, AMM_{NO3}, AMM_{SO4}, EC, OMC, SEA\_SALT\}$

- The presence of a vertical bar on some dots represent the potential for boundary condition assumptions to change the sign of the deviation. When a vertical bar is present, the sign can change due to assumptions in boundary conditions alone. We use two alternative assumptions about future boundary conditions to create a range of 2028 projections (see Appendix C).

A relatively large boundary contribution (included in "Mixed") and/or poor model performance will lead to a relatively large 2028 range. The range is relatively small (and therefore less uncertain) if model performance is generally good and the boundary contribution is small. When the site range crosses the glidepath, the range is sufficient to change the sign of the deviation and a vertical bar is overlaid on the IMPROVE sites circle.

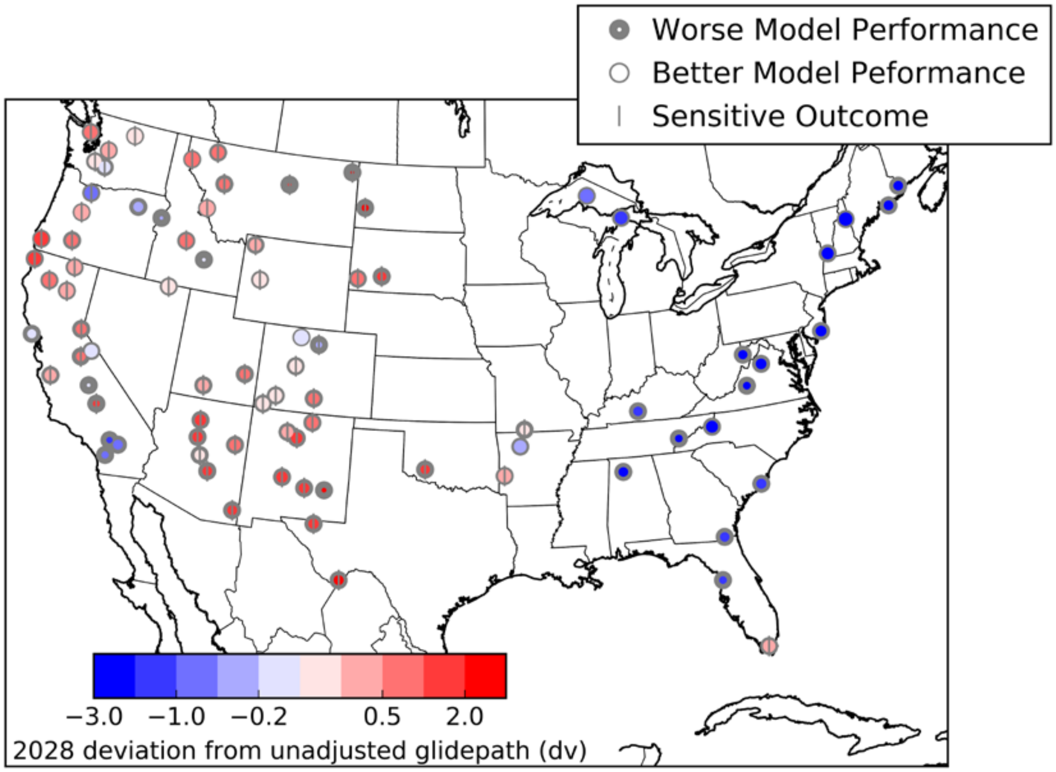

Figure 3-2 *Map of deviation from the 2028 glidepath at IMPROVE sites[30], with additional 2011 model performance and uncertainty information.*

If the sign of the deviation can change and/or model performance is particularly poor, confidence in the projection is low. There are two major features that can be seen in the map. First, Class I areas east of the Mississippi river tend to be significantly below the glidepath (with the exception of the Everglades in South Florida), performance is frequently good, and the binary results (being above or below the glidepath) are insensitive to the boundary condition assumptions. West of the Mississippi river, results are more mixed. For example, several sites in

[30] The map shows results at IMPROVE sites where a 2028 glidepath could be calculated. Note that many IMPROVE sites represent more than one Class I area.

Southern California are projected to be below the glidepath, have low model skill, and are insensitive to boundary conditions. Over large areas in the west, however, the deviation from the glidepath is positive (above the glidepath), model performance is relatively good, but the result *is* sensitive to assumptions in the boundary conditions.

4.0 PSAT Source Apportionment

In order to gain a better understanding of the source contributions to modeled visibility, the EPA used CAMx Particulate Source Apportionment Technology (PSAT) modeling. PSAT uses multiple tracer families to track the fate of both primary and secondary PM (Yarwood et al., 2004). PSAT is designed to apportion the following classes of CAMx PM species:

- Sulfate (PSO4)
- Particulate nitrate (PNO3)
- Ammonium (PNH4)
- Secondary organic aerosol (SOA)
- Primary PM (PEC, POA, FCRS, FPRM, CCRS, and CPRM)
- Particulate mercury (HgP)

For this application, sulfate, nitrate, ammonium, and primary PM were tracked using PSAT. Tracking of SOA contributions may also be of use, but SOA tagging in PSAT adds significant time to the model runs. Therefore, SOA was not explicitly tracked.

PSAT allows emissions to be tracked (tagged) by various combinations of sectors and geographic areas (e.g., by state). For this application, 2028 emissions were tagged by nationwide major source sector (not by state).[31] Table 4-1 below shows the sector tags that were modeled in 2028 using the CAMx PSAT. Each of these emissions source sectors were processed separately through SMOKE and tracked in PSAT as individual source tags. “Notes” included in the table add more information about the nature of some individual source sector tags.

[31] There were 18 source sector tags plus boundary conditions (which are always tracked). This is a reasonable number of tags that can completed in a single model run on the OAQPS computer system. Adding additional tags to track each sector by state would have multiplied the number of tags by 48, for a total of 864 tags (18 x 48 plus boundary conditions).

Table 4-1 CAMx source sector PSAT tags for 2028.

Tag #	Sector Description	SMOKE Sector Name	Notes
1	Biogenics	beis	
2	Area source fugitive dust	afdust	primary PM only
3	Agriculture ammonia	ag	ammonia only
4	Commerical Marine Vessels-onshore	cmv	Onshore port and underway emissions assigned to specific states (mostly within 3 miles of state boundaries)
5	Non-point	nonpt	Area sources that are not O&G
6	Onroad mobile	onroad, onroad_catx_adj	
7	Nonroad mobile	nonroad	
8	Nonpoint and Point oil and gas	np_oilgas, pt_oilgas	
9	Electric Generating Units (EGUs)	ptegu_summer, ptegu_winter	
10	Wildfires	ptwildfire3D	Wildfires (U.S. only)
12	Fires in Mexico and Canada	ptfire_mxca3D	Canada and Mexico, all fires
11	Prescribed fires	ptprescfire3D	Prescribed fires (U.S. only)
13	Agricultural fires	agfire	Ag fires
14	Point non-EGU sources	ptnonipm	All NonEGU point that are not O&G
15	Rail	Rail	
16	Residential Wood Combustion	rwc	
17	Canada and Mexico	othafdust_adj + othar + othon + othpt (excluding offshore)	All anthropopgenic emissions from Canada and Mexico
18	Offshore	othpt_offshore, c1c2_offshore	Offshore CMV - including c1c2 CMV and Gulf oil and gas platform emissions
IC/BC	Initial and Boundary Conditions		PM coming into the modeling domain from GEOSCHEM derived boundary conditions

The CAMx 2011 and 2028 model output was post-processed using a “species definition file” that cross references raw CAMx output species names with PM species needed for SMAT. The results of the post-processing are 24-hour average PM species with the “combine file” output names. These are matched to the SMAT species as shown in Table 4-2.

Table 4-2 Matching of CAMx raw output species to SMAT input variables.

SMAT Species	"Combine File" Output Name	Raw CAMx 6.32 Species
Sulfate	PM25_SO4	PSO4
Nitrate	PM25_NO3	PNO3
Ammonium [32]	PM25_NH4	PNH4
Organic carbon	PM25_OM	POA+SOA1+SOA2+SOPA+SOA3+SOA4+SOA5+SOA6+SOA7+SOPB
Elemental carbon	PM25_EC	PEC
Crustal	CRUSTAL	2.2*PAL+2.49*PSI+1.63*PCA+2.42*PFE+1.94*PTI
Coarse PM	PMC_TOT	CCRS+CPRM
PM2.5	PM25_SMAT	CRUSTAL+PSO4+PNO3+PNH4+PEC+NA+PCL+SOA1+SOA2+SOA3 +SOA4+SOA5+SOA6+SOA7+SOPA+SOPB+POA

4.1 Process for creating PSAT sector contributions for Class I Areas

The PSAT raw "tag" model outputs were post-processed to create SMAT input files. This involves processing both the 2028 "bulk outputs" and the sector specific source apportionment outputs. The "bulk outputs" are the total "bulk" 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 source apportionment outputs. Table 4-3 below shows the SMAT species definitions and matching for the 2028 bulk and 2028 source apportionment results.

[32] 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.

Table 4-3 Matching of "bulk raw species, PSAT output species, and SMAT input variables.

SMAT species	2028 Bulk raw species	2028 Source apportionment tag raw species
Sulfate	PSO4	PS4
Nitrate	PNO3	PN3
Ammonium[33]	PNH4	PN4
Organic carbon	POA + SOA1+ SOA2+ SOPA+ SOA3+ SOA4+ SOA5+ SOA6+ SOA7+ SOPB+ SOAH	POA
Crustal	FCRS	PFC
Coarse PM	CPRM	PCS
PM2.5[34]	PSO4+PNO3+PNH4+POA+PEC+FCRS	PS4+PN3+PN4+POA+PEC+PFC
Elemental carbon	PEC	PEC

The "SMAT species" are the standard PM species needed as input to SMAT. The "Bulk raw species" is the CAMx v6.32 raw output species (from the 2028 "bulk" results) variables that were matched to the SMAT species. The "2028 source apportionment tag raw species" is the CAMx v6.32 raw source apportionment tag output species variables (these are the default raw tag species names in CAMx) that were matched to the SMAT species.

SMAT input files for the 2028 bulk species and sector tag species were created as a first step in calculating the PM and visibility contributions from each tag/sector. The 2028 bulk species SMAT input files contain the 24-hr average daily modeled species concentrations for each grid cell. The "sector tag" SMAT input files contain the 24-hr average daily modeled species concentrations for each sector tag, for each grid cell. The sector tag SMAT input files are created as the *difference* between the baseline 2028 bulk model species concentrations and the concentration from each sector tag group such that the "sector tag" SMAT input files are

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

[34] Note that total $PM_{2.5}$ concentration data is needed as a SMAT input variable, but it is not used in the visibility calculations for regional haze. Visibility calculations only use the species specific model outputs.

2028 baseline concentrations *minus* 2028 sector tag concentrations.
The SMAT input files for the 2028 bulk case and the 2028 sector tags were then used to calculate sector tag extinction fractions using the following process:

1) Regional haze SMAT was run for the 2028 future case using "standard" 2011 and 2028 SMAT input files. In this SMAT run, the advanced option "Create forecast IMPROVE visibility file" was invoked (see picture below). This creates an output file with future year (2028) daily species extinction values at each IMPROVE monitor for each of the 20% best and most impaired days (based on 2011 ambient data). These are the extinction values that can be added and averaged to get the 2028 base case projected deciview values for each site. SMAT generates a new output file called "*scenario_name* Forecast IMPROVE Daily Data.csv" that can be re-used to calculate the sector tag fractions.

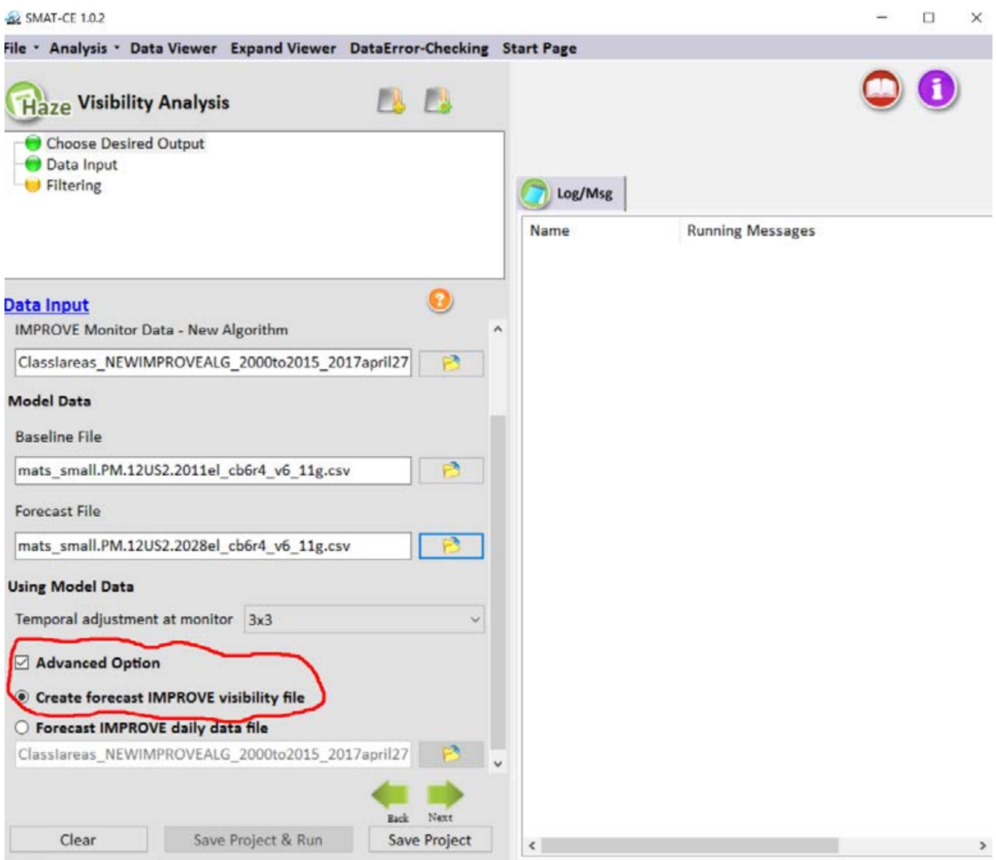

Figure 4-1 *SMAT advanced option "Create forecast IMPROVE visibility file".*

2) SMAT was then run again for each sector tag (18 tags plus boundary conditions), using the "advanced options" shown below. For each SMAT run, the "Forecast IMPROVE Daily Data" file (created as an output file from step 1 above) is used as the "advanced option" input file, the 2028 bulk SMAT input file is used as the "Baseline file", and each 2028 sector tag SMAT input file is used as the "Forecast file". For each sector tag, this creates sector tag species specific RRFs that are multiplied by the 2028 forecast extinction data for each IMPROVE site.

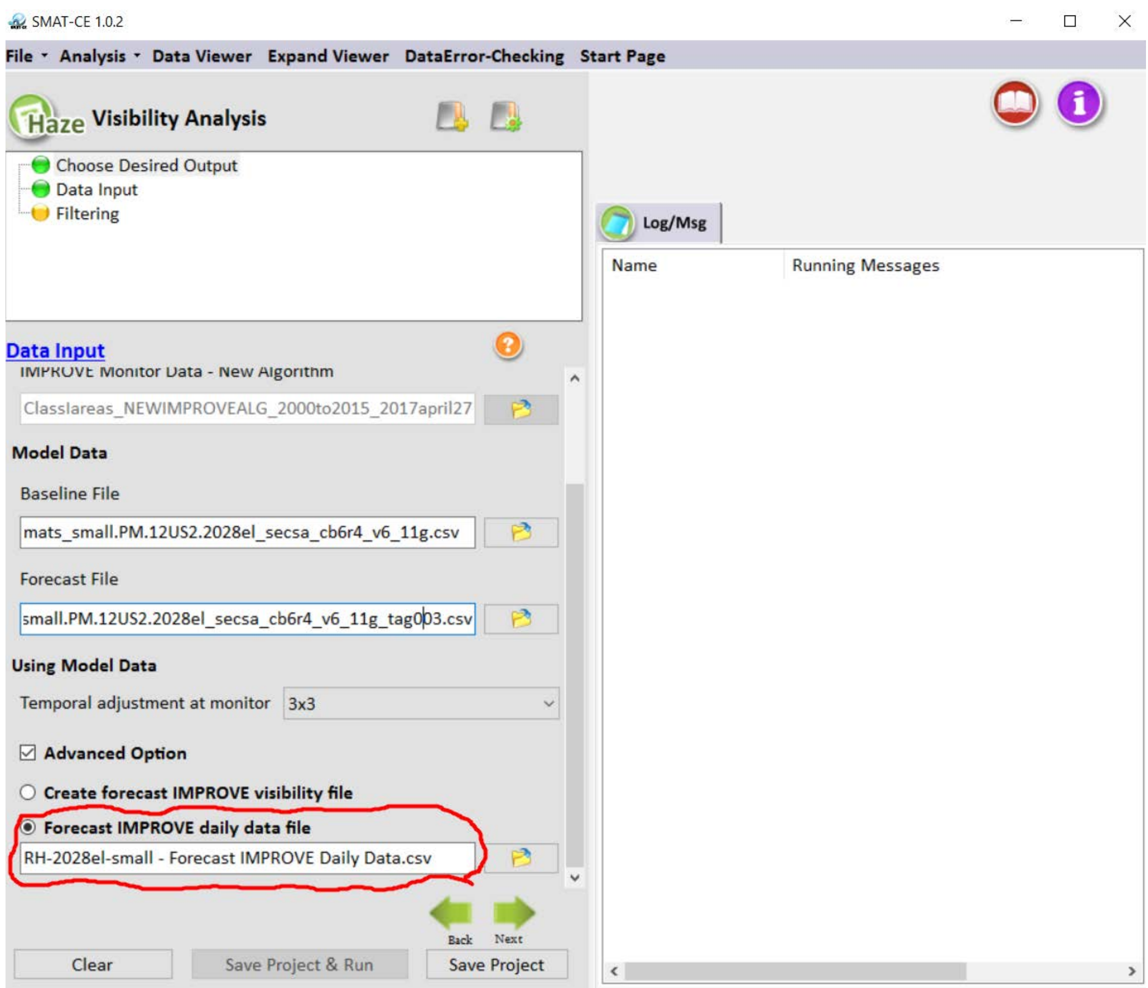

Figure 4-2 *SMAT advanced option "Forecast IMPROVE daily data file".*

3) The total extinction (on the 20% most impaired days) for each sector tag is calculated from the SMAT bulk output file and each of the sector tag output files. The total extinction variable (20% most impaired days) from the bulk file (tbext_g90_f) is subtracted from the total extinction variable from each sector tag output file. The difference is the contribution from the sector tag on the 20% most impaired days (at each IMPROVE site/Class I area). The same calculation can be done for the 20% clearest days by subtracting the total extinction variable on the 20% clearest days

(tbext_g10_f) from both files.

4) As a final step, there are several other extinction components that are calculated separately. Rayleigh scattering is constant and is added to the sector tag totals at each site. Next, the measured extinction from sea salt (E_sea_salt_g90_f) is added directly from the bulk SMAT output file (sea salt is held constant between years and was not tracked by source apportionment). The last PM species that needs to be accounted for is secondary organic aerosol (SOA). SOA was not tracked in PSAT (due to resource constraints), but since every other component of visibility extinction is accounted for in the above calculations, SOA is calculated as the difference between the bulk 2028 total extinction and the sum of all of the tagged sectors (plus Rayleigh and sea salt).

The individual sector tags have been summed into categories and summarized in “Class I area summary plots”, contained in Appendix B. The emissions summary categories are shown in table 4-4.

Table 4-4 Source apportionment emissions summary categories.

Emissions Summary Category	Emissions Sectors (PSAT tags)	Notes
U.S. Anthropogenic	On-road mobile, Non-road mobile, EGUs, NonEGU point, Oil and Gas, Nonpoint (area), Commercial marine (onshore), Prescribed fires, Ag fires, Rail, Residential Wood combustion (RWC)	Most certain contributors to U.S. anthropogenic visibility.
International	Anthropogenic Canada and Mexico	Contribution from Canadian and Mexican emissions within the 12km CONUS domain
Natural	Biogenic, Wildfires (domainwide), Sea salt	Most certain contributors to natural visibility
“Mixed”	Boundary conditions, Fugitive dust, Offshore (commercial marine and oil platforms), Secondary organics	Each of these sectors are particularly uncertain regarding their representation in the model, including their relative contribution of natural vs. international vs. U.S. anthropogenic sources. Need further discussion and assessment to improve our understanding of the contributions.

The summary plots also list the largest U.S. anthropogenic sector contributions for each IMPROVE site (in a pie plot). See Appendix B for the summary plots, including a detailed explanation of the plots.

4.2 Sector Tag Results

The sector tag modeling results were evaluated to better understand the individual source sector contributions to regional haze at Class I areas. See Appendix B for individual IMPROVE site summary plots which contain model performance, 2028 projection, and 2028 source apportionment information. The sector results can also be examined by individual PM species to learn more about which species are the largest contributors to regional haze. Although PM concentration does not linearly correspond to visibility impairment, it is a good surrogate for examining sector contributions to visibility. A convenient way to examine the sector tag results is to look at spatial maps of the raw source apportionment outputs (in modeled concentration units). Below are example plots of monthly average concentrations (in µg/m^3) for several source example sector tags. Additional examples of monthly average source sector tag spatial plots are contained in Appendix D.

The sector source apportionment tag results show that boundary conditions account for the largest contribution to visibility at many Class I areas. Figure 4-3 below shows the 2028 January monthly average nitrate contribution from boundary conditions. This shows a large contribution to nitrate (up to 6.9 µg/m^3 monthly average) in the northern plains, coming from the northern modeling boundary. This is presumably from high modeled nitrate in Canada from the GEOS-Chem model.

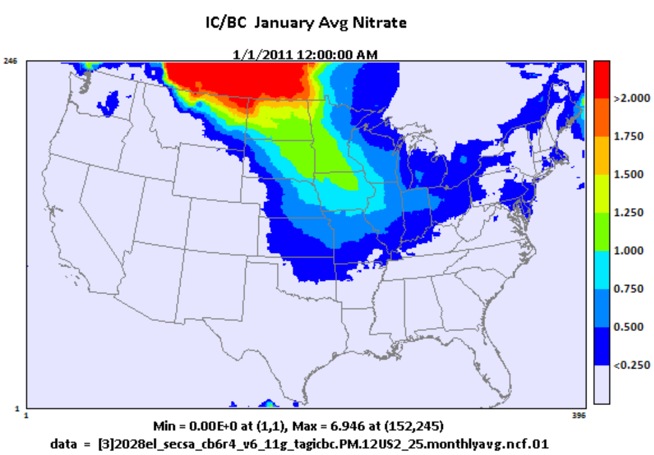

Figure 4-3 *January 2028 monthly average nitrate contribution (in ug/m3) from boundary conditions.*

Relatively high sulfate concentrations can also be seen coming from the boundaries. Figure 4-4 shows the 2028 July monthly average sulfate contribution from boundary conditions. Even though the average sulfate concentration in the contiguous U.S. is generally < 1 µg/m^3, this can be a large percentage of the total modeled sulfate concentrations, especially in the West. This is illustrated in Figure 4-5, which shows the fraction of total July monthly average sulfate from boundary conditions. For example, the orange color is a fraction of > 0.75 which means that more than 75% of the total modeled July average sulfate concentration is coming from boundary conditions.

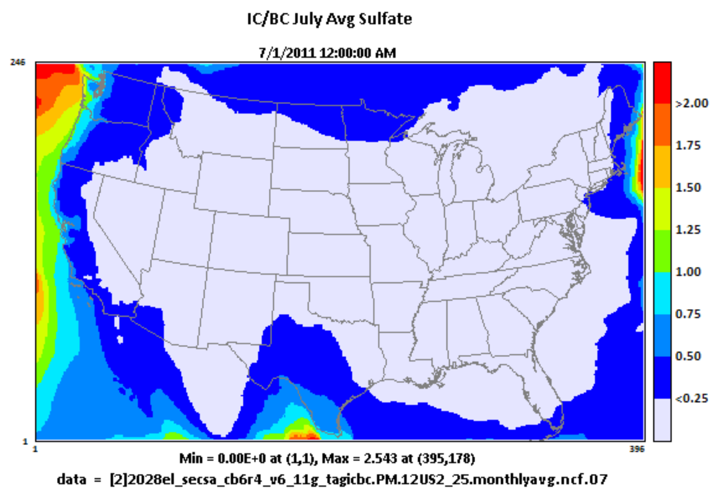

Figure 4-4 *July 2028 monthly average sulfate contribution (in µg/m3) from boundary conditions.*

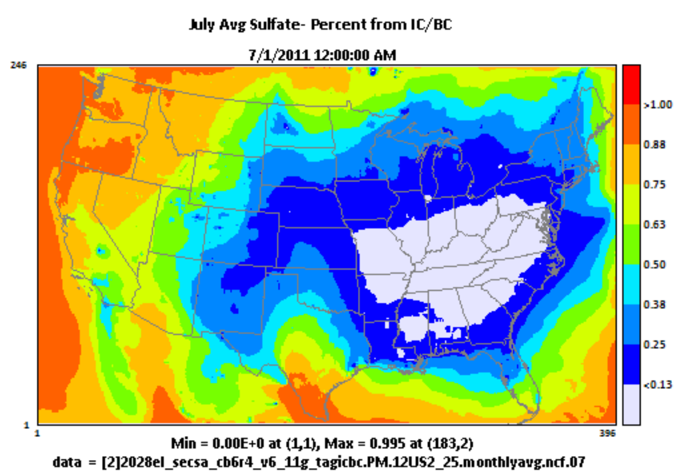

Figure 4-5 *July 2028 monthly average sulfate fraction (1.0 = 100%) from boundary conditions*

Below are several additional example spatial plots. Figure 4-6 shows the 2028 July monthly average sulfate contribution from EGU emissions. The largest impacts from EGUs are concentrated in the area of highest EGU emissions, centered in the Ohio Valley. Impacts in the West are much lower (the gray color on the scale is a monthly average concentration of < 0.05 µg/m3, but), but EGUs in the West can still be a relatively large fraction of the modeled U.S. anthropogenic visibility impacts.

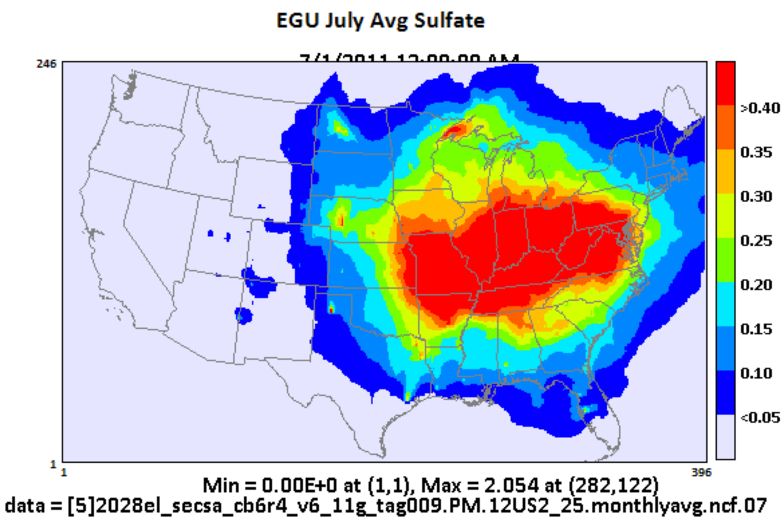

Figure 4-6 *July 2028 monthly average sulfate contribution (in µg/m3) from EGU emissions*

Figure 4-7 shows the 2028 January monthly average nitrate concentrations from offshore marine emissions (commercial marine vessals and offshore platforms). The largest impacts are focused off the coast of Texas, Louisiana, and California, near large ports and ship channels.

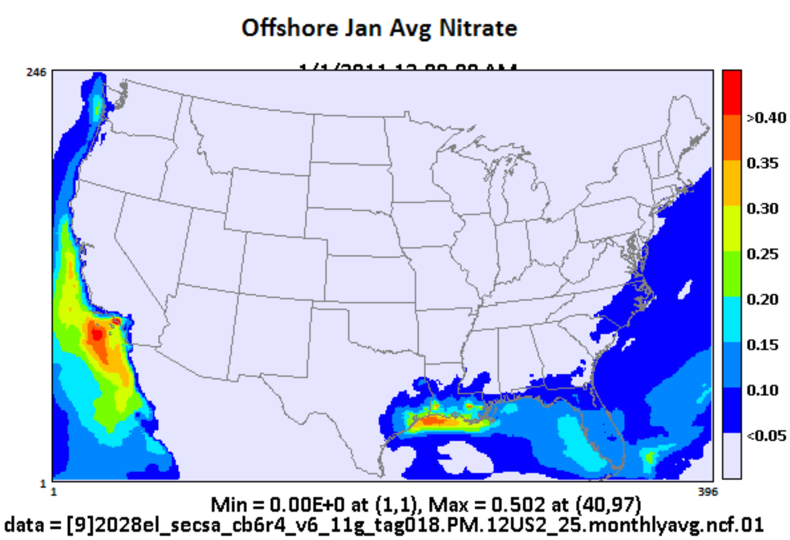

Figure 4-7 *July 2028 monthly average nitrate contribution (in µg/m3) from offshore emissions*

Figure 4-8 shows the 2028 July monthly average organic carbon concentrations from U.S. wildfire emissions. The impacts are large where wildfires occurred in July of 2011 and are relatively low elsewhere. The impacts from fires are highly spatially variable, depending on where and when large fires occurred in 2011.

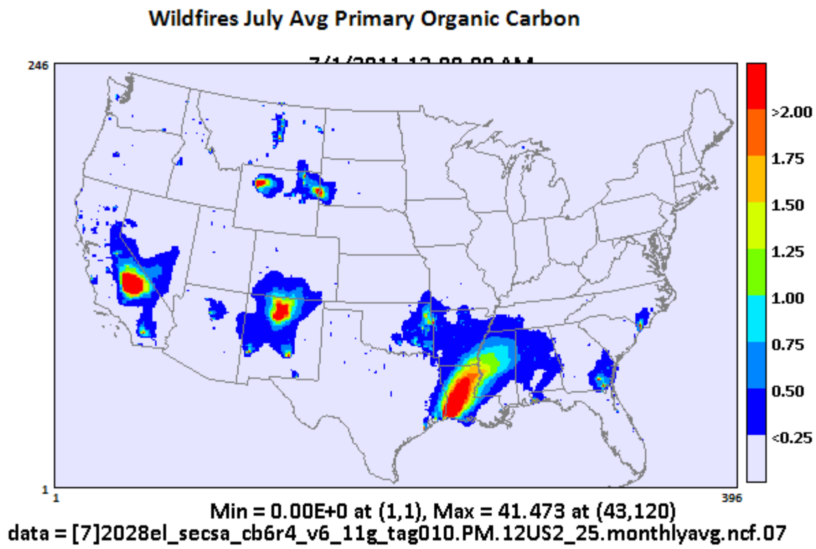

Figure 4-8 *July 2028 monthly average organic carbon contribution (in µg/m3) from U.S. wildfire emissions*

Additional example monthly average spatial plots for the other sector tags can be found in Appendix E.

5.0 Summary

The goal of the modeling was to project 2028 visibility conditions and source sector contribution information for each mandatory Class I federal area/IMPROVE site. The EPA conducted this preliminary visibility modeling with the intention of informing the regional haze state implementation plan (SIP) development process for the second implementation period.

Visibility at most eastern Class I areas on the 20% most anthropogenically impaired days is projected to be below the unadjusted glidepath in 2028, with a relatively higher percentage of the light extinction due to domestic anthropogenic sources. At many western Class I areas, visibility is projected to be above the unadjusted glidepath. However, at most of the western areas, the projections relative to the unadjusted glidepath are uncertain because of greater uncertainties associated with certain sources of the light extinction (in particular, boundary conditions) and in some cases, poor model performance.

Based on our assessment of these results, we identified a number of uncertainties and model performance issues that should be addressed in future EPA, state, multistate, or stakeholder modeling that may be used in SIP development. We have identified several aspects of this initial modeling that should be improved upon through coordination with interested stakeholders. These include, but are not limited to:

- *Expanded domain size* to reduce the impact of the boundary conditions assumptions on predictions, especially near the domain edge.
    - The boundary conditions were found to be the largest contributor to visibility at many Class I areas, especially those near the edge of the modeling domain. Expanding the regional photochemical modeling domain will potentially reduce the influence from global or hemispheric model derived boundary conditions. Those models have much coarser grid resolution and use global emissions inventories which may not be year specific or up to date.
    - There may also be recirculation of U.S. emissions in boundary conditions derived from global models, especially where the boundary is very close to the U.S. mainland. Moving the domain boundary further from the contiguous U.S. will minimize this issue.
- *Updated emission inventory and projections for certain sectors*
    - More recent nationwide photochemical modeling has incorporated updates in future year emissions inventories that should be considered for 2028.
        - Remove the Clean Power Plan and Texas regional haze FIP from the EGU assumptions.
        - Updates to the oil and gas emissions projections.
        - New Canadian base and future year emissions.
        - Other emissions updates based on more recent information.
- *Updated boundary conditions* based on more recent modeling of international emissions as well as additional modeling to help quantify and distinguish anthropogenic and natural international contributions.
    - The 2011 boundary conditions used for the regional haze modeling came from an older version of GEOS-Chem which did not contain the latest international emissions estimates for 2011.
    - In addition to projecting U.S. emissions to 2028, international emissions are changing between 2011 and 2028 as well. Consideration should be given to estimating future year global emissions to provide an alternate estimate of future year boundary conditions.

    - Global or hemispheric models can potentially be used to adjust the visibility glidepath for impacts from international anthropogenic sources. Sensitivity runs and additional refinements to international inventories may be needed in order to provide more confidence in the model results.[35]
- *Improved treatment of fire and fugitive dust emissions* in the model.
    - The current CAMx modeling platform does not include estimates of natural windblown dust emissions. Windblown dust (primarily contributing to coarse mass) is an important component of regional haze in some Class I areas.
    - The current modeling used year-specific fire emissions from 2011 which may not be representative of a "typical year" or multi-year period. The IMPROVE measurements used to establish both the base period impairment measurements and progress towards natural conditions, use a five-year average of IMPROVE measurements. Therefore, alternative estimates of fire emissions, which may better represent a longer term average, may be more appropriate for use in visibility projections.
    - Further refinements of fire emissions may also allow exploration of possible adjustments of the glidepath for prescribed fire impacts.
- *Treatment of secondary organic aerosols (SOA)* should be reviewed.
    - In many locations, there is relatively high modeled SOA as a fraction of total organic aerosols. Using the RRF approach, this apportions the modeled SOA as a fraction of the measured total organics. There is considerable uncertainty in the modeled SOA concentrations, which therefore translates into uncertainty in the apportioned SOA mass.
    - Additional information can be gained by running PSAT with SOA source apportionment turned on.
- *Estimation of "natural visibility conditions"* used in the glidepath framework should be further reviewed.
    - Further refinements in the draft methodology can be explored.
    - Further analysis of the IMPROVE data combined with modeled source apportionment information may be useful in evaluating the natural conditions estimates.

[35]Because boundary conditions in this modeling cannot be separated between anthropogenic and natural sources and because the modeling domain boundary is quite close to the U.S. border in some locations, such that recirculation of U.S. emissions back into the U.S. could not be explicitly distinguished, it is not possible to use these modeling results to adjust the glidepath for international anthropogenic impacts even as a pro forma analysis. We also recommend against attempting to use these modeling results to adjust the glidepath for prescribed fire impacts due to the uncertainties described in this TSD.

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Appendix A

Model Performance Evaluation

1. Model Evaluation Statistics and Regions

In order to estimate the ability of CAMx to replicate the 2011 base year concentrations of $PM_{2.5}$ and its speciated components, an operational model performance evaluation was conducted. For this evaluation, mean bias and normalized mean bias, mean error and normalized mean error, and Pearson's correlation coefficient were used.

Mean bias (MB) is the average difference between predicted (P) and observed (O) concentrations for a given number of samples (n):

$$MB\ (\mu g\ m^{-3}) = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)$$

Mean error (ME) is the average absolute value of the difference between predicted and observed concentrations for a given number of samples:

$$ME\ (\mu g\ m^{-3}) = \frac{1}{n}\sum_{i=1}^{n}|P_i - O_i|$$

Normalized mean bias (NMB) is the sum of the difference between predicted and observed values divided by the sum of the observed values:

$$NMB\ (\%) = \frac{\sum_1^n (P - O)}{\sum_1^n (O)} * 100$$

Normalized mean error (NME) is the sum of the absolute value of the difference between predicted and observed values divided by the sum of the observed values:

$$NME\ (\%) = \frac{\sum_1^n |P - O|}{\sum_1^n (O)} * 100$$

Pearson's correlation coefficient is defined as:

$$r = \frac{\sum_{i=1}^{n}(P_i - \bar{P})(O_i - \bar{O})}{\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}}$$

Model predictions were paired in space and time with observational data from the IMPROVE, CSN, and CASTNET monitoring networks. These results were organized by network, season (winter (DJF), spring (MAM), summer (JJA), and fall (SON)), and NOAA climate region (Figure 1).

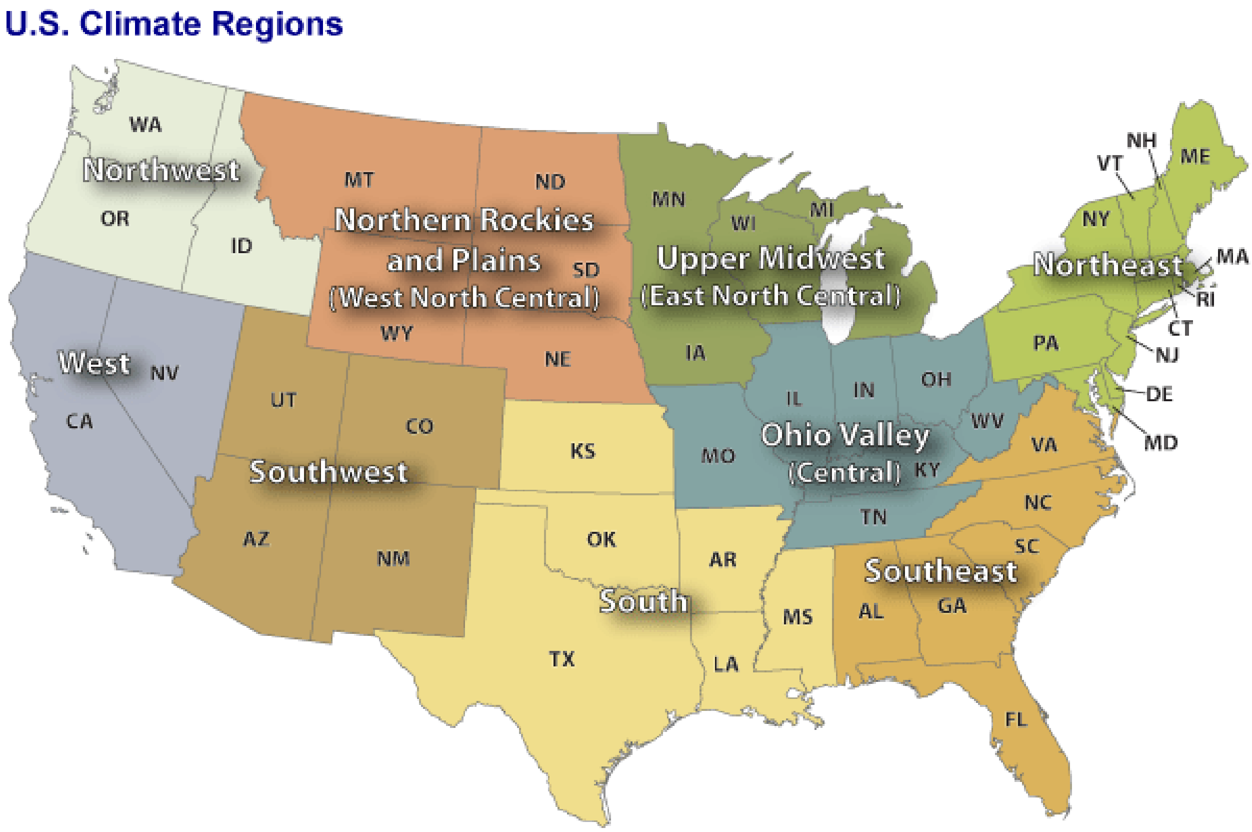


Figure 1. Climate regions used for aggregating model performance. Source: https://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-regions.php

2. PM2.5 Sulfate

Table 2-1 summarizes model performance statistics for PM2.5 sulfate. Boxplot comparisons of model predictions and observations (IMPROVE, CSN, and CASTNET) by month for each climate region are shown in Figures 1, 2, and 3. Nationwide spatial plots of NMB and NME for each season are shown in Figures 4 and 5.

Sulfate performance across seasons, networks, and regions is generally mixed. A notable underprediction of sulfate is observed across rural locations in the southwest and most of California during the summer. NMBs range from -57.5% to -45.1% in the west during the summer and -50.4% to -48.1% in the southwest during the summer. This underprediction is also noticeable during the fall, though the magnitude of the underprediction is less. Sulfate is also underpredicted in the east in the summer, with notable overpredictions in the northeast across all seasons. Sulfate is also overpredicted in the northwest in all seasons, with a smaller overprediction occurring in the summer.

Table 2-1. Model performance statistics for PM2.5 sulfate by region, network, and season.

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
Northeast	**IMPROVE**	Winter	368	1.23	1.48	0.75	19.9	39.7	0.25	0.49
		Spring	413	1.18	1.79	0.58	51.0	61.8	0.60	0.73
		Summer	373	1.78	1.91	0.72	7.0	48.6	0.13	0.87
		Fall	371	1.23	1.53	0.79	24.7	43.1	0.30	0.53
		All	1525	1.35	1.68	0.69	24.2	48.6	0.33	0.66
	CSN	Winter	677	1.99	2.12	0.58	6.2	34.7	0.12	0.69
		Spring	717	1.85	2.13	0.73	15.0	33.3	0.28	0.62
		Summer	720	3.07	2.71	0.84	-11.8	30.0	-0.36	0.92
		Fall	685	1.71	1.91	0.83	12.0	32.0	0.21	0.55
		All	2799	2.16	2.22	0.78	2.7	32.2	0.06	0.70
	CASTNET	Winter	170	1.79	1.75	0.83	-2.0	21.5	-0.04	0.38
		Spring	193	1.82	1.96	0.68	7.6	25.9	0.14	0.47
		Summer	186	2.84	2.32	0.88	-18.3	26.2	-0.52	0.74
		Fall	197	1.66	1.74	0.86	5.2	18.9	0.09	0.31
		All	746	2.02	1.95	0.83	-3.9	23.6	-0.08	0.48
Southeast	**IMPROVE**	Winter	263	1.63	2.06	0.66	26.1	40.4	0.43	0.66
		Spring	266	2.28	2.34	0.50	2.4	40.1	0.06	0.92
		Summer	277	3.27	2.41	0.72	-26.4	35.0	-0.87	1.15
		Fall	267	1.63	1.85	0.70	13.3	38.4	0.22	0.63
		All	1073	2.22	2.17	0.64	-2.3	37.9	-0.05	0.84
	CSN	Winter	435	1.82	2.25	0.65	23.8	37.7	0.43	0.69
		Spring	454	2.58	2.53	0.48	-2.1	36.1	-0.05	0.93
		Summer	471	3.34	2.42	0.59	-27.7	36.4	-0.92	1.22

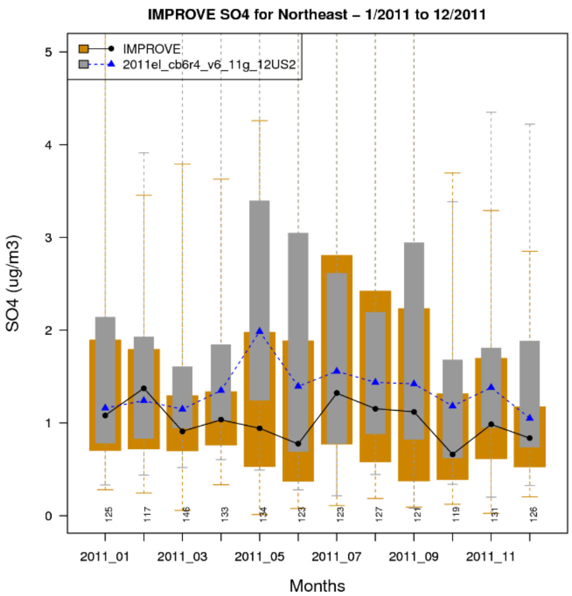
Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Fall	442	1.63	1.82	0.67	11.5	33.5	0.19	0.55
		All	1802	2.36	2.26	0.57	-4.4	36.1	-0.10	0.85
	CASTNET	Winter	138	1.96	2.02	0.66	3.3	20.1	0.06	0.39
		Spring	146	2.68	2.12	0.35	-21.0	28.5	-0.56	0.77
		Summer	147	3.49	2.12	0.82	-39.2	39.5	-1.37	1.38
		Fall	150	1.86	1.63	0.61	-12.4	27.2	-0.23	0.51
		All	581	2.50	1.97	0.63	-21.2	30.6	-0.53	0.77
Ohio Valley	**IMPROVE**	Winter	181	1.96	2.05	0.84	4.6	26.0	0.09	0.51
		Spring	205	2.37	2.33	0.60	-1.9	34.7	-0.04	0.82
		Summer	196	3.66	2.64	0.78	-28.0	35.4	-1.02	1.30
		Fall	196	1.75	1.89	0.70	8.0	36.7	0.14	0.65
		All	778	2.45	2.23	0.73	-8.7	33.7	-0.21	0.82
	CSN	Winter	588	2.23	1.98	0.72	-11.3	30.8	-0.25	0.69
		Spring	625	2.68	2.88	0.65	7.5	37.2	0.20	1.00
		Summer	649	3.90	3.24	0.80	-17.0	30.7	-0.66	1.20
		Fall	611	1.94	1.90	0.79	-2.0	29.8	-0.04	0.58
		All	2473	2.71	2.52	0.76	-7.1	32.2	-0.19	0.87
	CASTNET	Winter	201	2.37	2.16	0.83	-9.0	20.2	-0.21	0.48
		Spring	214	2.70	2.34	0.64	-13.3	21.0	-0.36	0.57
		Summer	207	4.21	2.93	0.79	-30.5	31.5	-1.29	1.33
		Fall	214	2.12	1.93	0.80	-8.6	20.7	-0.18	0.44
		All	836	2.85	2.34	0.81	-17.9	24.6	-0.51	0.70
Upper Midwest	**IMPROVE**	Winter	183	1.20	1.29	0.55	7.9	50.9	0.09	0.61
		Spring	174	1.43	1.61	0.81	13.1	31.4	0.19	0.45

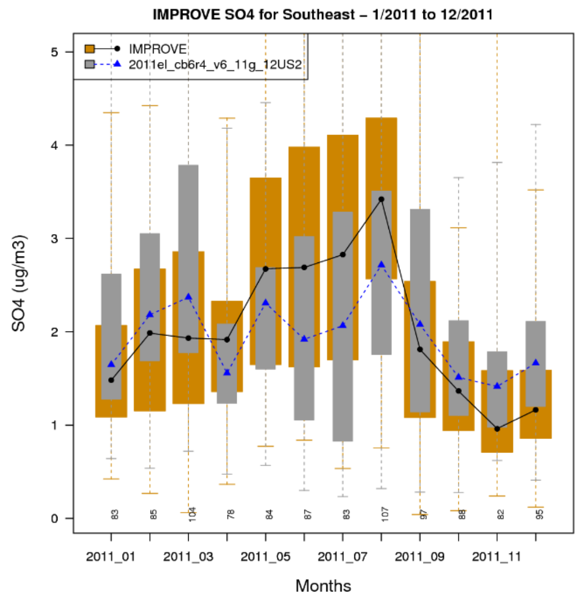
Region	Network	Season	N	Avg. Obs. (µg m-3)	Avg. Mod. (µg m-3)	R	NMB (%)	NME (%)	MB (µg m-3)	ME (µg m-3)
		Summer	190	1.43	1.35	0.80	-5.9	37.9	-0.08	0.54
		Fall	193	1.00	1.16	0.80	15.7	40.3	0.16	0.40
		All	740	1.26	1.35	0.72	6.9	39.7	0.09	0.50
	CSN	Winter	334	1.66	1.56	0.66	-6.1	37.9	-0.10	0.63
		Spring	337	1.92	2.53	0.73	32.1	43.7	0.62	0.84
		Summer	335	2.42	2.14	0.77	-11.6	32.7	-0.28	0.79
		Fall	340	1.53	1.62	0.81	5.8	32.0	0.09	0.49
		All	1346	1.88	1.96	0.71	4.3	36.5	0.08	0.69
	CASTNET	Winter	56	1.49	1.34	0.79	-10.3	22.4	-0.15	0.33
		Spring	62	1.61	1.81	0.87	12.4	20.7	0.20	0.33
		Summer	65	1.85	1.61	0.91	-12.6	18.2	-0.23	0.34
		Fall	62	1.51	1.53	0.89	1.2	20.9	0.02	0.32
		All	245	1.62	1.58	0.84	-2.6	20.4	-0.04	0.33
South	**IMPROVE**	Winter	231	1.21	1.28	0.73	5.4	39.9	0.07	0.48
		Spring	238	1.83	1.38	0.67	-24.9	38.8	-0.46	0.71
		Summer	258	2.16	1.17	0.72	-45.6	47.0	-0.98	1.01
		Fall	250	1.21	1.16	0.80	-4.4	29.5	-0.05	0.36
		All	977	1.61	1.24	0.66	-22.9	40.1	-0.37	0.65
	CSN	Winter	222	1.80	1.93	0.64	7.4	38.2	0.13	0.69
		Spring	248	2.56	2.20	0.72	-14.0	31.7	-0.36	0.81
		Summer	253	2.51	1.54	0.72	-38.5	42.5	-0.97	1.06
		Fall	238	1.71	1.80	0.71	5.6	32.8	0.10	0.56
		All	961	2.16	1.87	0.66	-13.5	36.5	-0.29	0.79
	CASTNET	Winter	70	1.76	1.50	0.80	-14.5	22.0	-0.26	0.39

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Spring	85	2.58	1.73	0.72	-32.8	34.7	-0.85	0.89
		Summer	87	2.45	1.18	0.62	-51.8	53.0	-1.27	1.30
		Fall	77	1.69	1.36	0.64	-19.5	27.3	-0.33	0.46
		All	319	2.15	1.44	0.62	-32.9	36.7	-0.71	0.79
Southwest	**IMPROVE**	Winter	846	0.35	0.50	0.53	44.2	64.0	0.15	0.22
		Spring	871	0.65	0.51	0.48	-22.6	43.0	-0.15	0.28
		Summer	865	0.90	0.45	0.59	-49.7	50.9	-0.45	0.46
		Fall	856	0.62	0.48	0.65	-23.2	36.2	-0.15	0.23
		All	3438	0.63	0.48	0.48	-23.4	47.0	-0.15	0.30
	CSN	Winter	185	0.69	0.66	0.43	-5.1	44.1	-0.03	0.30
		Spring	190	0.73	0.64	0.58	-12.5	36.3	-0.09	0.26
		Summer	192	0.99	0.52	0.45	-48.1	50.0	-0.48	0.50
		Fall	186	0.75	0.58	0.50	-22.5	34.7	-0.17	0.26
		All	753	0.79	0.60	0.42	-24.6	42.0	-0.20	0.33
	CASTNET	Winter	94	0.36	0.47	0.62	31.2	41.0	0.11	0.15
		Spring	102	0.66	0.50	0.52	-24.8	35.9	-0.16	0.24
		Summer	102	0.78	0.38	0.67	-50.4	50.4	-0.39	0.39
		Fall	101	0.62	0.44	0.64	-29.4	34.3	-0.18	0.21
		All	399	0.61	0.45	0.42	-26.5	40.9	-0.16	0.25
N. Rockies & Plains	**IMPROVE**	Winter	471	0.46	0.51	0.70	12.1	56.5	0.06	0.26
		Spring	525	0.67	0.73	0.61	9.2	47.7	0.06	0.32
		Summer	520	0.59	0.52	0.67	-12.0	36.1	-0.07	0.21
		Fall	503	0.43	0.54	0.58	24.9	46.4	0.11	0.20
		All	2019	0.54	0.58	0.63	6.9	45.9	0.04	0.25

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
	CSN	Winter	66	1.02	1.02	0.56	0.3	50.8	0.00	0.52
		Spring	70	1.51	1.43	0.80	-5.1	33.6	-0.08	0.51
		Summer	72	1.34	1.20	0.78	-10.6	36.8	-0.14	0.49
		Fall	69	0.85	0.95	0.77	12.2	35.8	0.10	0.30
		All	277	1.18	1.15	0.75	-2.6	38.4	-0.03	0.46
	CASTNET	Winter	77	0.54	0.53	0.76	-1.5	36.3	-0.01	0.20
		Spring	76	0.90	0.80	0.83	-10.5	22.6	-0.09	0.20
		Summer	88	0.77	0.51	0.82	-33.5	35.2	-0.26	0.27
		Fall	89	0.58	0.55	0.83	-5.7	21.6	-0.03	0.13
		All	330	0.70	0.59	0.79	-14.6	28.6	-0.10	0.20
Northwest	**IMPROVE**	Winter	398	0.24	0.49	0.49	100.0	121.0	0.24	0.30
		Spring	469	0.41	0.58	0.72	41.5	56.9	0.17	0.23
		Summer	407	0.62	0.64	0.59	3.3	41.4	0.02	0.26
		Fall	420	0.43	0.66	0.45	55.6	76.6	0.24	0.33
		All	1694	0.43	0.59	0.56	39.4	64.9	0.17	0.28
	CSN	Winter	166	0.72	0.99	0.48	37.3	62.6	0.27	0.45
		Spring	167	0.60	0.83	0.67	37.8	46.1	0.23	0.28
		Summer	172	0.97	1.05	0.51	8.5	43.4	0.08	0.42
		Fall	166	0.73	1.08	0.38	47.6	65.1	0.35	0.48
		All	671	0.76	0.99	0.49	30.4	53.6	0.23	0.41
	CASTNET	Winter	12	0.26	0.54	0.45	108.0	112.0	0.28	0.29
		Spring	13	0.47	0.59	0.77	25.4	30.1	0.12	0.14
		Summer	13	0.77	0.78	0.41	1.4	26.9	0.01	0.21
		Fall	13	0.51	0.73	0.57	43.3	55.4	0.22	0.28

Region	Network	Season	N	Avg. Obs. (µg m-3)	Avg. Mod. (µg m-3)	R	NMB (%)	NME (%)	MB (µg m-3)	ME (µg m-3)
		All	51	0.51	0.66	0.65	30.6	45.2	0.16	0.23
West	IMPROVE	Winter	407	0.30	0.43	0.49	47.0	80.5	0.14	0.24
		Spring	456	0.64	0.60	0.38	-6.7	48.1	-0.04	0.31
		Summer	441	0.98	0.54	0.16	-45.1	58.7	-0.44	0.57
		Fall	441	0.69	0.53	0.50	-22.9	46.6	-0.16	0.32
		All	1745	0.66	0.53	0.34	-19.8	55.1	-0.13	0.36
	CSN	Winter	225	0.73	0.74	0.27	1.2	56.0	0.01	0.41
		Spring	242	1.02	0.87	0.41	-15.1	42.7	-0.15	0.44
		Summer	247	1.78	0.91	0.51	-48.9	53.3	-0.87	0.95
		Fall	228	1.52	0.92	0.75	-39.1	48.5	-0.59	0.74
		All	942	1.27	0.86	0.55	-32.2	50.1	-0.41	0.64
	CASTNET	Winter	69	0.39	0.42	0.49	5.8	41.1	0.02	0.16
		Spring	73	0.82	0.58	0.46	-29.1	38.8	-0.24	0.32
		Summer	77	1.09	0.46	0.26	-57.5	59.0	-0.63	0.64
		Fall	77	0.82	0.48	0.54	-41.8	46.5	-0.34	0.38
		All	296	0.79	0.48	0.39	-38.7	48.4	-0.31	0.38


IMPROVE SO4 for Northeast – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


IMPROVE SO4 for Southeast – 1/2011 to 12/2011
IMPROVE
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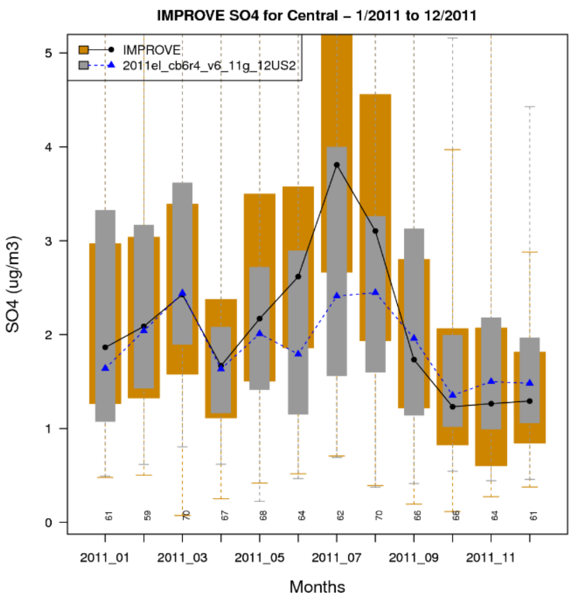
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


IMPROVE SO4 for Central – 1/2011 to 12/2011
IMPROVE
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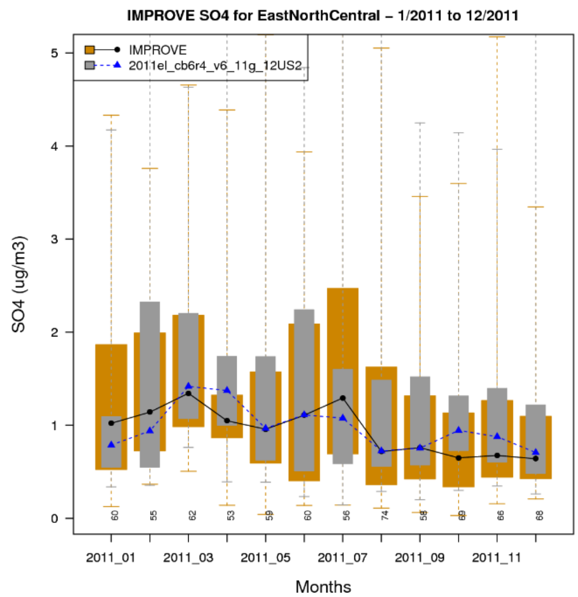
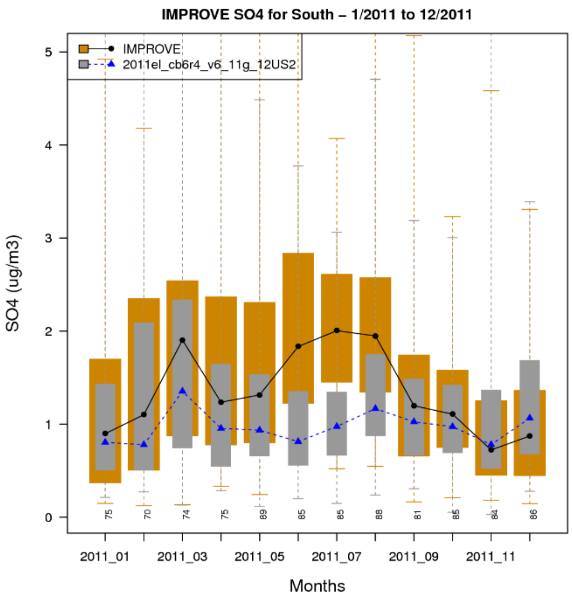
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


IMPROVE SO4 for EastNorthCentral – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


IMPROVE SO4 for South – 1/2011 to 12/2011
IMPROVE
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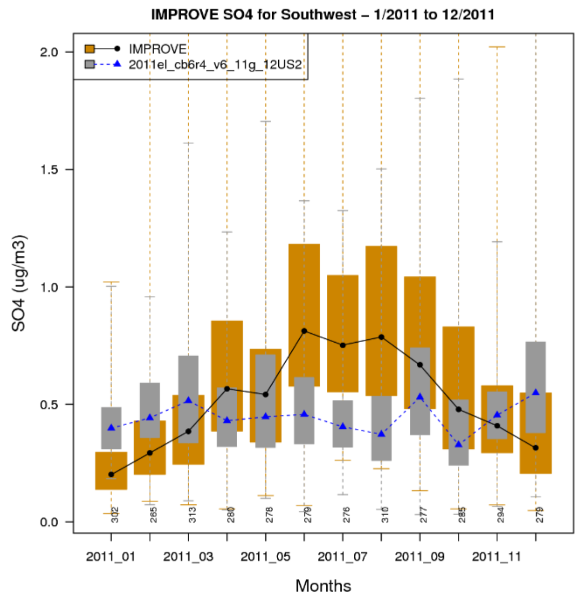
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


IMPROVE SO4 for Southwest – 1/2011 to 12/2011
IMPROVE
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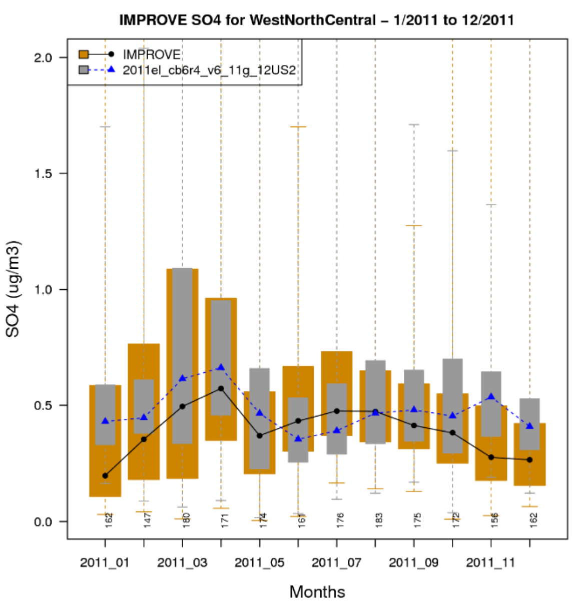
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


IMPROVE SO4 for WestNorthCentral – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
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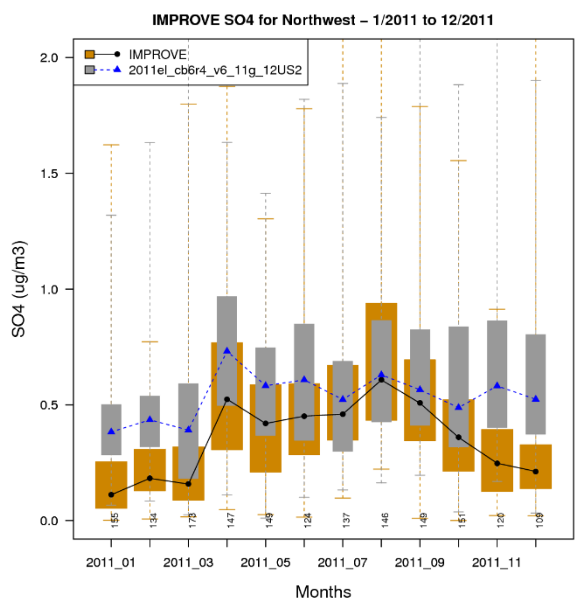
2011_03
2011_05
2011_07
2011_09
2011_11


IMPROVE SO4 for Northwest – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
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2011_07
2011_09
2011_11

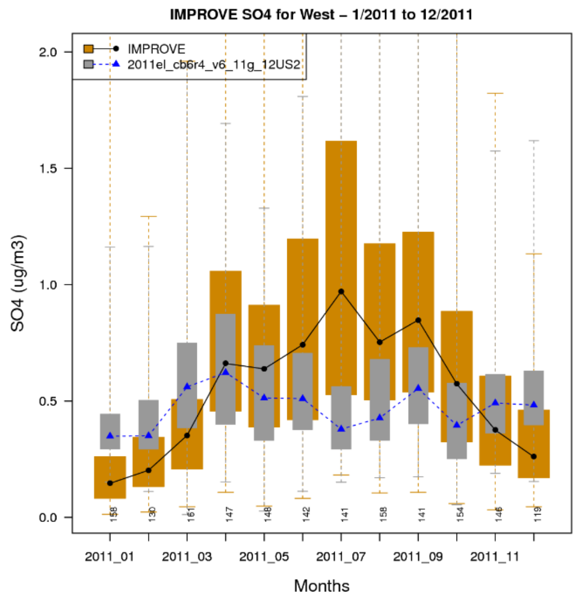
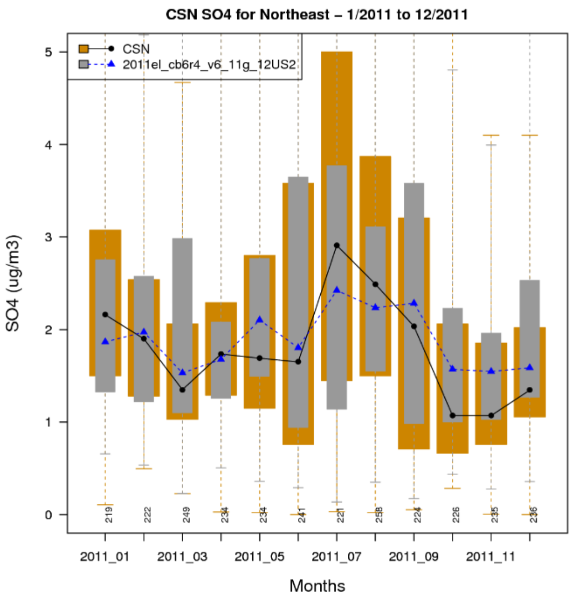
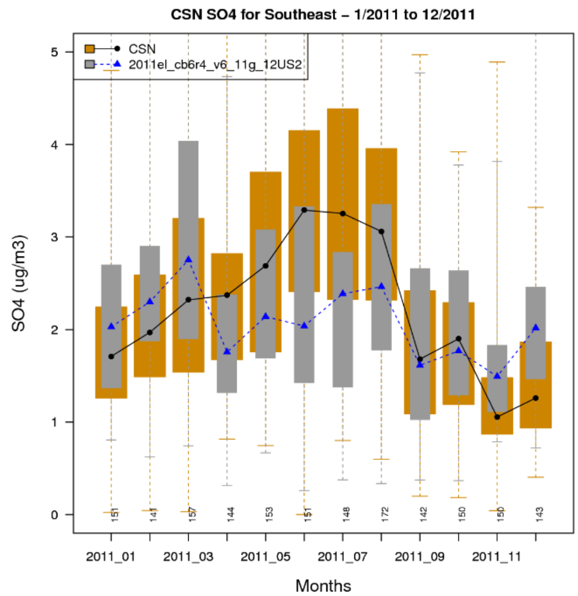
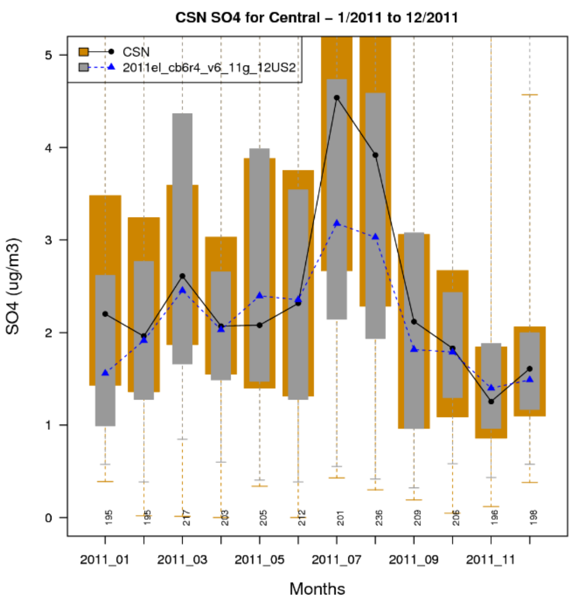
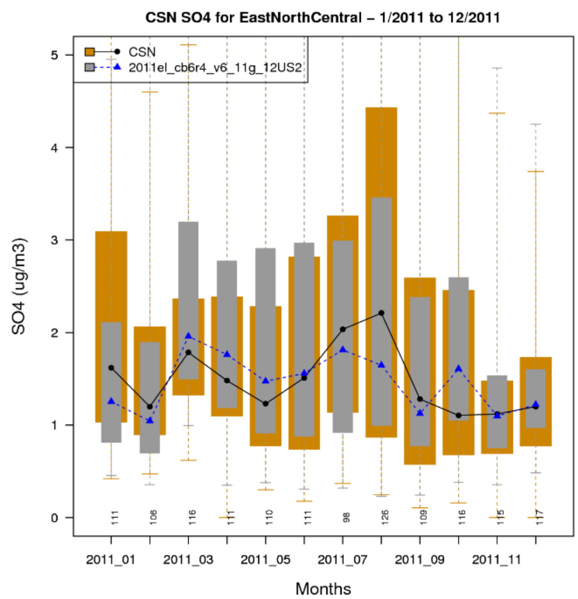


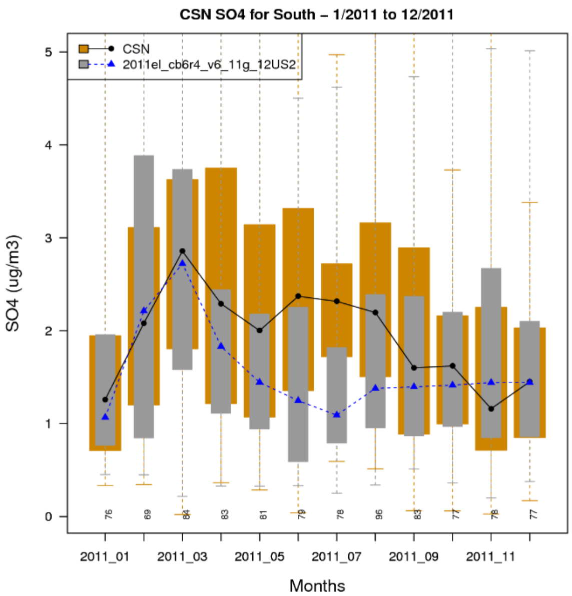
Figure 2. Boxplot comparisons of model predictions and IMPROVE sulfate observations for each climate region by month.

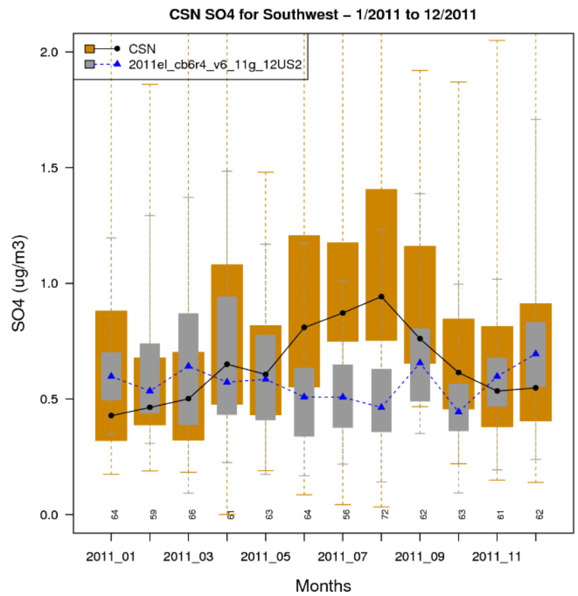

CSN SO4 for Northeast – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11

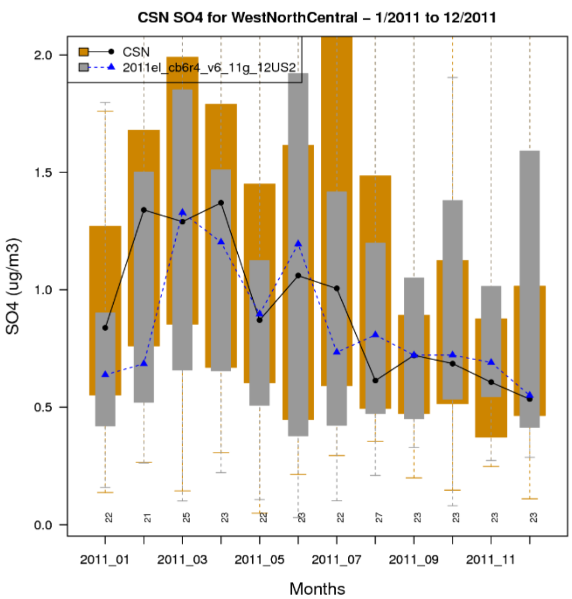

CSN SO4 for Southeast – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11

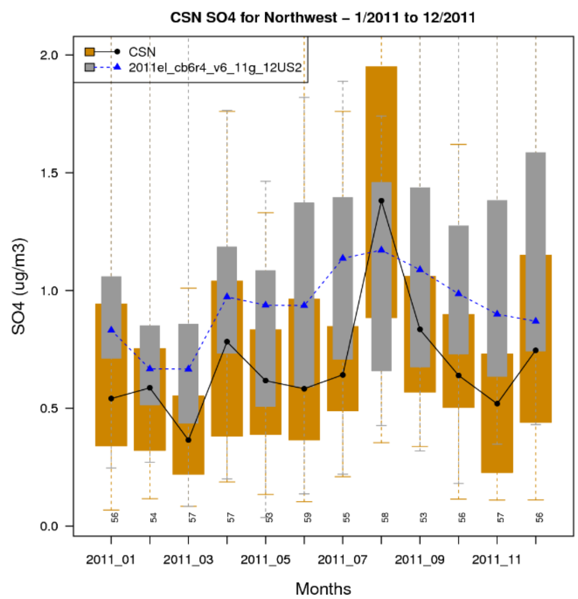

CSN SO4 for Central – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


CSN SO4 for EastNorthCentral – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


CSN SO4 for South – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months


CSN SO4 for Southwest – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months


CSN SO4 for WestNorthCentral – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months


CSN SO4 for Northwest – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months

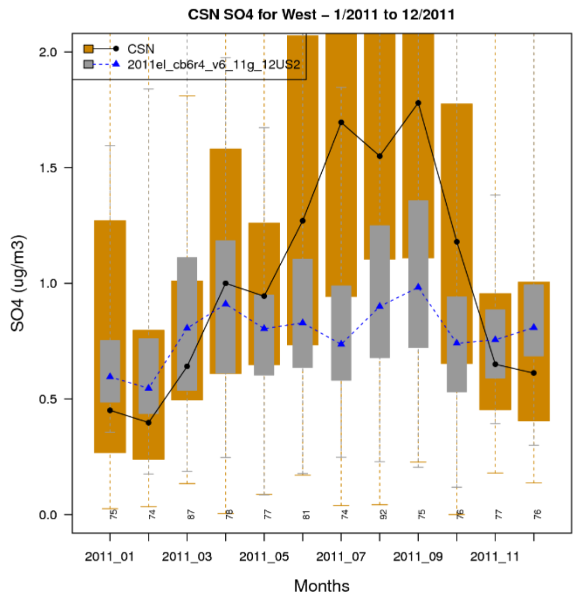
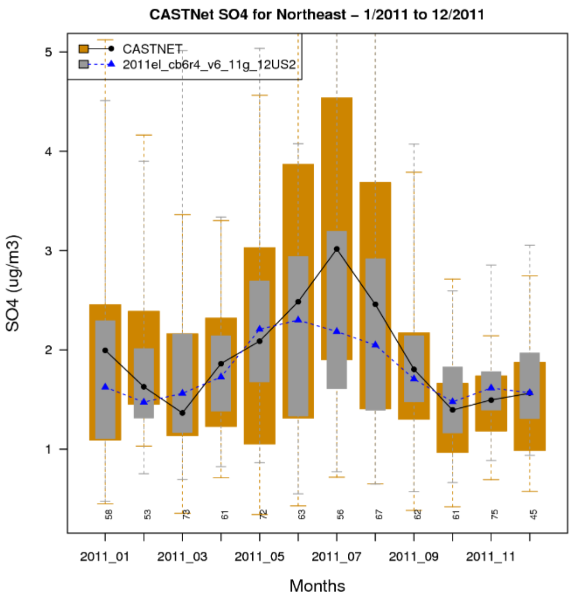
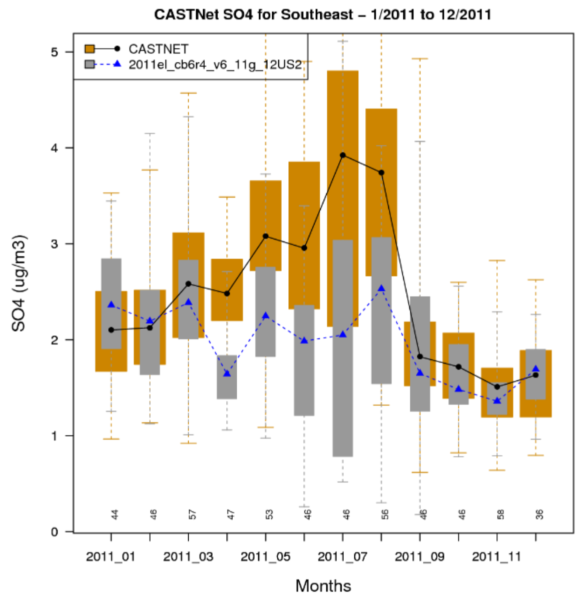
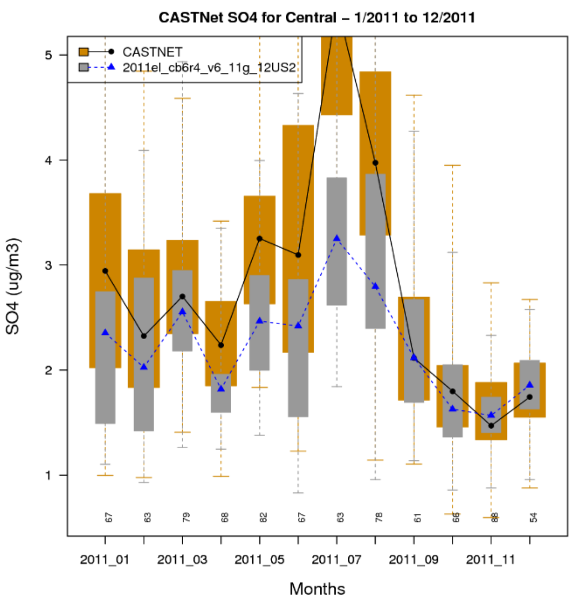
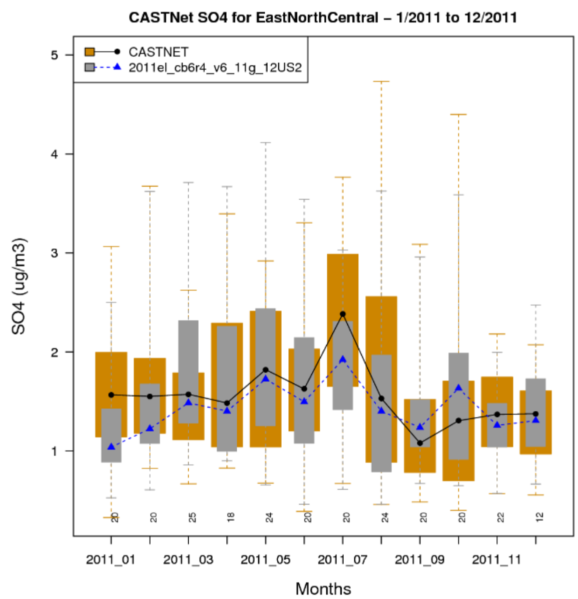


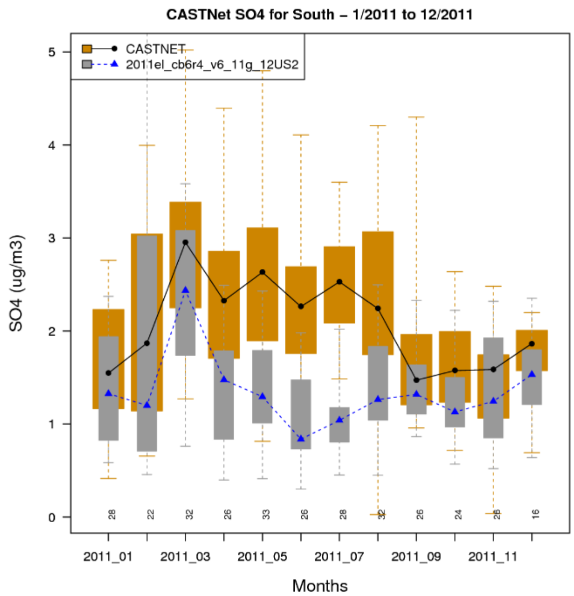
Figure 3. Boxplot comparisons of model predictions and CSN sulfate observations for each climate region by month.

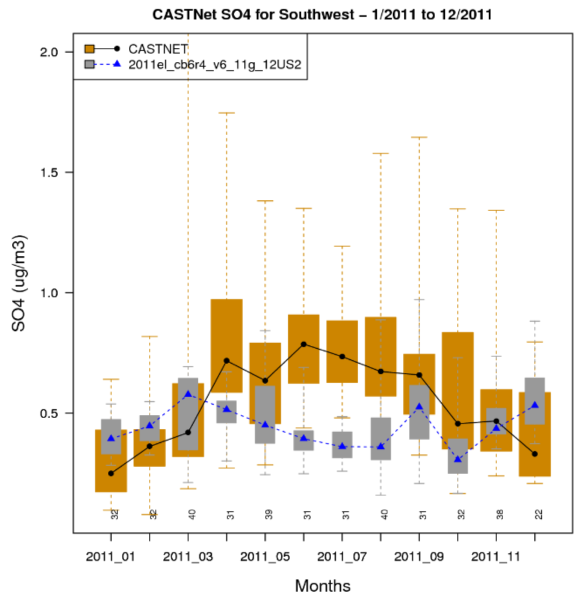

CASTNet SO4 for Northeast – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
1
2
3
4
5
58 53 73 61 72 63 56 67 62 61 75 45
2011_01 2011_03 2011_05 2011_07 2011_09 2011_11
Months

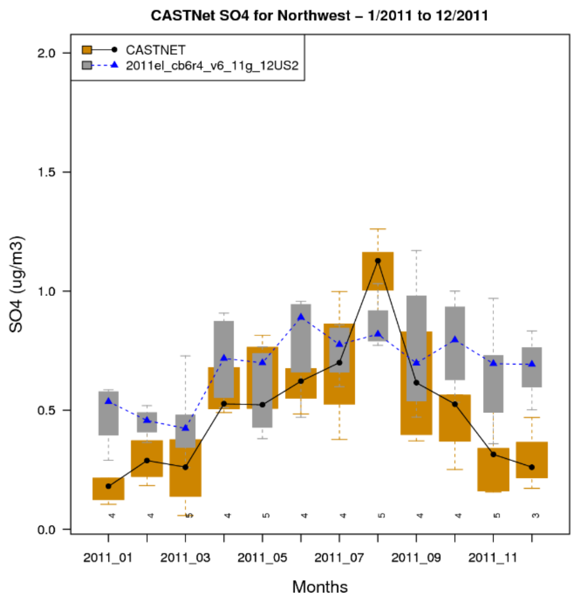

CASTNet SO4 for Southeast – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
0
1
2
3
4
5
44 46 57 47 53 46 46 56 46 46 58 36
2011_01 2011_03 2011_05 2011_07 2011_09 2011_11
Months

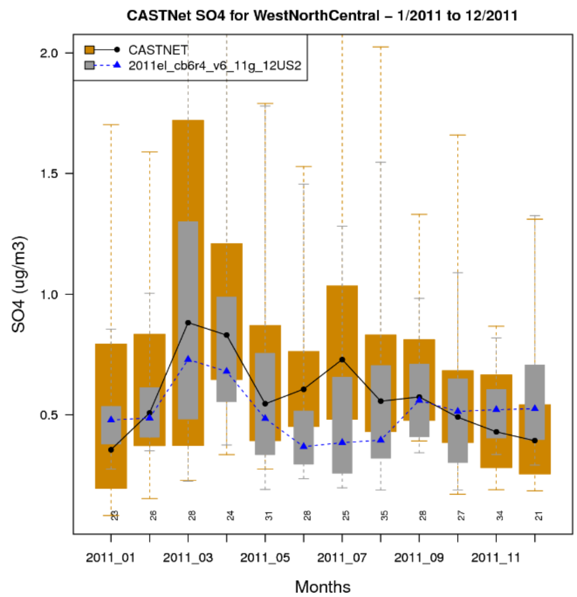

CASTNet SO4 for Central – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
1
2
3
4
5
67 63 79 68 82 67 63 78 61 65 68 54
2011_01 2011_03 2011_05 2011_07 2011_09 2011_11
Months


CASTNet SO4 for EastNorthCentral – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
1
2
3
4
5
20 20 25 18 24 20 20 24 20 20 22 12
2011_01 2011_03 2011_05 2011_07 2011_09 2011_11
Months


CASTNet SO4 for South – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


CASTNet SO4 for Southwest – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


CASTNet SO4 for Northwest – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


CASTNet SO4 for WestNorthCentral – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
SO4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11

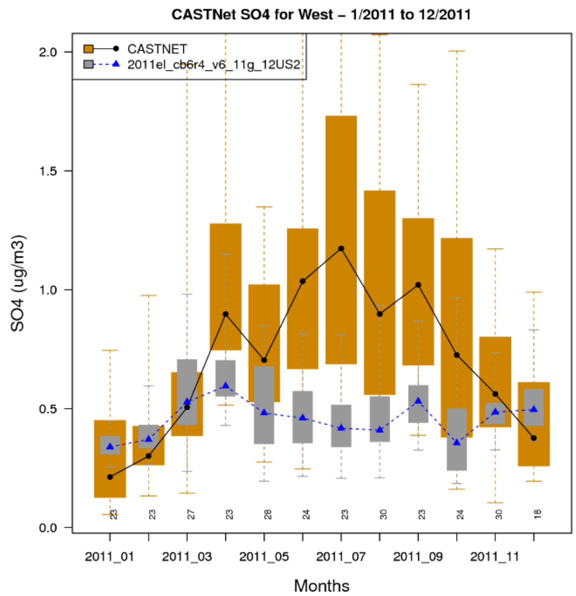


Figure 4. Boxplot comparisons of model predictions and CASTNet sulfate observations for each climate region by month.

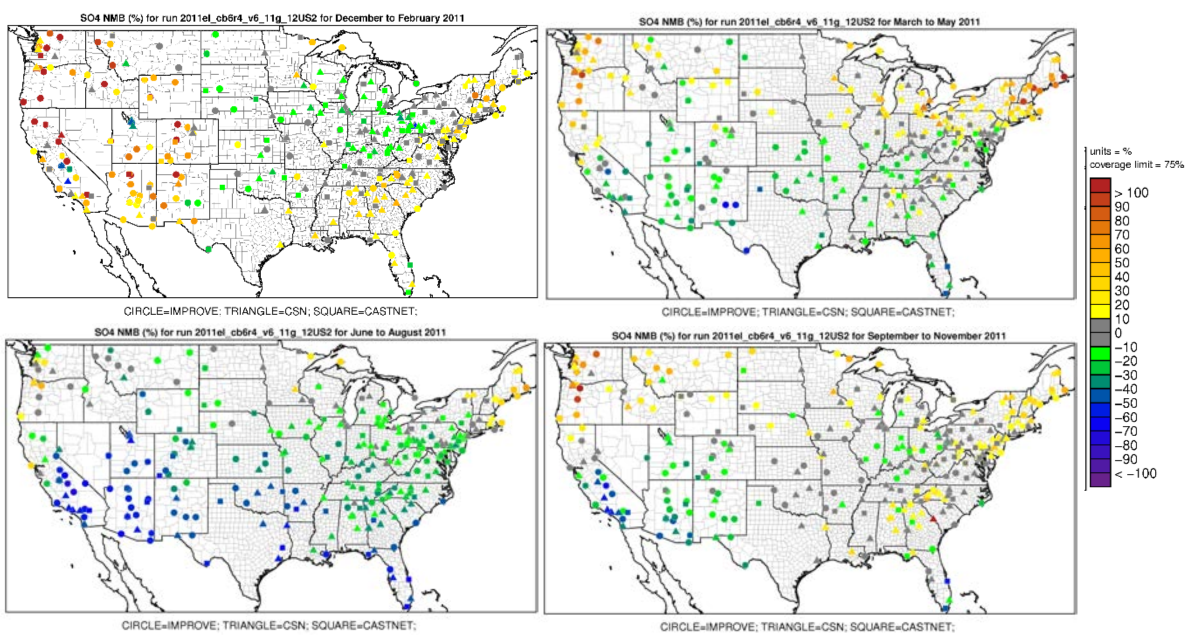


Figure 5. Spatial plots of sulfate NMB by season and network.

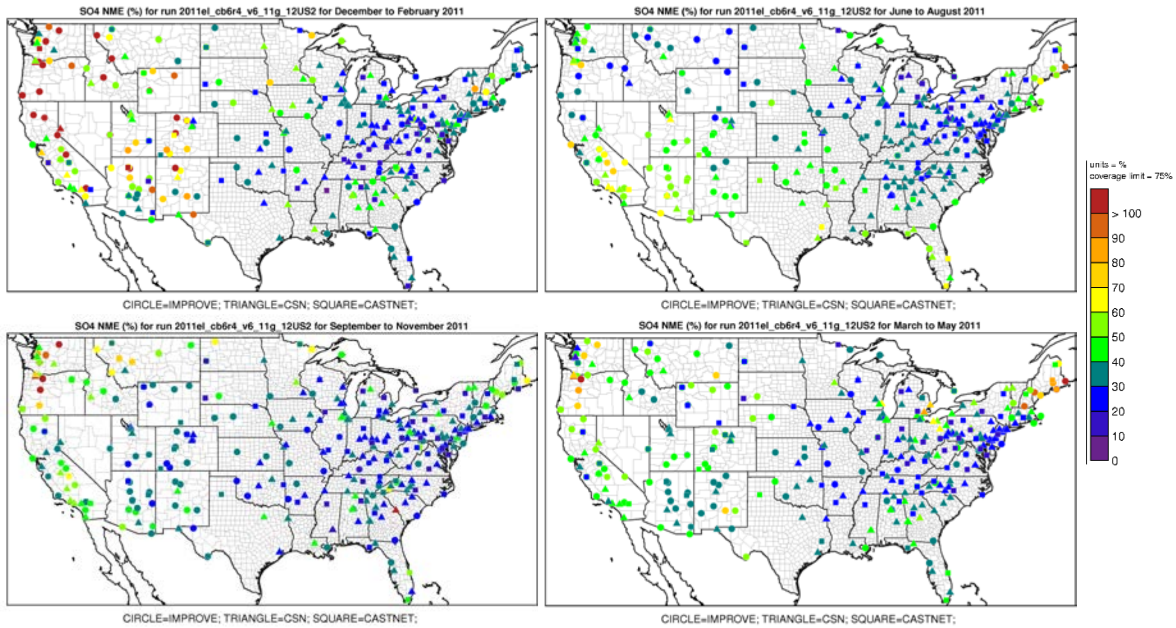


Figure 6. Spatial plots of sulfate NME by season and network.

3. $PM_{2.5}$ Nitrate

Table 3-1 summarizes model performance statistics for $PM_{2.5}$ nitrate. Boxplot comparisons of model predictions and observations (IMPROVE, CSN, and CASTNET) by month for each climate region are shown in Figures 7, 8, and 9. Nationwide spatial plots of NMB and NME for each season are shown in Figures 10 and 11.

Nitrate in general is significantly underpredicted at many Class I areas, especially in the western US during the summer months. NMBs range from -95.6 to -78.1% in the western US during the summer and -96.4 to -90.1% in the southwestern US. Underpredictions of nitrate persist across all seasons, though the magnitude is less. Significant overpredictions of nitrate are observed in the northern rockies and plains, northwest, northeast, and southeast, especially during Winter, Spring, and Fall months when observed nitrate is highest.

Table 3-1. Model performance statistics for PM2.5 nitrate by region, network, and season.

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
Northeast	IMPROVE	Winter	368	0.56	0.88	0.74	57.5	79.9	0.32	0.45
		Spring	412	0.27	0.45	0.51	65.4	109.0	0.18	0.30
		Summer	373	0.16	0.13	0.57	-20.0	78.9	-0.03	0.13
		Fall	371	0.26	0.41	0.66	55.8	101.0	0.15	0.27

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		All	1524	0.31	0.47	0.70	49.1	91.1	0.15	0.28
	CSN	Winter	677	2.08	2.03	0.63	-2.6	41.9	-0.05	0.87
		Spring	717	1.03	1.03	0.60	-0.2	55.6	0.00	0.57
		Summer	720	0.50	0.32	0.52	-37.2	71.7	-0.19	0.36
		Fall	685	0.83	0.98	0.69	19.0	63.1	0.16	0.52
		All	2799	1.10	1.07	0.70	-2.1	52.6	-0.02	0.58
	CASTNET	Winter	170	1.21	1.22	0.69	0.5	39.5	0.01	0.48
		Spring	193	0.58	0.80	0.61	39.2	70.4	0.23	0.41
		Summer	186	0.17	0.17	0.32	-2.8	83.0	0.00	0.14
		Fall	197	0.52	0.66	0.63	25.9	62.3	0.14	0.33
		All	746	0.61	0.70	0.71	15.6	55.4	0.09	0.34
Southeast	IMPROVE	Winter	263	0.58	0.66	0.29	12.8	82.0	0.07	0.48
		Spring	266	0.38	0.40	0.25	4.6	89.9	0.02	0.34
		Summer	277	0.18	0.14	0.25	-21.9	88.0	-0.04	0.16
		Fall	267	0.25	0.39	0.41	53.3	113.0	0.14	0.29
		All	1073	0.35	0.39	0.36	13.3	90.5	0.05	0.31
	CSN	Winter	435	0.90	1.10	0.41	22.0	78.1	0.20	0.70
		Spring	454	0.53	0.57	0.40	8.7	75.4	0.05	0.40
		Summer	471	0.27	0.17	0.18	-36.0	71.4	-0.10	0.19
		Fall	442	0.35	0.62	0.45	80.1	122.0	0.28	0.42
		All	1802	0.51	0.61	0.49	20.2	83.8	0.10	0.42
	CASTNET	Winter	138	1.00	0.77	0.52	-22.4	50.2	-0.22	0.50
		Spring	146	0.74	0.46	0.31	-37.5	62.4	-0.28	0.46
		Summer	147	0.36	0.20	0.62	-43.3	60.9	-0.15	0.22

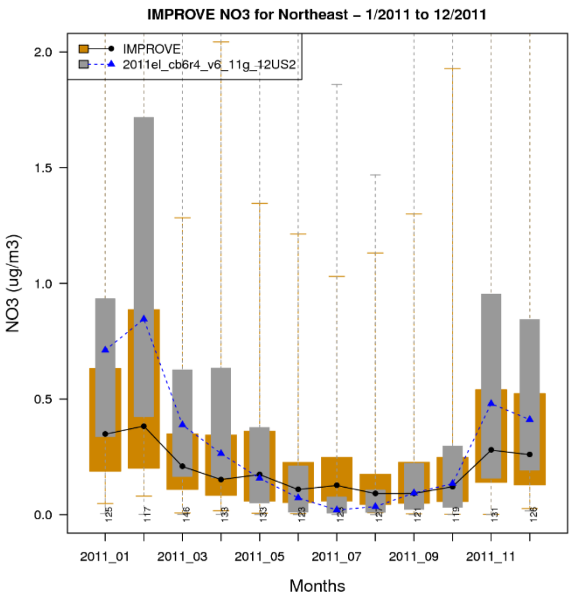
Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Fall	150	0.54	0.46	0.34	-15.7	60.0	-0.09	0.33
		All	581	0.65	0.47	0.52	-28.2	57.2	-0.18	0.37
Ohio Valley	**IMPROVE**	Winter	181	1.92	1.59	0.71	50.6	-17.2	-0.33	0.97
		Spring	205	0.82	1.33	0.74	100.0	62.5	0.51	0.82
		Summer	196	0.23	0.12	0.60	70.4	-45.7	-0.10	0.16
		Fall	196	0.50	0.76	0.71	97.9	53.6	0.27	0.49
		All	778	0.85	0.94	0.68	71.5	11.7	0.10	0.60
	CSN	Winter	588	2.91	2.41	0.75	41.1	-17.2	-0.50	1.19
		Spring	625	1.60	2.08	0.74	65.2	30.1	0.48	1.04
		Summer	649	0.54	0.34	0.53	66.0	-37.2	-0.20	0.35
		Fall	611	0.92	1.05	0.65	61.2	14.7	0.14	0.56
		All	2473	1.46	1.45	0.74	53.2	-1.1	-0.02	0.78
	CASTNET	Winter	201	2.55	1.79	0.81	39.1	-29.9	-0.76	1.00
		Spring	214	0.94	1.45	0.70	82.6	53.9	0.51	0.78
		Summer	207	0.34	0.25	0.49	67.7	-27.0	-0.09	0.23
		Fall	214	0.75	0.92	0.78	47.3	23.0	0.17	0.35
		All	836	1.13	1.10	0.72	51.9	-2.8	-0.03	0.59
Upper Midwest	**IMPROVE**	Winter	183	2.19	2.04	0.71	-6.7	43.5	-0.15	0.95
		Spring	174	1.35	1.61	0.89	19.2	44.5	0.26	0.60
		Summer	190	0.23	0.28	0.72	26.5	84.6	0.06	0.19
		Fall	192	0.68	1.13	0.92	64.9	74.5	0.44	0.51
		All	739	1.09	1.25	0.82	14.2	51.0	0.16	0.56
	CSN	Winter	334	3.41	2.71	0.77	-20.7	37.9	-0.71	1.29
		Spring	337	2.23	2.45	0.81	10.0	42.8	0.22	0.95

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Summer	335	0.59	0.41	0.45	-30.9	68.9	-0.18	0.41
		Fall	340	1.29	1.67	0.82	29.5	56.7	0.38	0.73
		All	1346	1.88	1.81	0.79	-3.7	45.0	-0.07	0.85
	CASTNET	Winter	56	2.16	1.82	0.79	-15.7	29.1	-0.34	0.63
		Spring	62	0.88	1.31	0.74	47.8	69.2	0.42	0.61
		Summer	65	0.25	0.28	0.69	11.6	66.3	0.03	0.17
		Fall	62	0.83	1.11	0.73	33.7	52.5	0.28	0.44
		All	245	0.99	1.10	0.78	10.9	45.6	0.11	0.45
South	IMPROVE	Winter	231	1.37	0.93	0.60	-32.5	58.0	-0.45	0.80
		Spring	238	0.74	0.56	0.90	-24.4	54.6	-0.18	0.40
		Summer	258	0.26	0.05	0.22	-82.7	89.9	-0.22	0.24
		Fall	250	0.35	0.30	0.59	-13.9	76.9	-0.05	0.27
		All	977	0.66	0.44	0.74	-33.1	62.9	-0.22	0.42
	CSN	Winter	222	1.88	1.58	0.51	-15.9	60.9	-0.30	1.15
		Spring	248	0.92	0.75	0.80	-19.3	64.0	-0.18	0.59
		Summer	253	0.34	0.09	0.30	-72.8	86.5	-0.25	0.29
		Fall	238	0.56	0.58	0.64	2.3	73.6	0.01	0.42
		All	961	0.90	0.72	0.69	-19.6	66.2	-0.18	0.60
	CASTNET	Winter	70	1.72	1.19	0.83	-30.6	43.5	-0.53	0.75
		Spring	85	1.10	0.63	0.67	-43.1	66.3	-0.47	0.73
		Summer	87	0.61	0.04	0.27	-94.0	94.0	-0.57	0.57
		Fall	77	0.59	0.32	0.61	-46.2	64.7	-0.27	0.38
		All	319	0.98	0.51	0.78	-47.3	62.0	-0.46	0.61
Southwest	IMPROVE	Winter	845	0.34	0.09	0.60	-72.7	81.7	-0.25	0.28

Region	Network	Season	N	Avg. Obs. (µg m-3)	Avg. Mod. (µg m-3)	R	NMB (%)	NME (%)	MB (µg m-3)	ME (µg m-3)
		Spring	871	0.20	0.02	0.24	-88.5	91.8	-0.18	0.19
		Summer	865	0.17	0.01	0.27	-95.6	95.6	-0.16	0.16
		Fall	856	0.14	0.03	0.45	-78.4	88.4	-0.11	0.12
		All	3437	0.21	0.04	0.56	-82.0	88.0	-0.17	0.19
	CSN	Winter	185	3.37	0.92	0.64	-72.6	73.4	-2.45	2.47
		Spring	190	0.64	0.22	0.64	-65.2	68.2	-0.41	0.43
		Summer	192	0.31	0.03	0.63	-90.1	90.2	-0.28	0.28
		Fall	186	0.81	0.21	0.70	-74.6	74.7	-0.61	0.61
		All	753	1.27	0.34	0.71	-73.1	74.0	-0.93	0.94
	CASTNET	Winter	94	0.22	0.10	-0.14	-56.3	95.3	-0.13	0.21
		Spring	102	0.30	0.04	0.06	-86.1	90.0	-0.26	0.27
		Summer	102	0.23	0.01	0.09	-96.4	96.4	-0.22	0.22
		Fall	101	0.17	0.04	-0.03	-77.6	93.5	-0.13	0.16
		All	399	0.23	0.05	-0.05	-80.4	93.5	-0.19	0.22
N. Rockies & Plains	**IMPROVE**	Winter	469	0.35	0.55	0.49	56.8	112.0	0.20	0.39
		Spring	524	0.37	0.55	0.74	48.8	92.0	0.18	0.34
		Summer	518	0.11	0.05	0.44	-56.4	84.1	-0.06	0.09
		Fall	503	0.13	0.24	0.74	74.7	131.0	0.10	0.18
		All	2014	0.24	0.34	0.64	42.7	103.0	0.10	0.25
	CSN	Winter	66	2.45	1.84	0.68	-24.9	49.2	-0.61	1.21
		Spring	70	1.74	1.63	0.90	-6.7	36.9	-0.12	0.64
		Summer	72	0.32	0.18	0.76	-44.2	62.2	-0.14	0.20
		Fall	69	0.76	1.04	0.78	37.1	77.3	0.28	0.59
		All	277	1.30	1.15	0.82	-10.9	49.9	-0.14	0.65

Region	Network	Season	N	Avg. Obs. (µg m-3)	Avg. Mod. (µg m-3)	R	NMB (%)	NME (%)	MB (µg m-3)	ME (µg m-3)
	CASTNET	Winter	77	0.50	0.56	0.85	13.0	52.1	0.06	0.26
		Spring	76	0.59	0.68	0.91	14.2	45.4	0.08	0.27
		Summer	88	0.24	0.07	0.73	-72.6	77.0	-0.18	0.19
		Fall	89	0.27	0.25	0.82	-9.2	55.6	-0.02	0.15
		All	330	0.39	0.37	0.88	-4.8	54.5	-0.02	0.21
Northwest	IMPROVE	Winter	392	0.36	0.34	0.36	-5.6	101.0	-0.02	0.36
		Spring	467	0.14	0.19	0.65	37.4	95.4	0.05	0.13
		Summer	405	0.13	0.05	0.38	-62.4	83.1	-0.08	0.11
		Fall	417	0.18	0.24	0.48	35.5	119.0	0.06	0.21
		All	1681	0.20	0.20	0.41	2.7	101.0	0.01	0.20
	CSN	Winter	166	1.73	1.70	0.32	-1.5	69.1	-0.03	1.19
		Spring	167	0.42	0.44	0.47	5.8	58.8	0.02	0.25
		Summer	172	0.31	0.15	0.49	-50.7	61.8	-0.16	0.19
		Fall	166	0.64	0.87	0.32	35.0	92.0	0.23	0.59
		All	671	0.77	0.78	0.49	2.0	71.7	0.02	0.55
	CASTNET	Winter	12	0.10	0.36	0.78	241.0	241.0	0.25	0.25
		Spring	13	0.14	0.23	-0.07	65.0	80.4	0.09	0.11
		Summer	13	0.12	0.07	0.23	-41.5	51.6	-0.05	0.06
		Fall	13	0.11	0.26	0.03	134.0	157.0	0.15	0.17
		All	51	0.12	0.23	0.03	89.0	123.0	0.11	0.15
West	IMPROVE	Winter	401	0.90	0.35	0.71	-60.5	74.6	-0.54	0.67
		Spring	456	0.44	0.21	0.51	-53.5	76.3	-0.24	0.34
		Summer	441	0.37	0.06	0.03	-84.0	98.7	-0.31	0.36
		Fall	438	0.47	0.24	0.70	-47.7	79.3	-0.22	0.37

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		All	1736	0.53	0.21	0.65	-60.2	80.2	-0.32	0.43
	CSN	Winter	225	4.85	1.91	0.54	-60.7	69.7	-2.94	3.38
		Spring	242	1.74	0.99	0.66	-43.2	58.5	-0.75	1.02
		Summer	247	2.06	0.45	0.77	-78.1	78.9	-1.61	1.62
		Fall	228	3.50	1.31	0.81	-62.6	66.9	-2.19	2.34
		All	942	2.99	1.14	0.67	-61.8	68.9	-1.85	2.06
	CASTNET	Winter	69	0.73	0.22	0.36	-69.3	80.2	-0.50	0.58
		Spring	73	0.56	0.14	0.15	-74.9	82.9	-0.42	0.47
		Summer	77	0.49	0.02	0.26	-95.4	95.8	-0.47	0.47
		Fall	77	0.52	0.13	0.53	-75.5	86.7	-0.39	0.45
		All	296	0.57	0.13	0.38	-78.0	85.9	-0.45	0.49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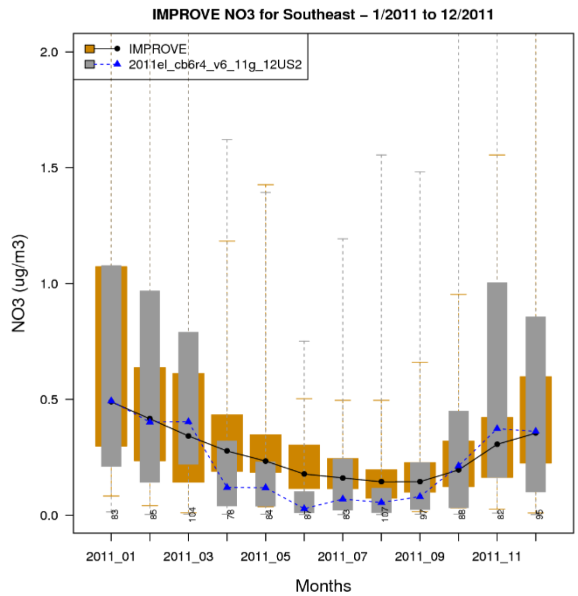
Months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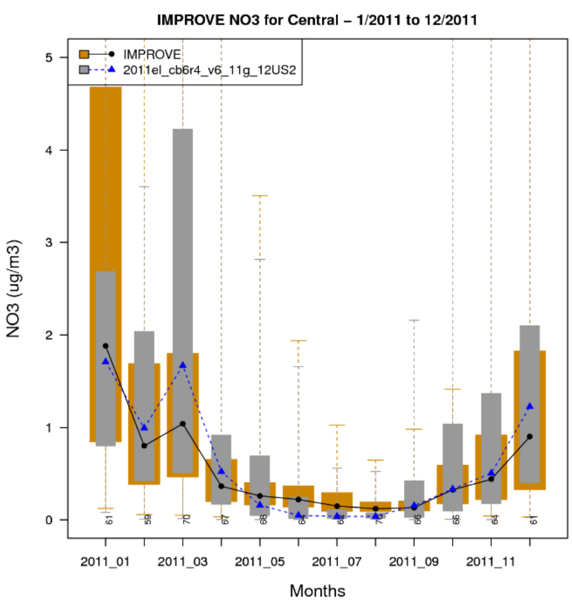
Months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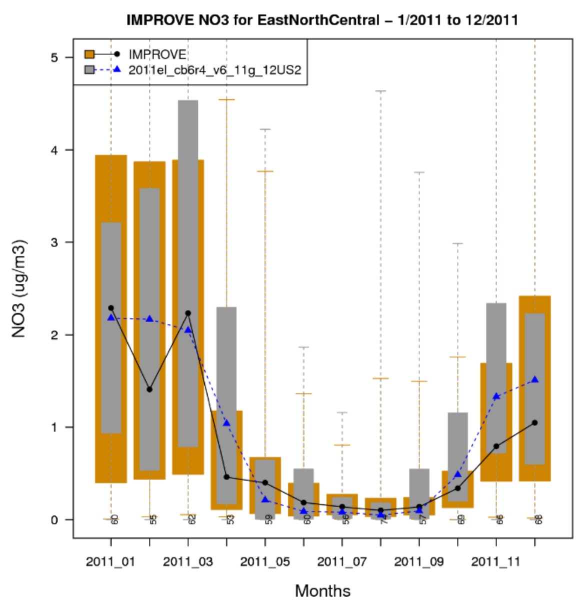
Months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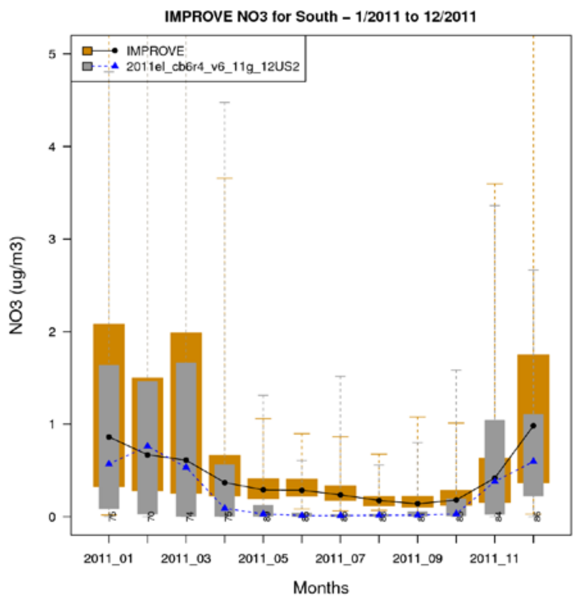
Months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3
4
5
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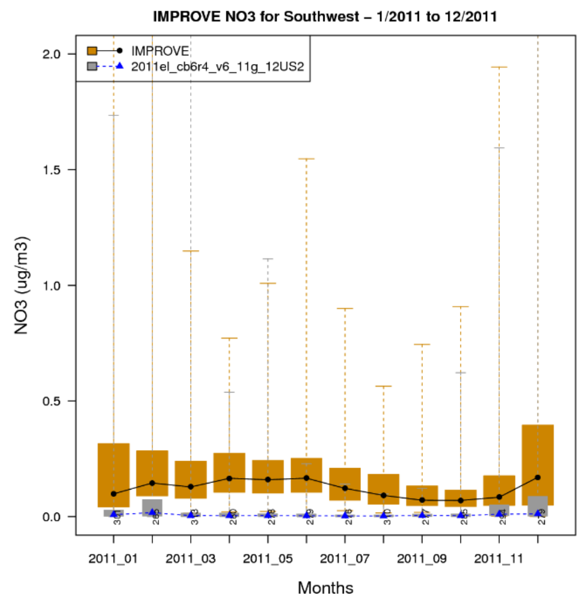
2011_03
2011_05
2011_07
2011_09
2011_11
Months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1.5
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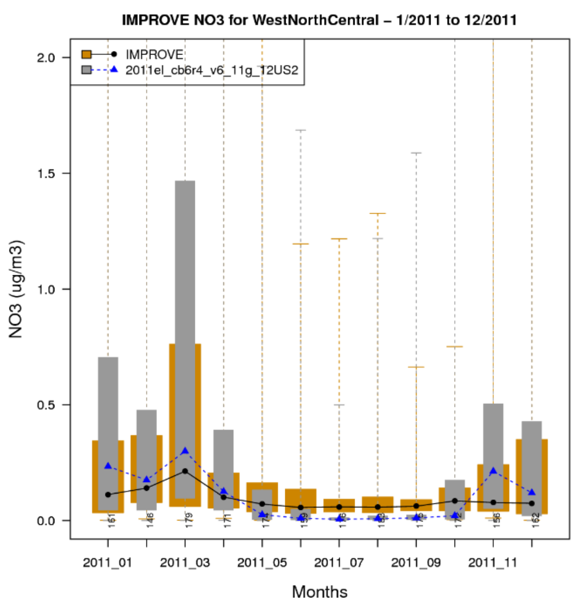
2011_05
2011_07
2011_09
2011_11
Months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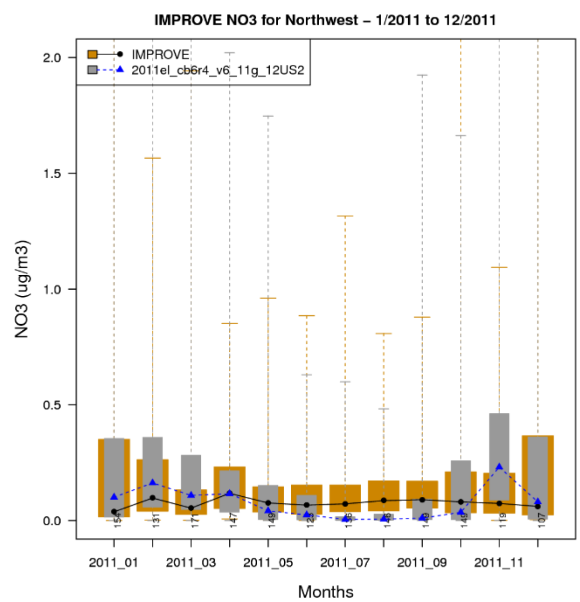
Months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2011_09
2011_11
Months

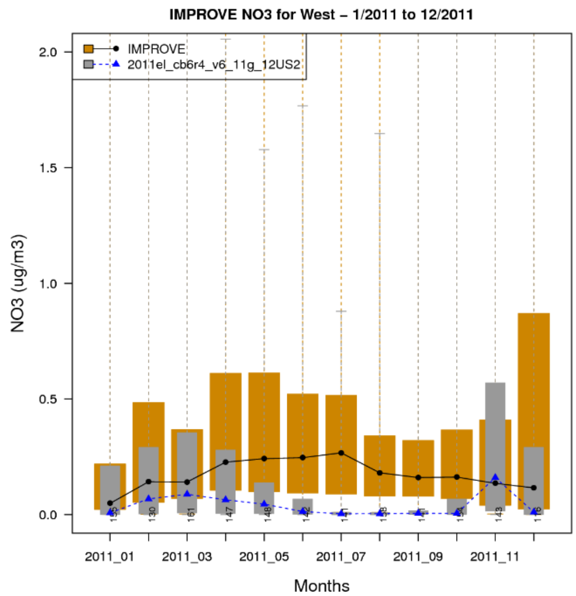
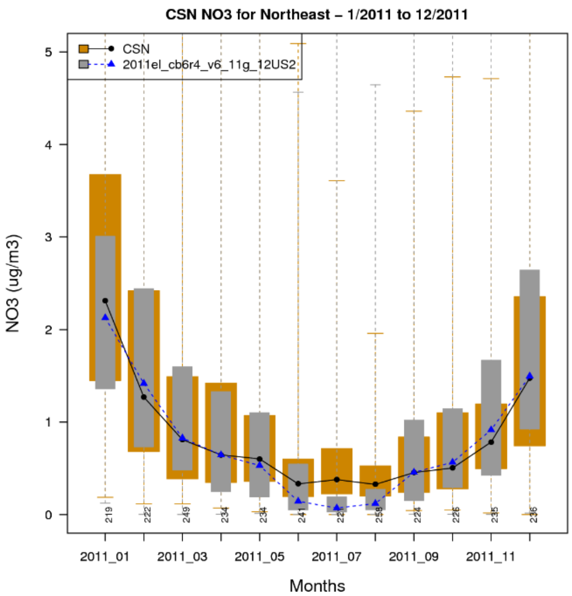


Figure 7. Boxplot comparisons of model predictions and IMRPOVE nitrate observations for each climate region by month.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2011_03
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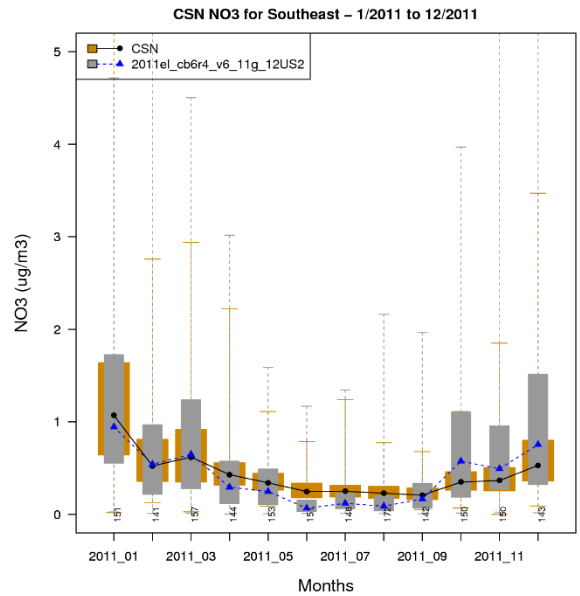
2011_11
Months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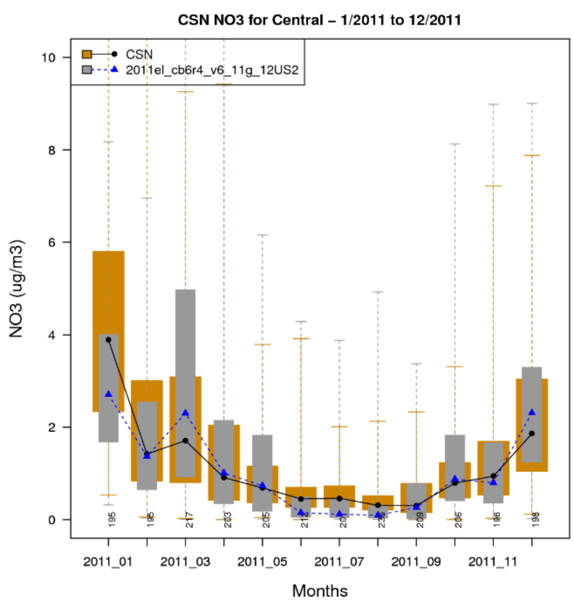
2011_09
2011_11
Months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NO3 (ug/m3)
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2011_03
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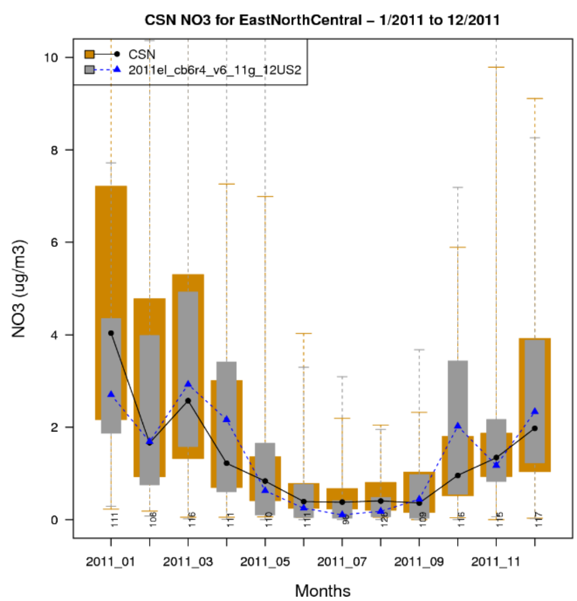
2011_09
2011_11
Months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NO3 (ug/m3)
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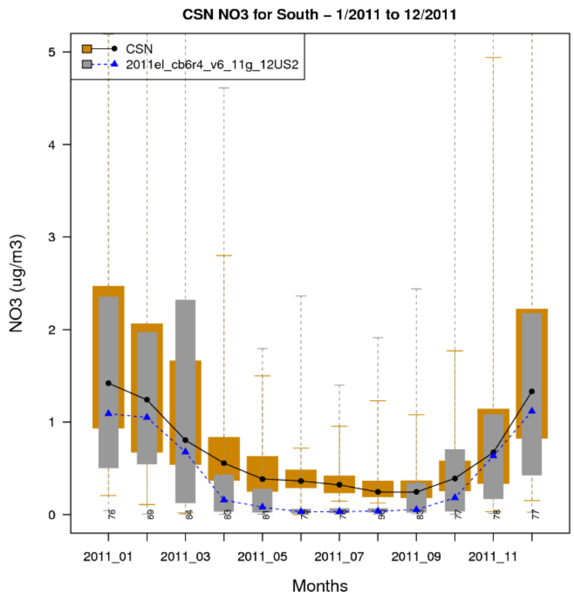
2011_03
2011_05
2011_07
2011_09
2011_11
Months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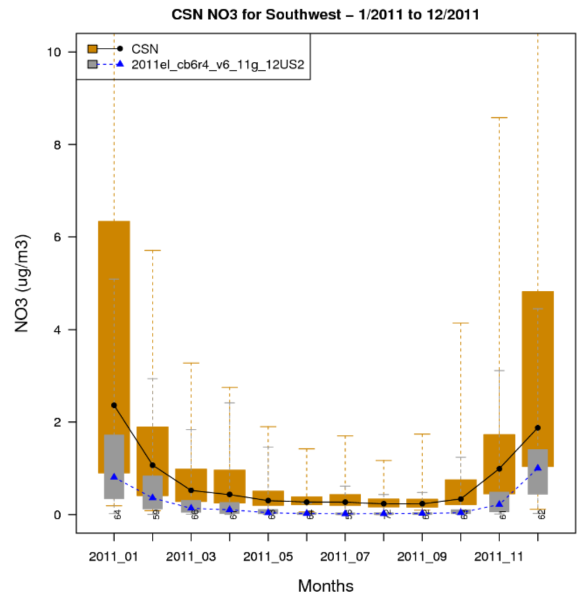
NO3 (ug/m3)
Months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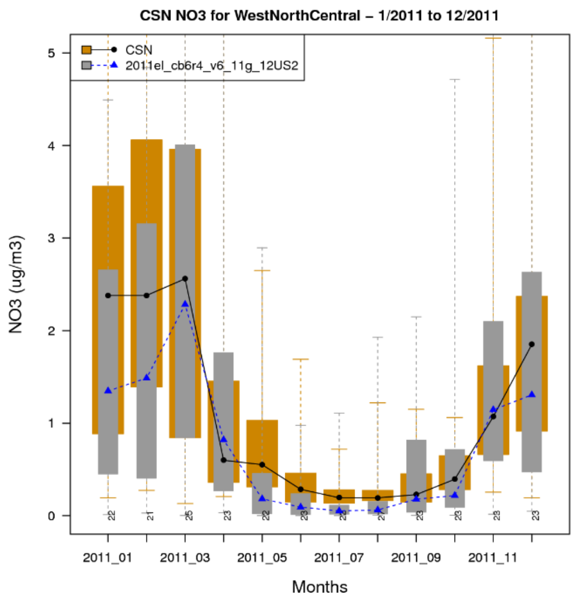
NO3 (ug/m3)
Months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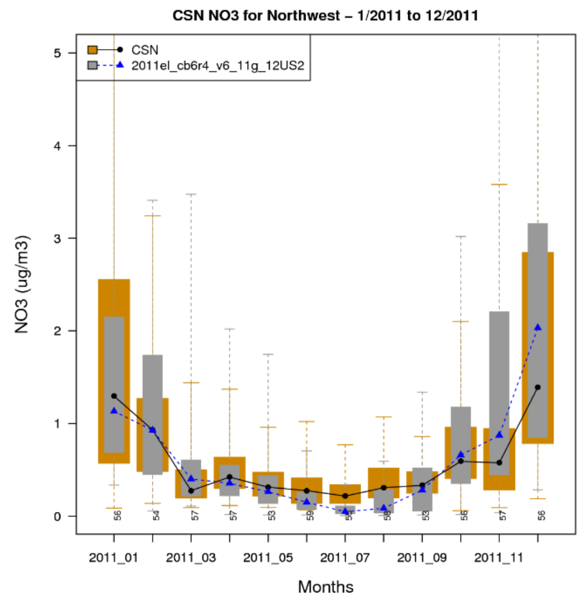
Months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NO3 (ug/m3)
Months

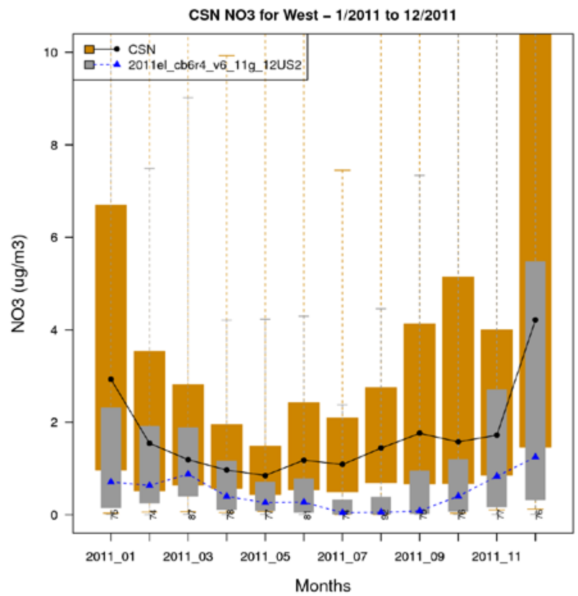
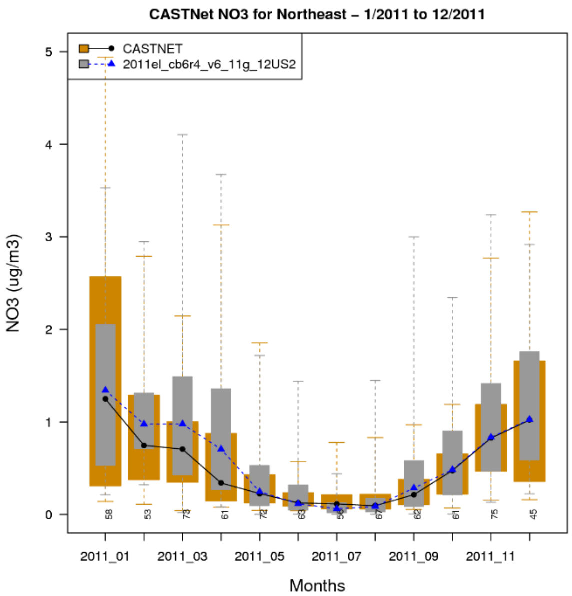


Figure 8. Boxplot comparisons of model predictions and CSN nitrate observations for each climate region by month.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NO3 (ug/m3)
Months
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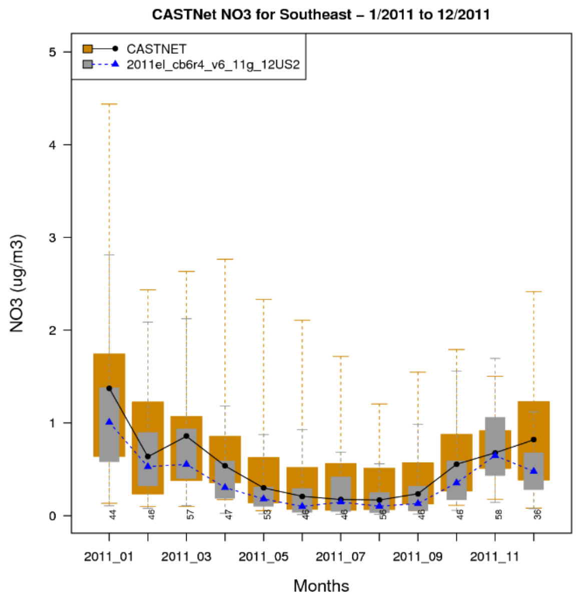
2011_07
2011_09
2011_11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NO3 (ug/m3)
Months
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2011_07
2011_09
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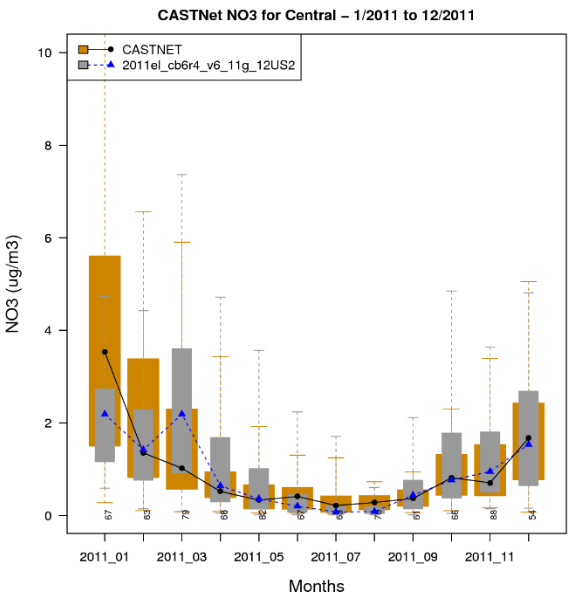
CASTNet NO3 for Central – 1/2011 to 12/2011
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NO3 (ug/m3)
Months
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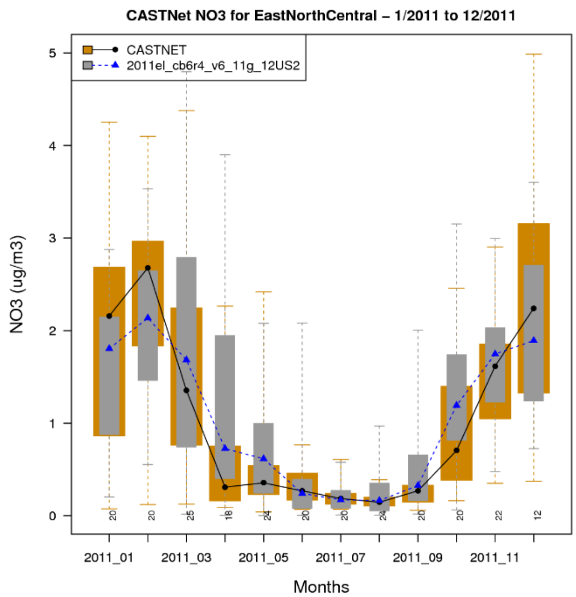
2011_09
2011_11


CASTNet NO3 for EastNorthCentral – 1/2011 to 12/2011
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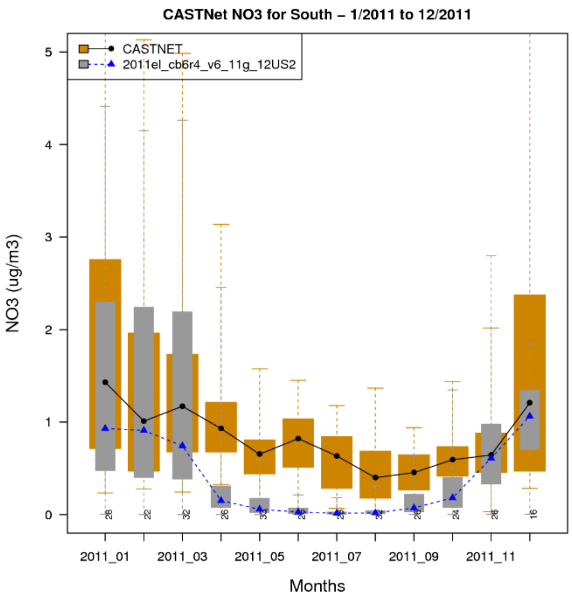
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CASTNET
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NO3 (ug/m3)
Months
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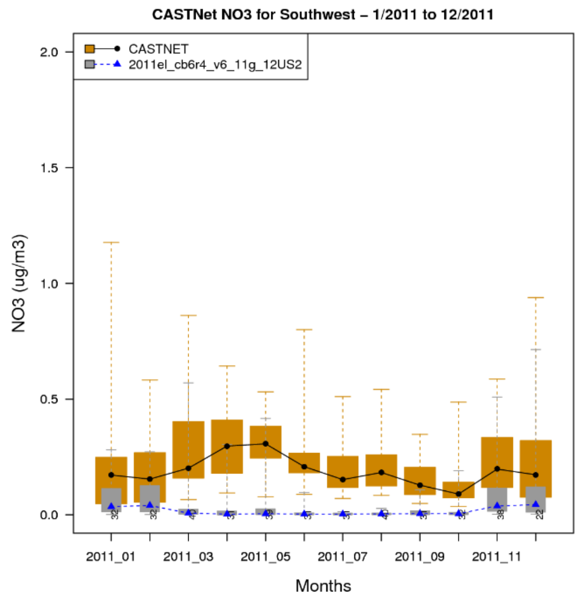
2011_07
2011_09
2011_11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CASTNET
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NO3 (ug/m3)
Months
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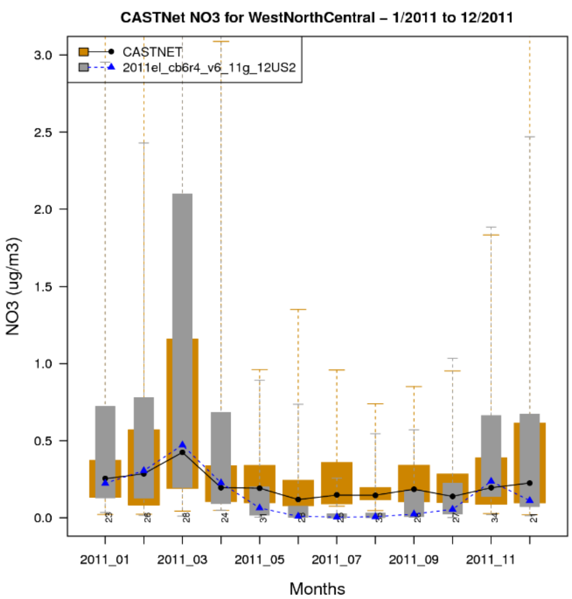
2011_07
2011_09
2011_11


CASTNet NO3 for WestNorthCentral – 1/2011 to 12/2011
CASTNET
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NO3 (ug/m3)
Months
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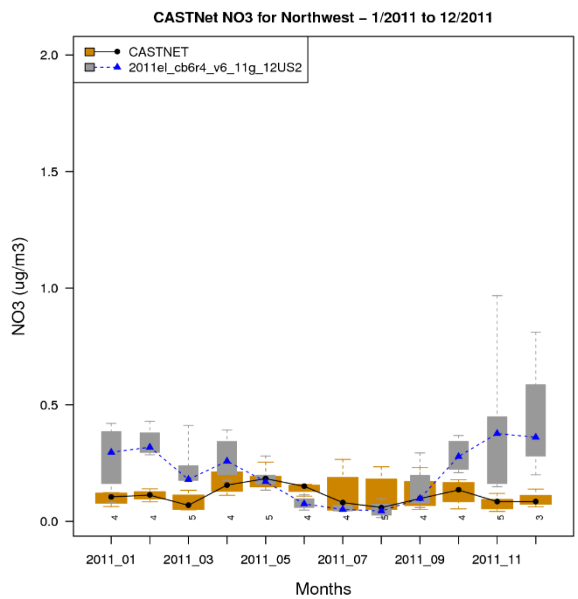
2011_07
2011_09
2011_11


CASTNet NO3 for Northwest – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
NO3 (ug/m3)
Months
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2011_09
2011_11

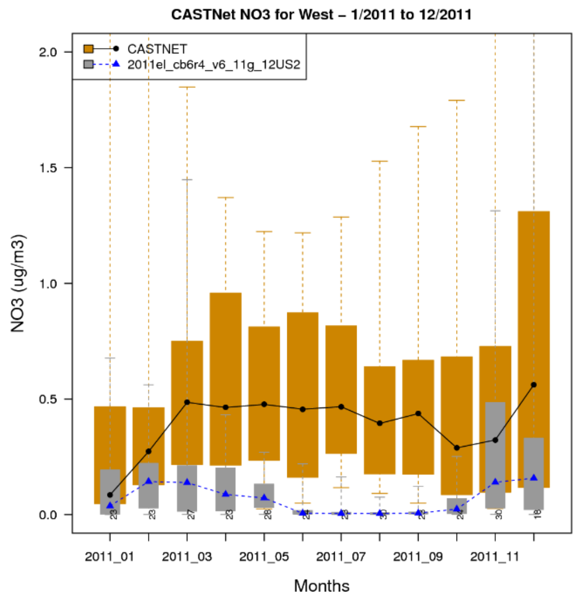


Figure 9. Boxplot comparisons of model predictions and CASTNet nitrate observations for each climate region by month.

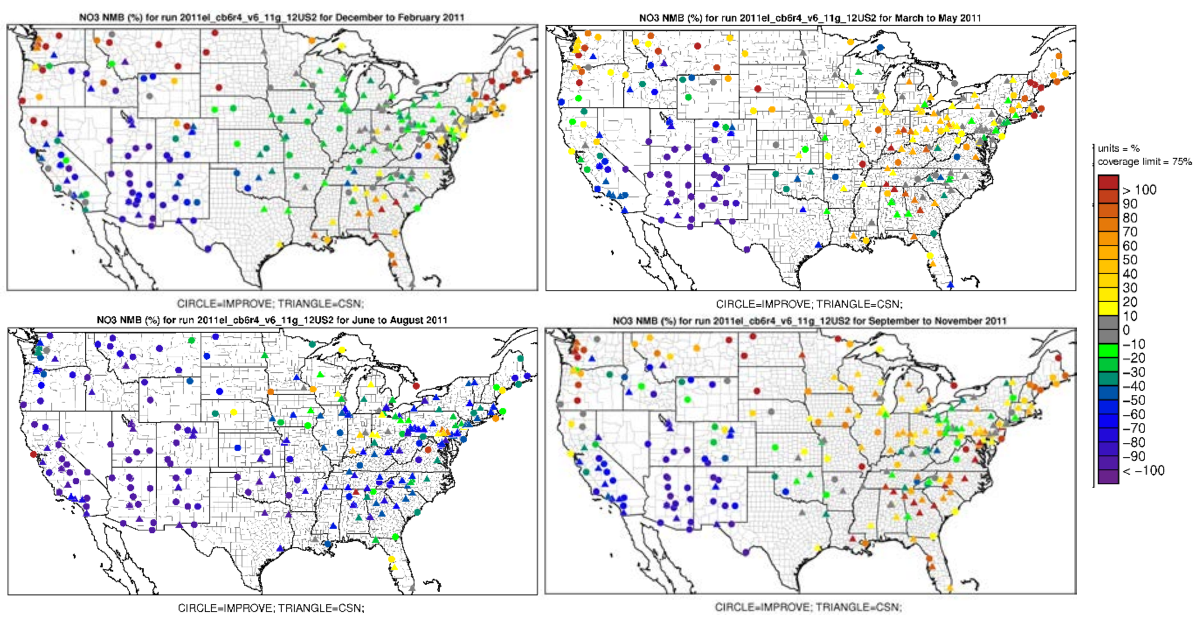


Figure 10. Spatial plots of nitrate NMB by season and network.

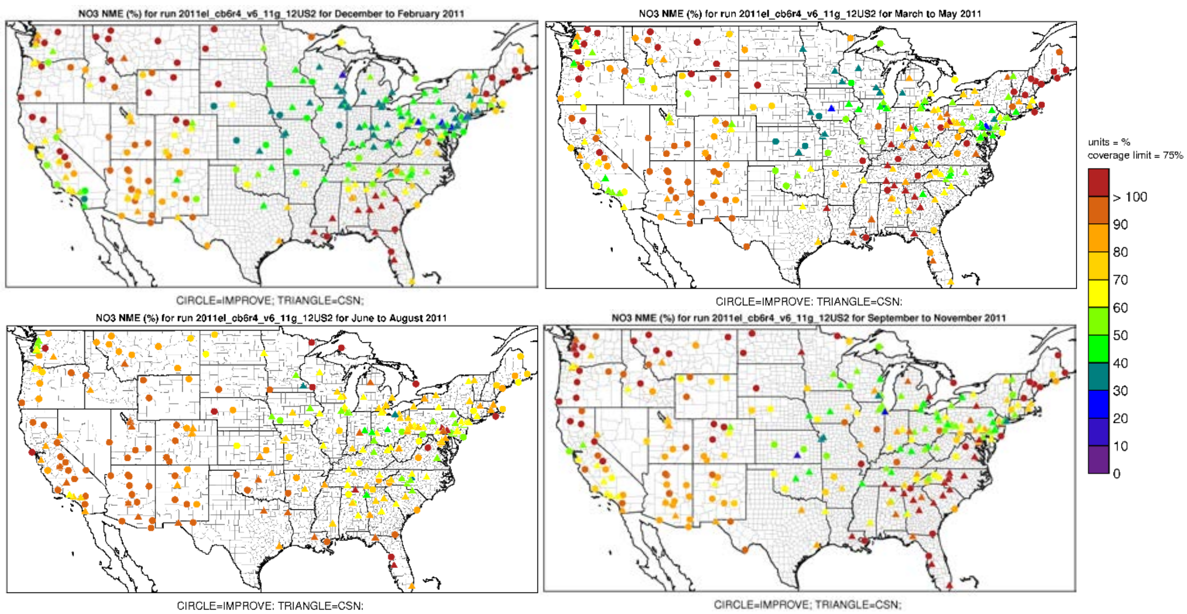


Figure 11. Spatial plots of nitrate NMB by season and network.

4. PM2.5 Ammonium

Table 4-1 summarizes model performance statistics for $PM_{2.5}$ ammonium. Boxplot comparisons of model predictions and observations (CSN and CASTNET) by month for each climate region are shown in Figures 12 and 13. Nationwide spatial plots of NMB and NME for each season are shown in Figures 14 and 15 (note that the IMPROVE network does not measure ammonium).

Ammonium is generally underpredicted across the western US in all seasons, with the exception of the northwestern US where a moderate to significant overprediction persists across all seasons. In the eastern US, ammonium is generally overpredicted during the spring and fall, with a slight overprediction observed during the summer and winter months.

Table 4-1. Model performance statistics for PM2.5 ammonium by region, network, and season

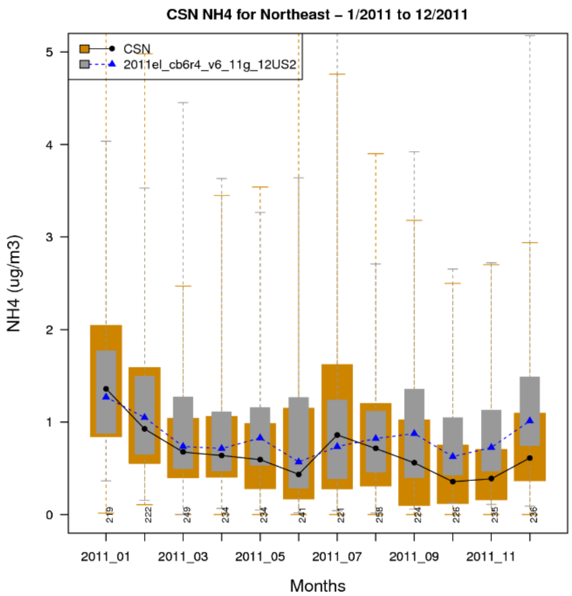
Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
Northeast	**CSN**	Winter	677	1.16	1.28	0.63	9.9	39.4	0.12	0.46
		Spring	717	0.78	0.93	0.71	19.9	43.7	0.16	0.34
		Summer	720	0.92	0.89	0.78	-3.5	39.4	-0.03	0.36
		Fall	685	0.56	0.86	0.77	52.8	66.1	0.30	0.37
		All	2799	0.85	0.99	0.71	15.5	44.7	0.13	0.38

Region	Network	Season	N	Avg. Obs. (µg m-3)	Avg. Mod. (µg m-3)	R	NMB (%)	NME (%)	MB (µg m-3)	ME (µg m-3)
	CASTNET	Winter	170	0.86	0.86	0.81	0.5	23.6	0.00	0.20
		Spring	193	0.66	0.78	0.81	17.4	28.4	0.12	0.19
		Summer	186	0.97	0.71	0.87	-26.0	29.6	-0.25	0.29
		Fall	197	0.62	0.68	0.67	9.2	28.0	0.06	0.18
		All	746	0.77	0.76	0.75	-2.2	27.5	-0.02	0.21
Southeast	CSN	Winter	435	0.73	0.97	0.59	33.4	54.1	0.24	0.39
		Spring	454	0.77	0.85	0.57	10.4	46.7	0.08	0.36
		Summer	471	0.81	0.79	0.65	-3.0	36.4	-0.02	0.30
		Fall	442	0.36	0.72	0.63	99.2	105.0	0.36	0.38
		All	1802	0.67	0.83	0.58	24.0	53.1	0.16	0.36
	CASTNET	Winter	138	0.71	0.71	0.83	-0.3	21.9	0.00	0.16
		Spring	146	0.75	0.66	0.70	-12.8	27.9	-0.10	0.21
		Summer	147	1.04	0.63	0.85	-39.4	40.2	-0.41	0.42
		Fall	150	0.58	0.55	0.72	-5.9	30.6	-0.03	0.18
		All	581	0.77	0.63	0.73	-17.8	31.3	-0.14	0.24
Ohio Valley	CSN	Winter	588	1.51	1.38	0.73	-8.4	38.4	-0.13	0.58
		Spring	625	1.23	1.56	0.70	26.4	47.5	0.33	0.59
		Summer	649	1.13	1.12	0.78	-1.3	32.3	-0.02	0.37
		Fall	611	0.68	0.93	0.76	37.1	54.5	0.25	0.37
		All	2473	1.13	1.24	0.71	9.7	41.7	0.11	0.47
	CASTNET	Winter	201	1.44	1.19	0.84	-17.6	26.7	-0.25	0.39
		Spring	214	1.05	1.19	0.67	13.0	32.2	0.14	0.34
		Summer	207	1.37	0.95	0.67	-31.2	33.8	-0.43	0.46
		Fall	214	0.79	0.87	0.55	9.7	33.4	0.08	0.26

Region	Network	Season	N	Avg. Obs. (µg m-3)	Avg. Mod. (µg m-3)	R	NMB (%)	NME (%)	MB (µg m-3)	ME (µg m-3)
		All	836	1.16	1.05	0.63	-9.7	31.2	-0.11	0.36
Upper Midwest	**CSN**	Winter	334	1.48	1.37	0.69	-7.7	43.7	-0.11	0.65
		Spring	337	1.21	1.57	0.75	29.7	45.4	0.36	0.55
		Summer	335	0.74	0.85	0.76	15.9	47.7	0.12	0.35
		Fall	340	0.68	1.05	0.82	54.0	61.7	0.37	0.42
		All	1346	1.03	1.21	0.74	17.9	47.9	0.18	0.49
	CASTNET	Winter	56	1.06	0.95	0.83	-10.1	22.2	-0.11	0.24
		Spring	62	0.76	0.97	0.84	28.8	36.2	0.22	0.27
		Summer	65	0.67	0.63	0.86	-5.5	19.3	-0.04	0.13
		Fall	62	0.67	0.82	0.81	22.1	31.0	0.15	0.21
		All	245	0.78	0.84	0.78	7.5	26.9	0.06	0.21
South	**CSN**	Winter	222	0.97	1.03	0.57	6.1	48.7	0.06	0.47
		Spring	248	0.90	0.85	0.79	-5.6	37.2	-0.05	0.34
		Summer	253	0.61	0.51	0.73	-16.3	40.9	-0.10	0.25
		Fall	238	0.51	0.71	0.61	39.5	61.8	0.20	0.31
		All	961	0.74	0.77	0.67	3.3	45.6	0.02	0.34
	CASTNET	Winter	70	0.94	0.81	0.73	-13.7	32.5	-0.13	0.30
		Spring	85	0.76	0.71	0.68	-7.4	37.0	-0.06	0.28
		Summer	87	0.70	0.39	0.65	-44.6	47.6	-0.31	0.33
		Fall	77	0.56	0.52	0.52	-8.4	32.4	-0.05	0.18
		All	319	0.74	0.60	0.68	-19.0	37.6	-0.14	0.28
Southwest	**CSN**	Winter	185	1.16	0.48	0.62	-58.3	67.1	-0.68	0.78
		Spring	190	0.33	0.24	0.55	-24.8	46.9	-0.08	0.15
		Summer	192	0.31	0.17	0.37	-45.5	54.1	-0.14	0.17

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Fall	186	0.36	0.24	0.59	-33.1	47.0	-0.12	0.17
		All	753	0.53	0.28	0.63	-47.1	58.7	-0.25	0.31
	CASTNET	Winter	94	0.15	0.17	0.25	9.8	44.8	0.01	0.07
		Spring	102	0.21	0.15	0.30	-28.4	40.1	-0.06	0.08
		Summer	102	0.30	0.12	0.60	-58.2	58.2	-0.17	0.17
		Fall	101	0.24	0.15	0.60	-35.9	40.3	-0.09	0.10
		All	399	0.23	0.15	0.22	-34.4	47.0	-0.08	0.11
N. Rockies & Plains	CSN	Winter	66	0.91	0.89	0.61	-1.5	51.5	-0.01	0.47
		Spring	70	0.93	0.99	0.88	6.4	33.1	0.06	0.31
		Summer	72	0.34	0.47	0.82	40.2	57.8	0.14	0.20
		Fall	69	0.35	0.63	0.71	82.5	102.0	0.29	0.35
		All	277	0.63	0.74	0.78	19.0	52.4	0.12	0.33
	CASTNET	Winter	77	0.29	0.33	0.89	13.6	35.3	0.04	0.10
		Spring	76	0.41	0.47	0.93	15.6	27.0	0.06	0.11
		Summer	88	0.29	0.19	0.77	-32.6	39.2	-0.09	0.11
		Fall	89	0.24	0.26	0.74	8.9	35.1	0.02	0.08
		All	330	0.30	0.31	0.87	1.5	33.7	0.00	0.10
Northwest	CSN	Winter	166	0.56	0.83	0.38	48.8	99.3	0.27	0.55
		Spring	167	0.15	0.32	0.59	110.0	124.0	0.17	0.19
		Summer	172	0.21	0.31	0.61	53.5	69.1	0.11	0.14
		Fall	166	0.20	0.53	0.23	167.0	193.0	0.33	0.39
		All	671	0.28	0.50	0.46	79.0	114.0	0.22	0.32
	CASTNET	Winter	12	0.11	0.22	0.88	98.1	98.1	0.11	0.11
		Spring	13	0.13	0.18	0.57	44.0	50.8	0.06	0.06

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Summer	13	0.24	0.23	0.62	-4.2	20.7	-0.01	0.05
		Fall	13	0.14	0.24	0.25	69.0	76.3	0.10	0.11
		All	51	0.15	0.22	0.44	39.9	52.8	0.06	0.08
West	**CSN**	Winter	225	1.56	0.76	0.53	-51.1	67.1	-0.80	1.05
		Spring	242	0.62	0.47	0.61	-25.1	56.4	-0.16	0.35
		Summer	247	0.86	0.30	0.74	-64.8	68.9	-0.56	0.59
		Fall	228	1.34	0.63	0.77	-53.0	63.6	-0.71	0.85
		All	942	1.08	0.53	0.65	-50.7	64.9	-0.55	0.70
	CASTNET	Winter	69	0.28	0.19	0.42	-31.4	62.5	-0.09	0.17
		Spring	73	0.25	0.19	0.08	-24.0	53.3	-0.06	0.13
		Summer	77	0.39	0.12	0.05	-69.8	70.6	-0.27	0.28
		Fall	77	0.35	0.18	0.39	-48.9	58.2	-0.17	0.20
		All	296	0.32	0.17	0.25	-47.3	62.1	-0.15	0.20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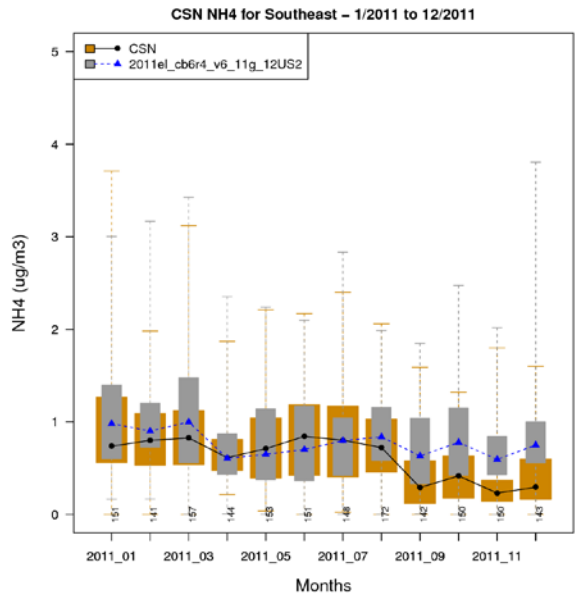
NH4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


CSN NH4 for Southeast – 1/2011 to 12/2011
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NH4 (ug/m3)
Months
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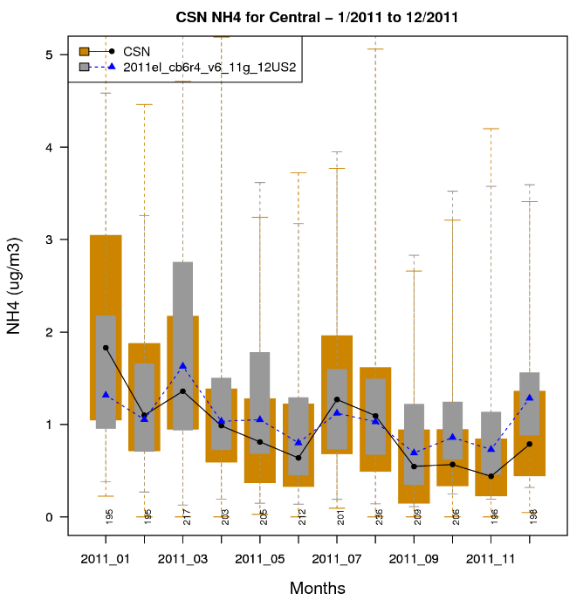
2011_07
2011_09
2011_11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NH4 (ug/m3)
Months
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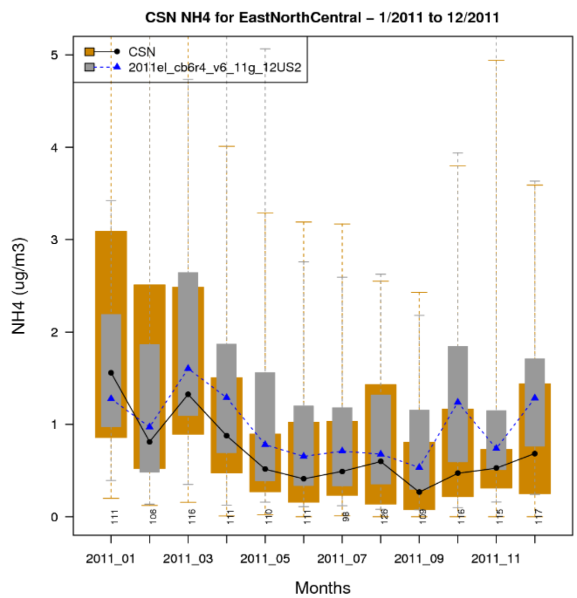
2011_07
2011_09
2011_11


CSN NH4 for EastNorthCentral – 1/2011 to 12/2011
CSN
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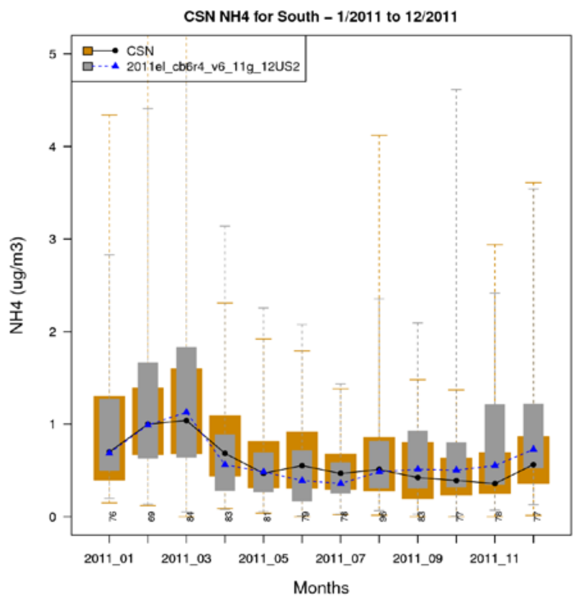
NH4 (ug/m3)
Months
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11


CSN NH4 for South – 1/2011 to 12/2011
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NH4 (ug/m3)
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1
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3
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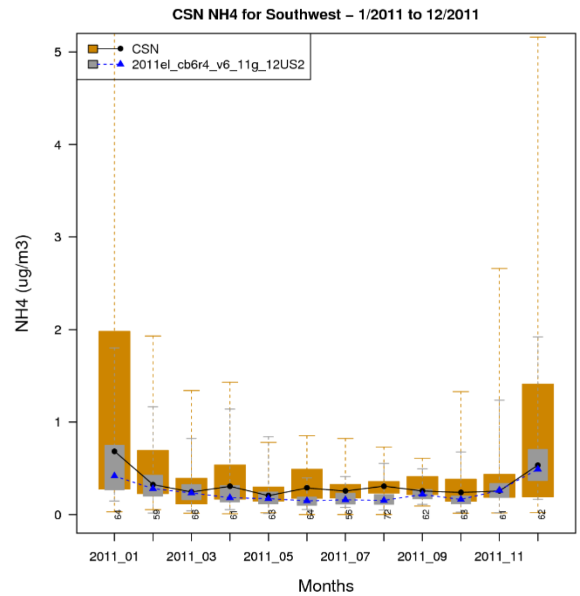
5
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months


CSN NH4 for Southwest – 1/2011 to 12/2011
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2011el_cb6r4_v6_11g_12US2
NH4 (ug/m3)
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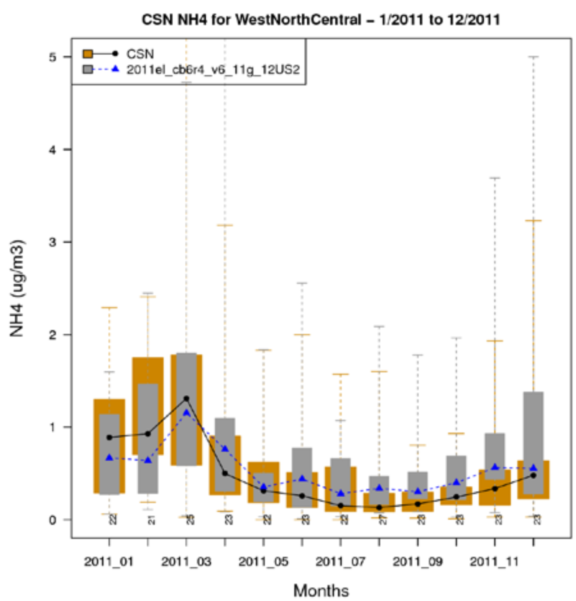
1
2
3
4
5
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months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NH4 (ug/m3)
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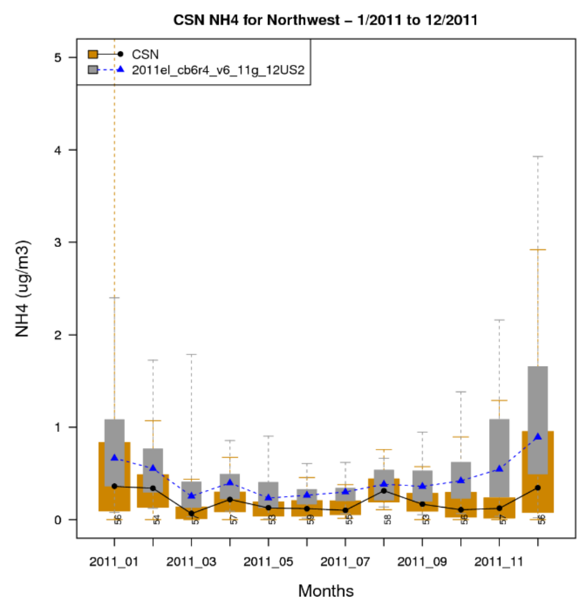
1
2
3
4
5
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months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NH4 (ug/m3)
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1
2
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2011_09
2011_11
Months

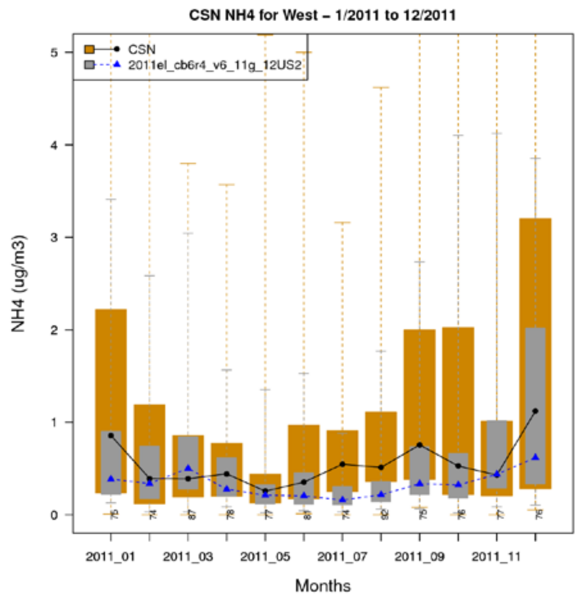
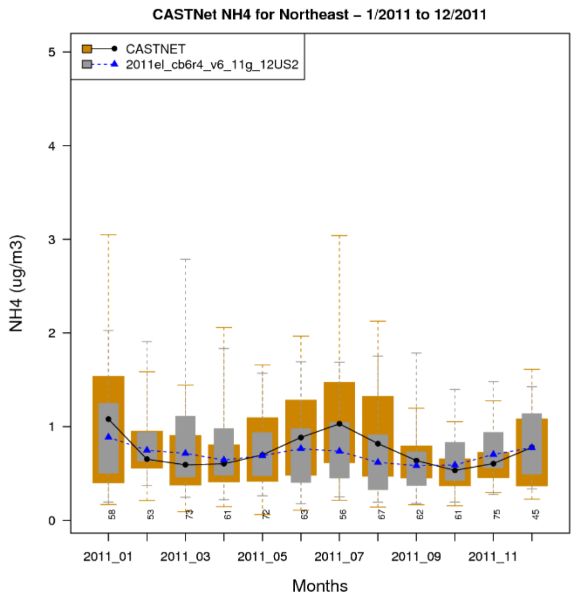


Figure 12. Boxplot comparisons of model predictions and CSN ammonium observations for each climate region by month.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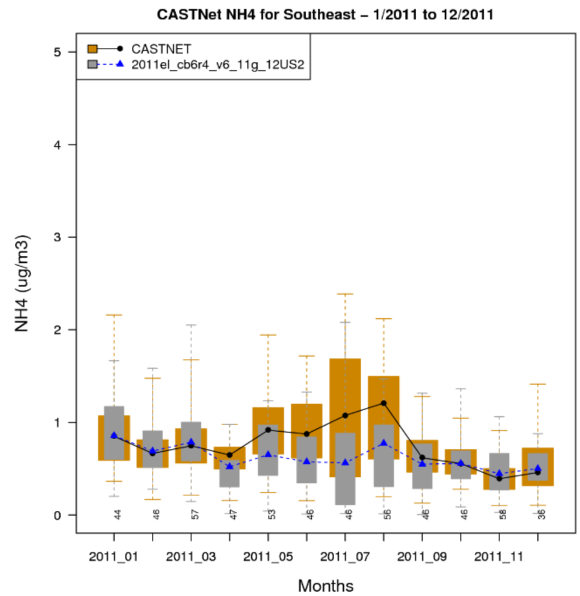
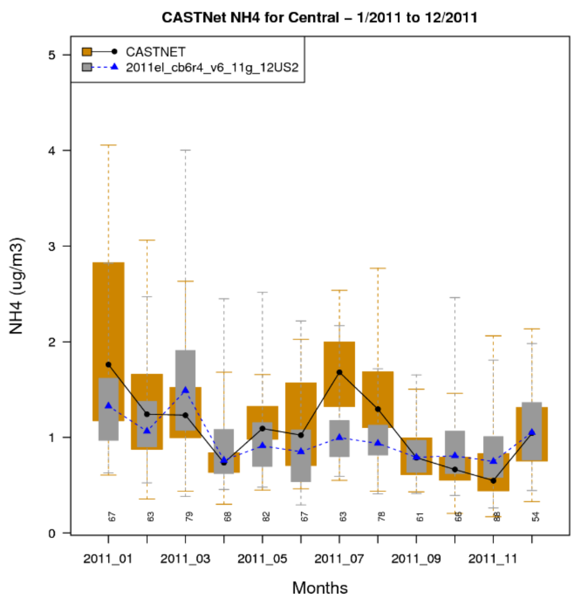
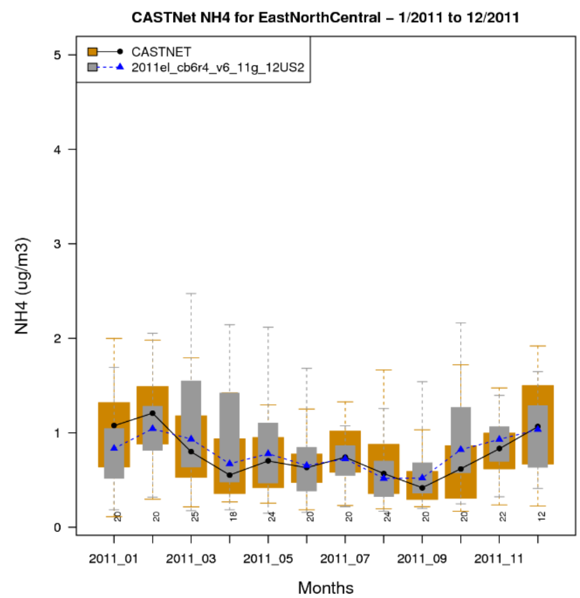
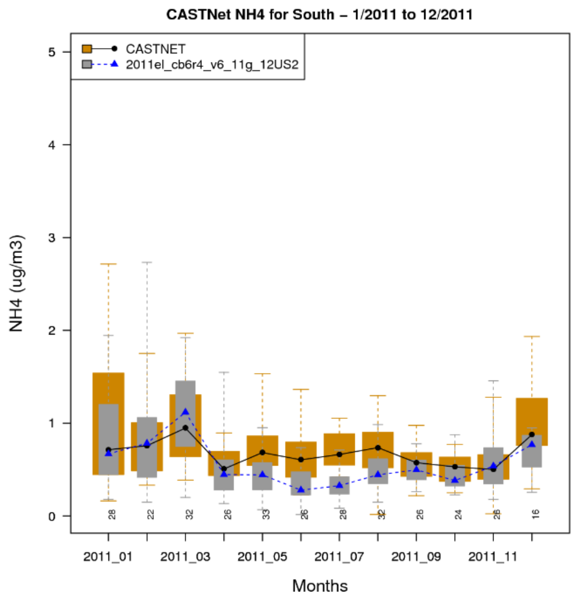
CASTNET
2011el_cb6r4_v6_11g_12US2
NH4 (ug/m3)
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months

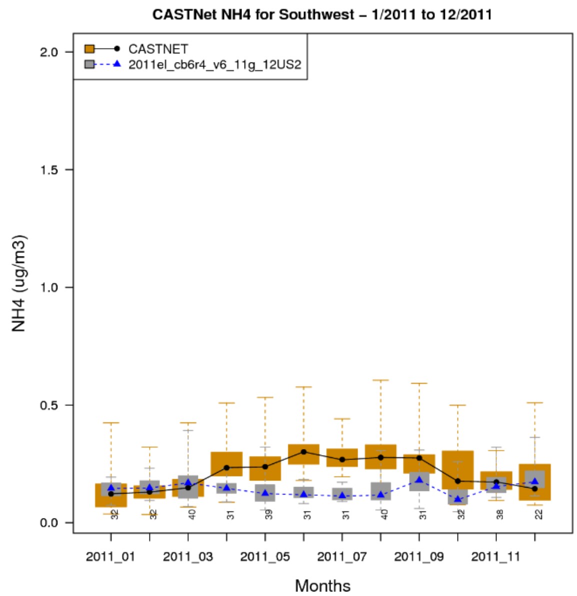

CASTNet NH4 for Southeast – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
NH4 (ug/m3)
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months


CASTNet NH4 for Central – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
NH4 (ug/m3)
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months


CASTNet NH4 for EastNorthCentral – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
NH4 (ug/m3)
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months



CASTNet NH4 for South – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
NH4 (ug/m3)
Months



CASTNet NH4 for Southwest – 1/2011 to 12/2011
CASTNET
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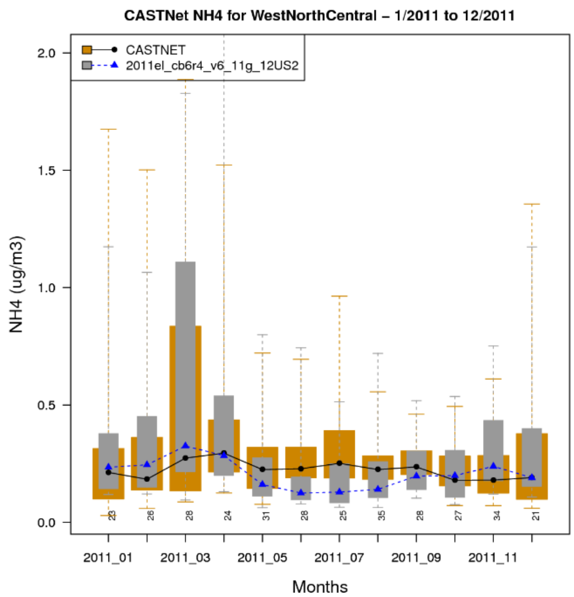
NH4 (ug/m3)
Months



CASTNet NH4 for WestNorthCentral – 1/2011 to 12/2011
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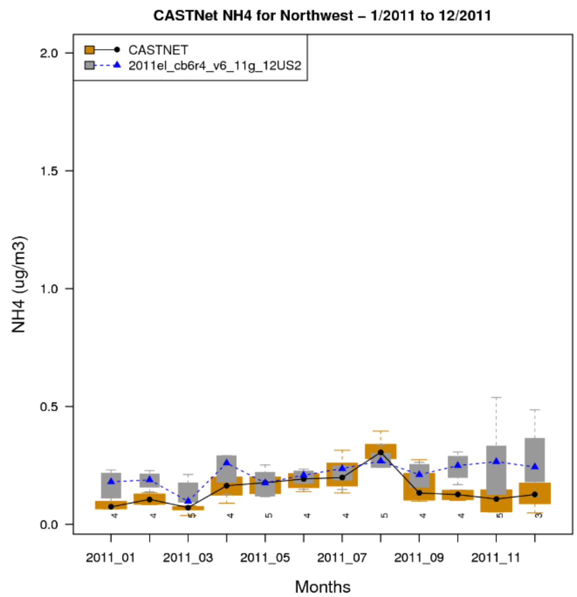
NH4 (ug/m3)
Months



CASTNet NH4 for Northwest – 1/2011 to 12/2011
CASTNET
2011el_cb6r4_v6_11g_12US2
NH4 (ug/m3)
Months

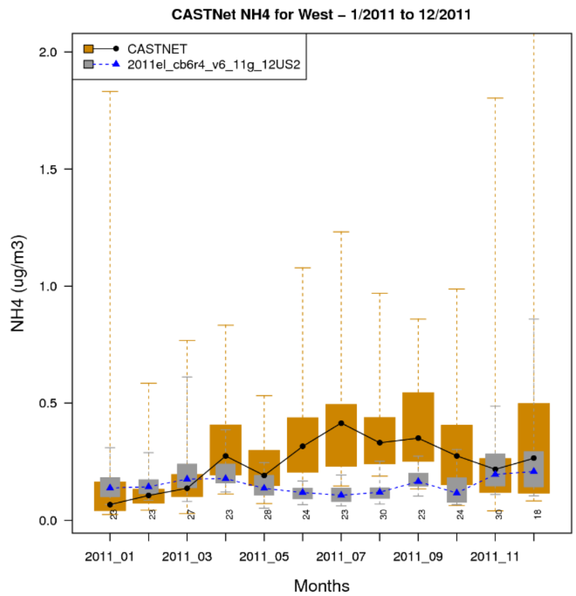


Figure 13. Boxplot comparisons of model predictions and CASTNet ammonium observations for each climate region by month.

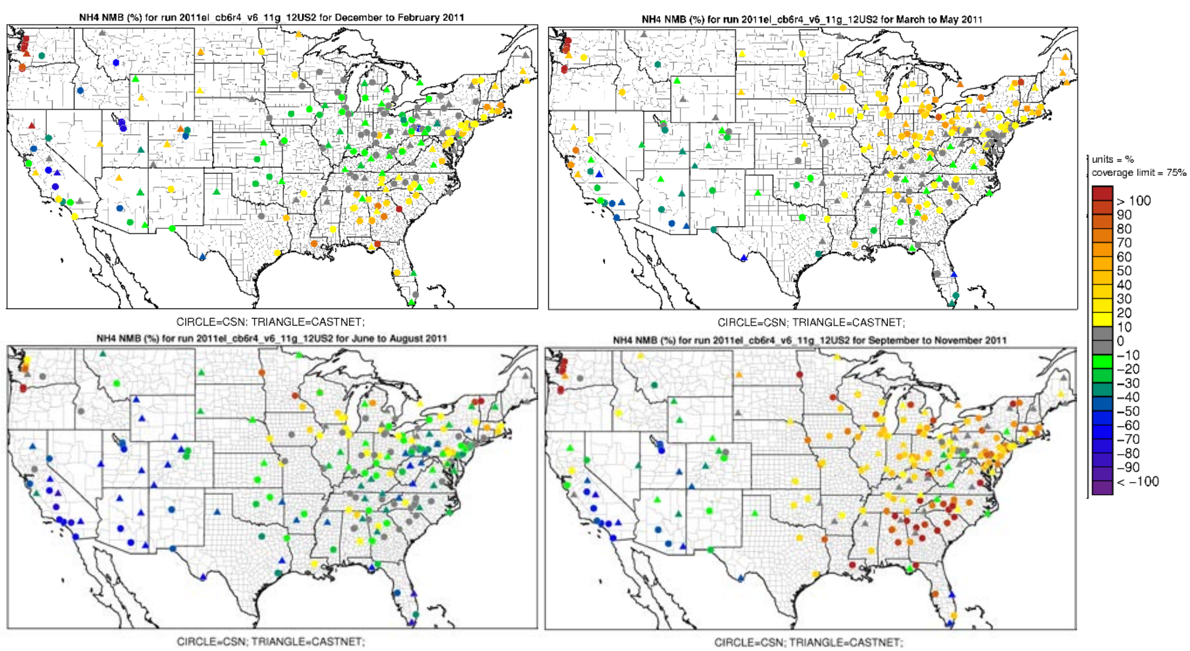


Figure 14. Spatial plots of ammonium NMB by season and network.

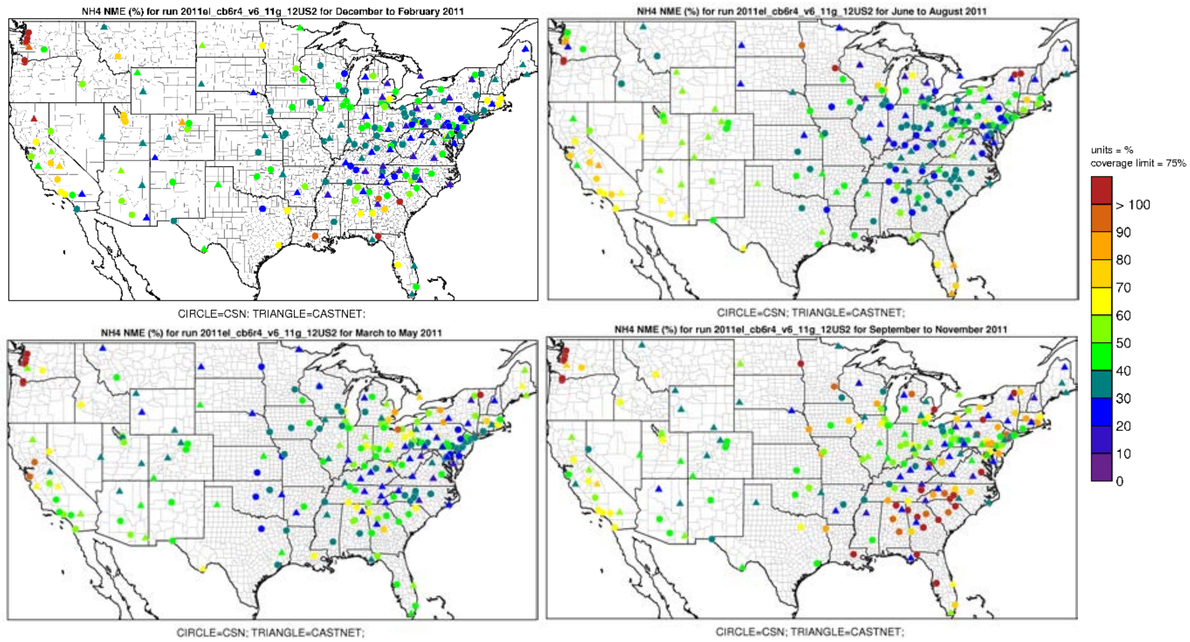


Figure 15. Spatial plots of ammonium NME by season and network.

5. PM2.5 OC

Table 5-1 summarizes model performance statistics for PM2.5 organic carbon (OC). Boxplot comparisons of model predictions and observations (IMPROVE, CSN and CASTNET) by month for each climate region are shown in Figures 16 and 17. Nationwide spatial plots of NMB and NME for each season are shown in Figures 18 and 19.

OC is generally overpredicted across most regions and seasons. Some exceptions are noted in the Northern Rockies and Plains during the winter and spring, and the Northeast and Upper Midwest in the summer, where slight underpredictions are observed. Organic carbon is significantly overpredicted in the Northwest, Upper Midwest, and the Northeast in the winter, where NMBs range at CSN sites range from 85 to 165%.

Table 5-1. Model performance statistics for PM2.5 OC by region, network, and season.

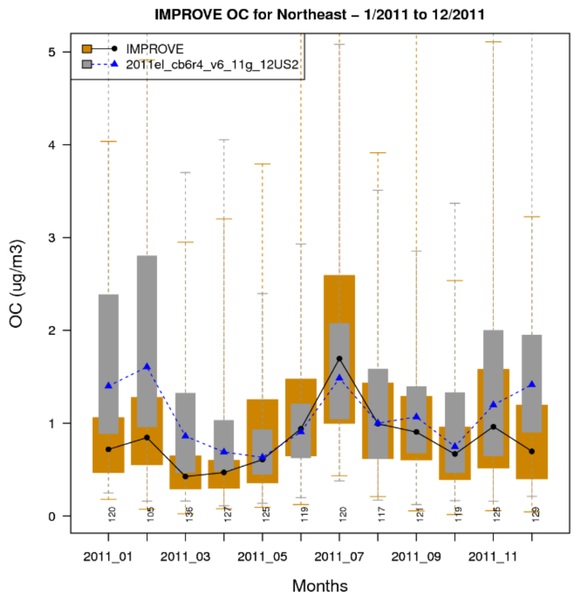
Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
Northeast	IMPROVE	Winter	354	0.94	1.81	0.66	92.1	99.3	0.87	0.93
		Spring	388	0.65	0.88	0.52	35.3	63.9	0.23	0.42
		Summer	356	1.47	1.29	0.59	-12.5	36.3	-0.18	0.54
		Fall	365	0.99	1.19	0.70	20.3	40.2	0.20	0.40

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		All	1463	1.01	1.28	0.55	27.5	56.2	0.28	0.57
	CSN	Winter	637	1.61	4.26	0.63	165.0	167.0	2.65	2.69
		Spring	681	1.09	1.94	0.47	78.1	93.1	0.85	1.01
		Summer	696	2.07	2.10	0.61	1.5	31.1	0.03	0.64
		Fall	622	1.42	2.29	0.74	61.5	69.5	0.87	0.99
		All	2636	1.55	2.63	0.52	69.4	84.8	1.08	1.31
Southeast	**IMPROVE**	Winter	292	1.53	2.14	0.61	39.8	65.4	1.19	1.54
		Spring	316	2.02	1.85	0.32	-8.6	53.1	-0.17	1.07
		Summer	308	2.13	2.37	0.45	11.1	55.6	0.24	1.18
		Fall	300	1.51	1.84	0.41	22.0	66.0	0.33	1.00
		All	1216	1.80	2.05	0.39	13.4	59.0	0.24	1.06
	CSN	Winter	415	2.11	3.30	0.61	56.7	73.3	1.19	1.54
		Spring	429	1.93	2.59	0.63	34.3	52.8	0.66	1.02
		Summer	458	2.67	4.06	0.35	51.8	73.0	1.38	1.95
		Fall	421	1.72	2.81	0.65	63.5	74.3	1.09	1.28
		All	1723	2.12	3.20	0.55	51.3	68.8	1.09	1.46
Ohio Valley	**IMPROVE**	Winter	193	1.35	1.74	0.63	28.5	53.3	0.39	0.72
		Spring	207	1.41	1.31	0.65	-6.8	41.2	-0.10	0.58
		Summer	195	1.84	1.90	0.67	3.4	31.5	0.06	0.58
		Fall	206	1.21	1.40	0.75	15.3	38.9	0.19	0.47
		All	801	1.45	1.58	0.67	9.01	40.4	0.13	0.59
	CSN	Winter	574	1.56	2.96	0.55	89.9	96.6	1.40	1.51
		Spring	601	1.46	1.85	0.65	26.5	46.7	0.39	0.68
		Summer	658	2.27	2.41	0.63	6.2	28.9	0.14	0.66

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Fall	610	1.47	1.95	0.71	32.7	46.2	0.48	0.68
		All	2443	1.70	2.28	0.58	34.1	50.9	0.58	0.87
Upper Midwest	**IMPROVE**	Winter	199	0.66	1.15	0.60	74.9	83.9	0.49	0.55
		Spring	211	0.78	0.92	0.63	19.5	54.3	0.15	0.42
		Summer	203	1.49	1.35	0.57	-9.5	34.7	-0.14	0.52
		Fall	202	1.76	2.31	0.71	31.6	85.5	0.56	1.50
		All	815	1.17	1.43	0.70	22.4	63.7	0.26	0.74
	CSN	Winter	324	1.27	3.11	0.55	146.0	149.0	1.85	1.89
		Spring	330	1.09	1.99	0.52	81.5	90.5	0.89	0.99
		Summer	332	1.91	1.97	0.59	3.2	31.7	0.06	0.60
		Fall	333	1.37	2.13	0.57	55.4	64.8	0.76	0.89
		All	1319	1.41	2.30	0.43	62.7	77.0	0.89	1.09
South	**IMPROVE**	Winter	223	0.83	1.23	0.41	48.9	75.8	0.41	0.63
		Spring	237	1.51	1.39	0.60	-7.7	54.3	-0.12	0.82
		Summer	241	1.56	2.16	0.61	38.4	55.5	0.60	0.87
		Fall	222	1.00	1.27	0.69	26.3	53.4	0.26	0.54
		All	923	1.24	1.53	0.58	23.3	58.0	0.29	0.72
	CSN	Winter	219	1.89	2.96	0.43	56.8	79.7	1.07	1.51
		Spring	250	2.08	1.97	0.25	-5.2	53.0	-0.11	1.10
		Summer	257	1.81	3.07	0.54	70.1	84.7	1.27	1.53
		Fall	239	1.67	2.72	0.63	62.7	75.8	1.05	1.27
		All	965	1.86	2.68	0.29	43.6	72.4	0.81	1.35
Southwest	**IMPROVE**	Winter	894	0.53	0.60	0.40	13.5	70.6	0.07	0.37
		Spring	930	0.43	0.47	0.35	7.7	59.9	0.03	0.26

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Summer	955	1.02	1.20	0.41	16.7	68.5	0.17	0.70
		Fall	918	0.63	0.89	0.45	41.2	79.9	0.26	0.50
		All	3697	0.66	0.79	0.39	20.4	70.2	0.13	0.46
	CSN	Winter	181	2.14	4.19	0.33	95.9	112.0	2.05	2.40
		Spring	184	0.66	1.86	0.43	184.0	189.0	1.21	1.24
		Summer	194	1.33	1.74	0.34	30.6	66.2	0.41	0.88
		Fall	188	1.34	2.62	0.43	95.6	102.0	1.28	1.37
		All	747	1.36	2.59	0.42	89.7	107.0	1.22	1.46
N. Rockies & Plains	**IMPROVE**	Winter	485	0.31	0.29	0.45	-7.3	54.2	-0.02	0.17
		Spring	537	0.36	0.28	0.69	-24.3	51.0	-0.09	0.19
		Summer	526	1.03	1.09	0.41	5.2	55.2	0.05	0.57
		Fall	520	1.05	1.19	0.67	13.7	59.7	0.14	0.63
		All	2068	0.69	0.71	0.60	3.1	56.2	0.02	0.39
	CSN	Winter	63	2.98	1.51	-0.15	-49.3	101.0	-1.47	3.01
		Spring	58	1.00	0.99	0.58	-1.3	66.2	-0.01	0.66
		Summer	70	1.44	1.29	0.57	-10.5	38.2	-0.15	0.55
		Fall	68	1.74	1.64	0.56	-5.9	57.4	-0.10	1.00
		All	259	1.80	1.37	0.17	-23.8	71.9	-0.43	1.29
Northwest	**IMPROVE**	Winter	393	0.66	0.98	0.34	48.1	108.0	0.32	0.72
		Spring	457	0.34	0.69	0.65	103.0	150.0	0.35	0.51
		Summer	425	0.77	0.99	0.42	28.5	77.4	0.22	0.60
		Fall	430	1.47	2.34	0.52	59.2	104.0	0.87	1.52
		All	1705	0.81	1.25	0.51	54.7	103.0	0.44	0.83
	CSN	Winter	166	4.28	7.91	0.44	84.9	112.0	3.63	4.78

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Spring	162	0.79	3.92	0.59	397.0	397.0	3.13	3.13
		Summer	154	1.03	2.45	0.23	138.0	148.0	1.42	1.53
		Fall	159	2.55	5.49	0.56	115.0	126.0	2.94	3.22
		All	641	2.19	4.99	0.58	128.0	146.0	2.80	3.19
West	**IMPROVE**	Winter	460	0.76	0.63	0.88	-18.0	47.2	-0.14	0.36
		Spring	468	0.53	0.38	0.45	-28.3	58.3	-0.15	0.31
		Summer	469	1.15	1.15	0.64	0.1	58.0	0.00	0.67
		Fall	500	1.05	1.20	0.57	14.9	59.0	0.16	0.62
		All	1897	0.88	0.85	0.62	-3.3	56.1	-0.03	0.49
	CSN	Winter	219	3.67	3.82	0.68	4.1	44.0	0.15	1.61
		Spring	235	1.31	2.00	0.47	53.4	69.5	0.70	0.91
		Summer	242	1.65	1.67	0.56	1.4	31.2	0.02	0.52
		Fall	225	2.74	3.04	0.58	11.1	37.0	0.30	1.01
		All	921	2.31	2.60	0.70	12.8	43.2	0.29	1.00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Months
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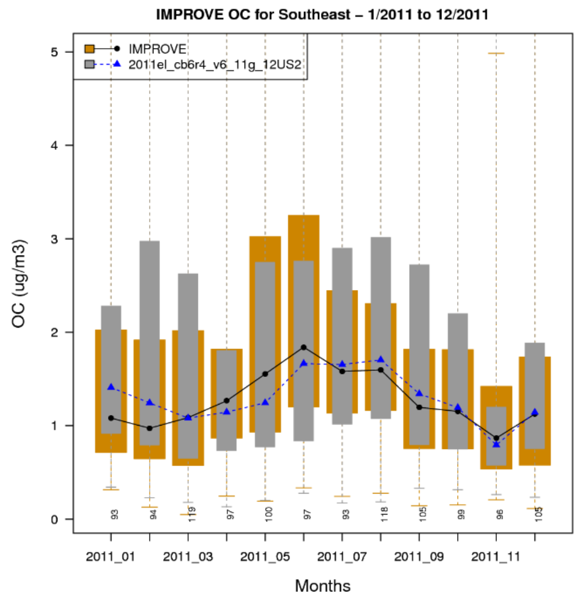
2011_07
2011_09
2011_11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OC (ug/m3)
Months
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2011_07
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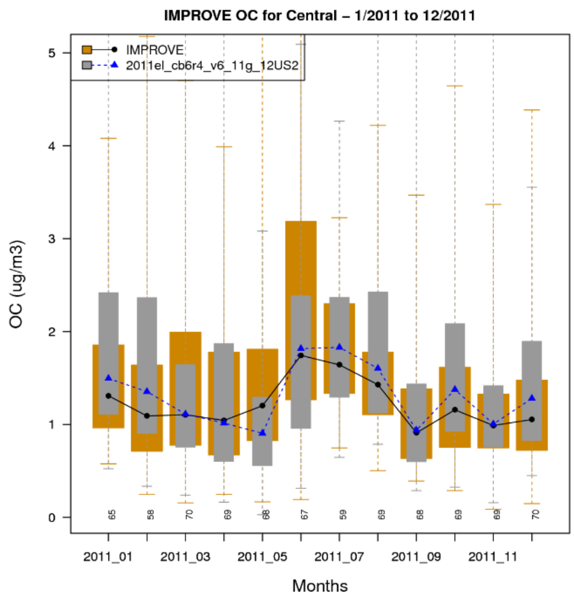
2011_11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OC (ug/m3)
Months
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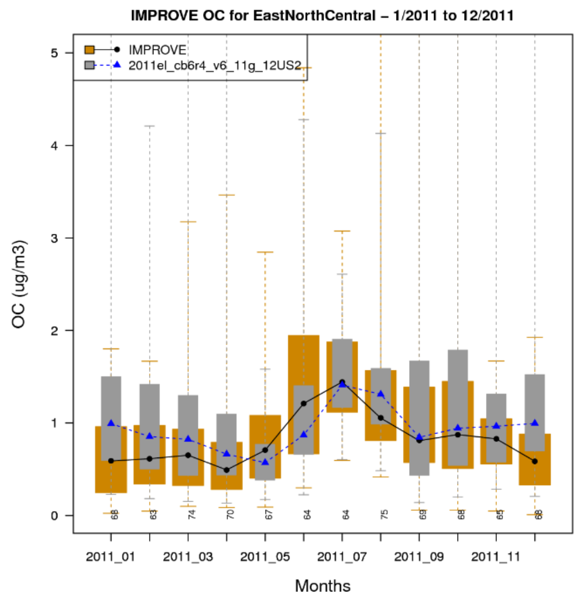
2011_09
2011_11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OC (ug/m3)
Months
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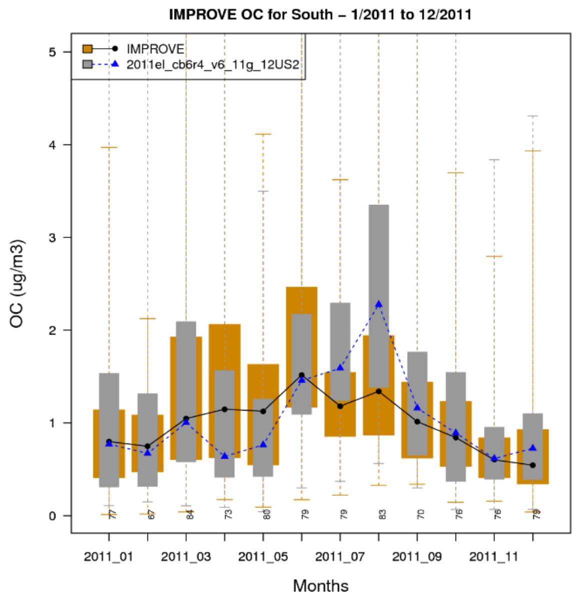
2011_07
2011_09
2011_11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OC (ug/m3)
Months
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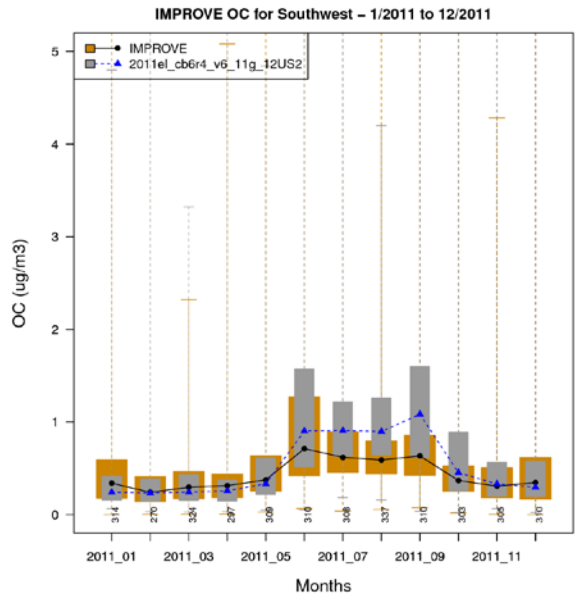
2011_09
2011_11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OC (ug/m3)
Months
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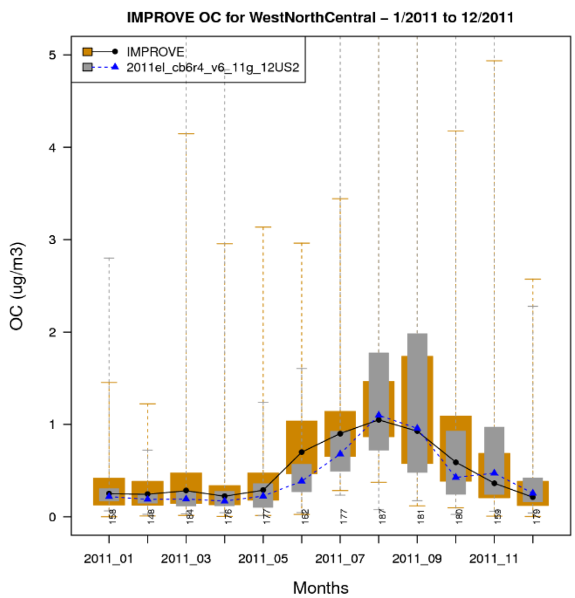
2011_07
2011_09
2011_11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OC (ug/m3)
Months
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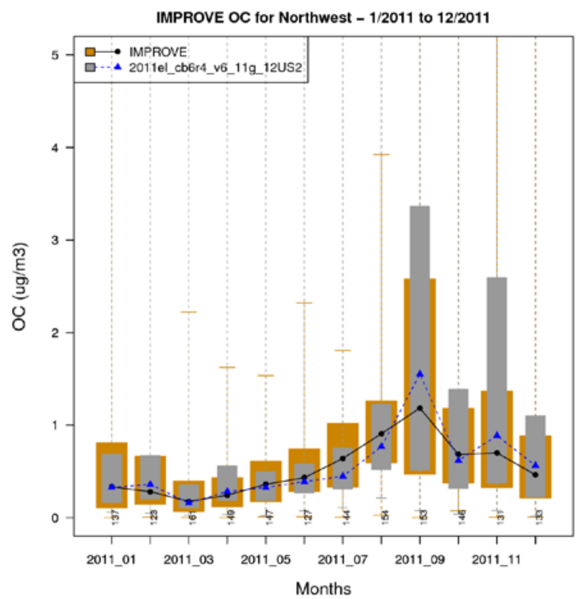
IMPROVE OC for Northwest – 1/2011 to 12/2011
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OC (ug/m3)
Months
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2011_07
2011_09
2011_11

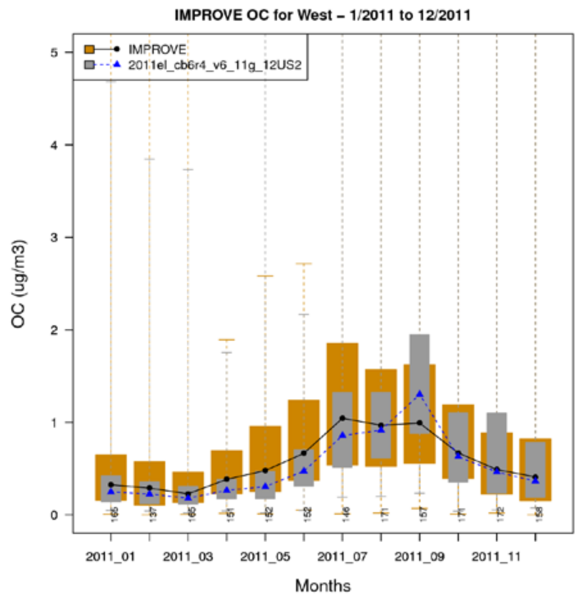
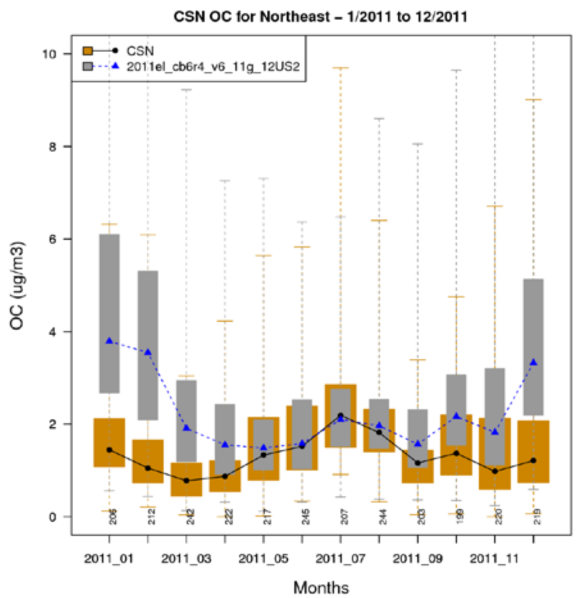


Figure 16. Boxplot comparisons of model predictions and IMPROVE organic carbon observations for each climate region by month.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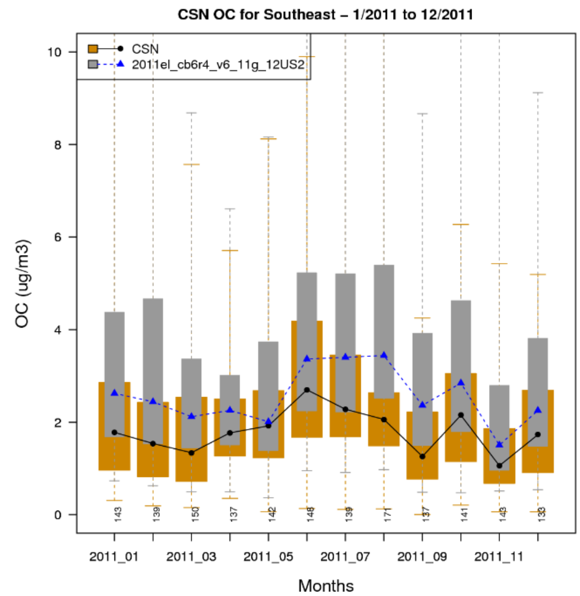
OC (ug/m3)
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months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OC (ug/m3)
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2011_03
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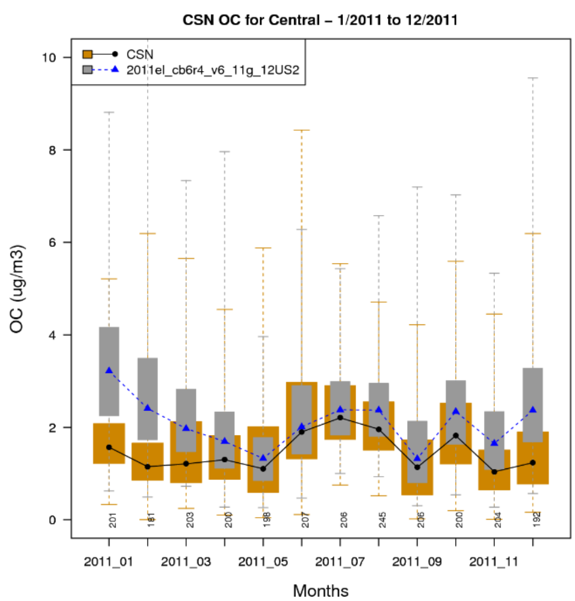
2011_09
2011_11
Months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CSN
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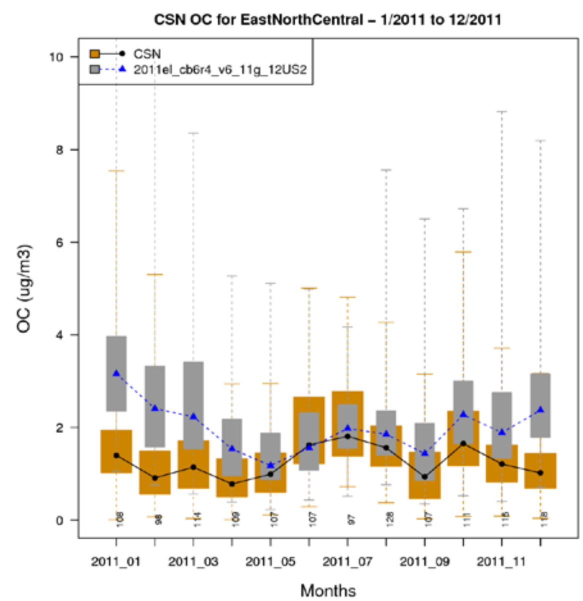
OC (ug/m3)
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months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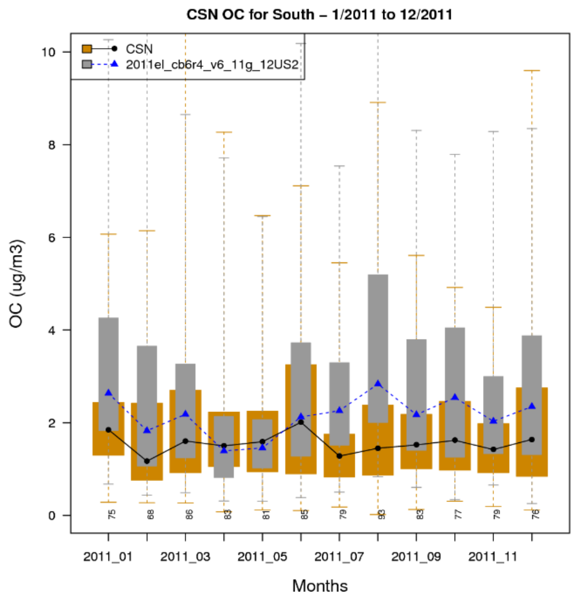
Months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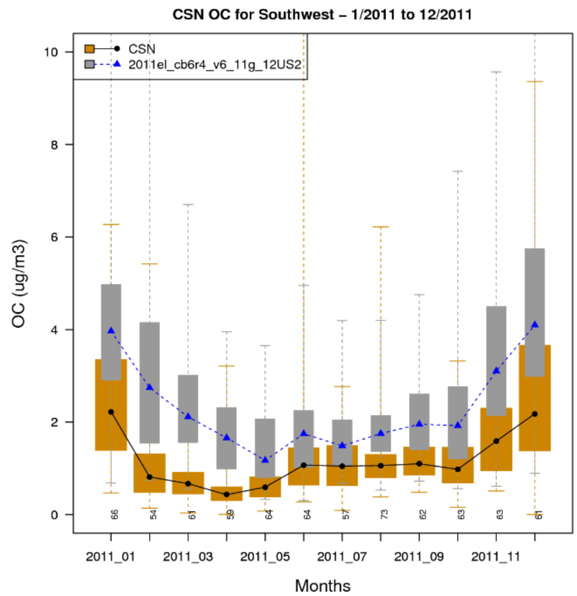
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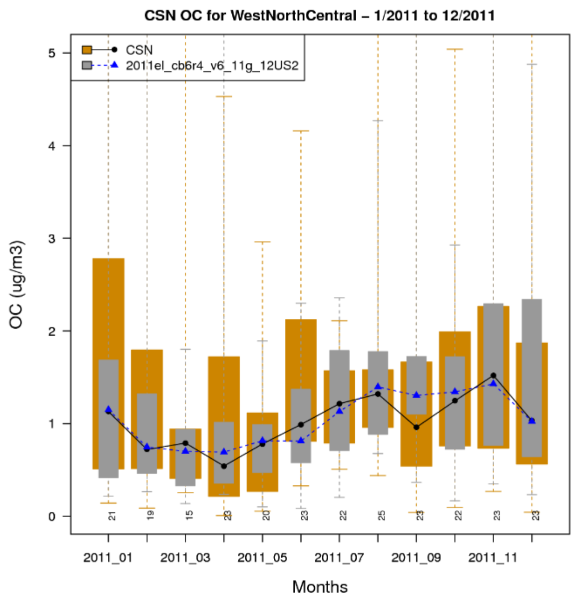
CSN OC for WestNorthCentral – 1/2011 to 12/2011
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OC (ug/m3)
Months
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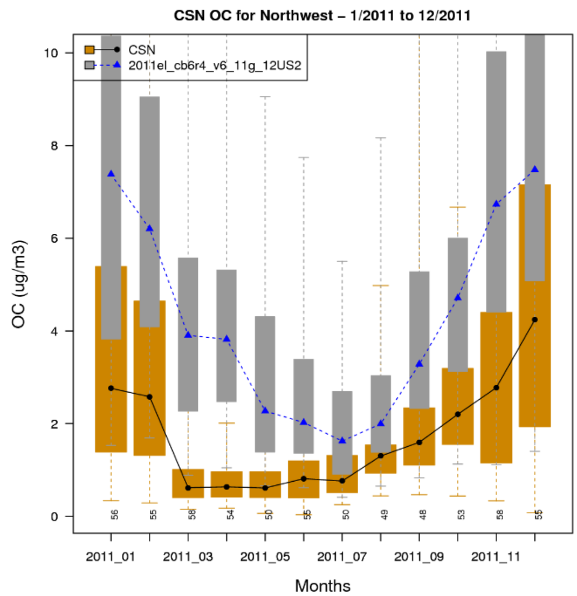
CSN OC for Northwest – 1/2011 to 12/2011
CSN
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OC (ug/m3)
Months
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2011_11

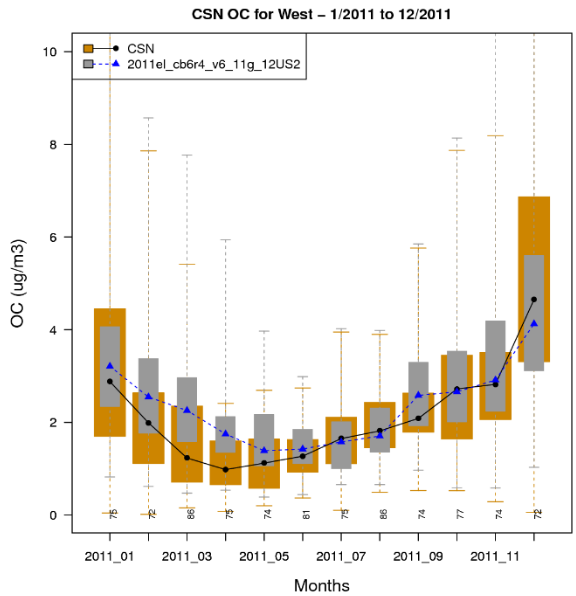


Figure 17. Boxplot comparisons of model predictions and CSN organic carbon observations for each climate region by month.

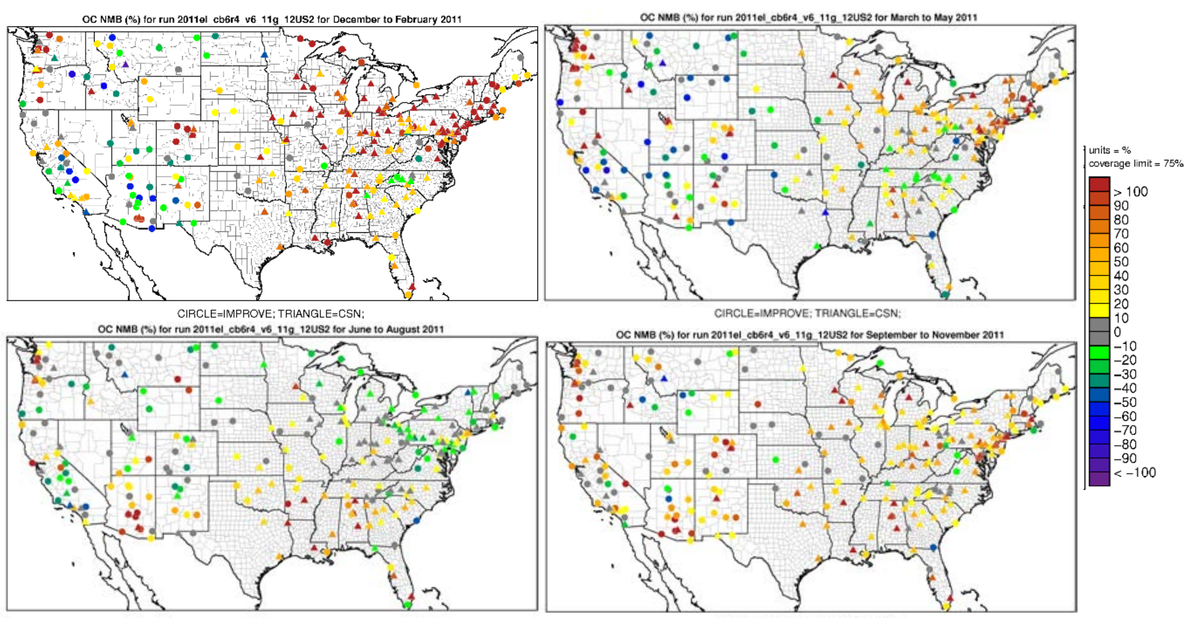


Figure 18. Spatial plot of organic carbon NMB by season and network.

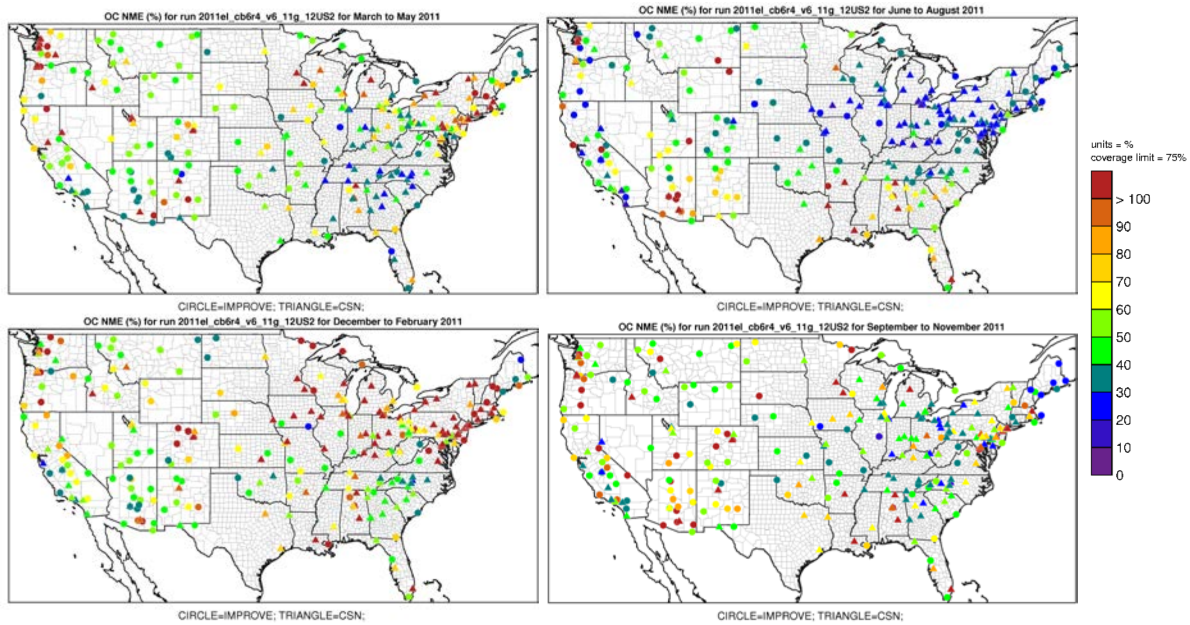


Figure 19. Spatial plot of organic carbon NME by season and network.

6. PM$_{2.5}$ EC

Table 6-1 summarizes model performance statistics for PM2.5 elemental carbon (EC). Boxplot comparisons of model predictions and observations (IMPROVE, CSN and CASTNET) by month for each climate region are shown in Figures 20 and 21. Nationwide spatial plots of NMB and NME for each season are shown in Figures 22 and 23.

EC is generally overpredicted across most seasons and all regions. Significant overpredictions are observed across the northwest where NMBs range from 32.7% to 247%. The most significant overprediction occurs during the winter and spring in the central and eastern US. The period of least overprediction is observed during the summer across the country.

Table 6-1. Model performance statistics for PM$_{2.5}$ EC by region, network, and season.

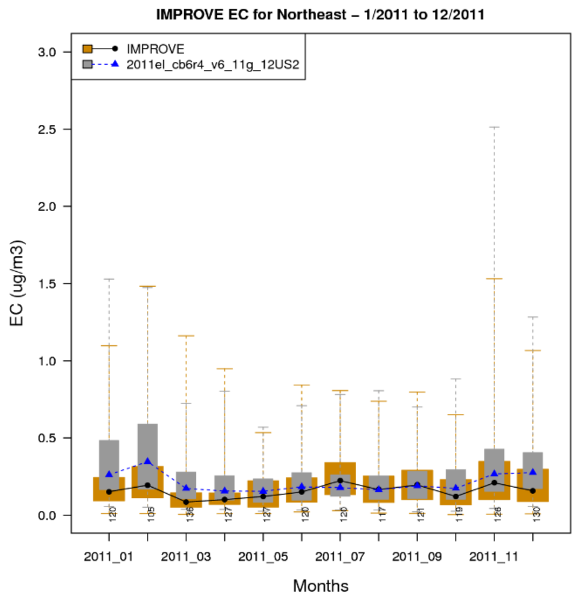
Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
Northeast	**IMPROVE**	Winter	355	0.22	0.36	0.62	62.3	83.5	0.14	0.19
		Spring	390	0.13	0.20	0.53	55.6	76.7	0.07	0.10
		Summer	357	0.21	0.21	0.71	0.23	36.6	0.00	0.08
		Fall	366	0.22	0.26	0.66	21.9	46.1	0.05	0.10
		All	1468	0.19	0.26	0.64	32.8	59.4	0.06	0.12

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
	CSN	Winter	643	0.70	1.21	0.36	72.8	89.9	0.52	0.63
		Spring	686	0.48	0.73	0.49	44.4	74.2	0.25	0.35
		Summer	697	0.76	0.79	0.58	3.4	43.0	0.03	0.33
		Fall	625	0.72	0.96	0.66	33.4	58.5	0.24	0.42
		All	2651	0.66	0.92	0.58	38.0	64.8	0.25	0.43
Southeast	**IMPROVE**	Winter	292	0.40	0.53	0.810	35.2	56.9	0.14	0.23
		Spring	316	0.40	0.39	0.51	-1.45	49.2	-0.01	0.20
		Summer	305	0.35	0.33	0.77	-5.74	42.5	-0.02	0.15
		Fall	301	0.34	0.38	0.82	12.3	44.5	0.04	0.15
		All	1214	0.37	0.41	0.69	10.0	48.5	0.04	0.18
	CSN	Winter	417	0.72	0.93	0.55	30.7	60.2	0.22	0.43
		Spring	430	0.57	0.69	0.43	21.1	56.1	0.12	0.32
		Summer	460	0.62	0.71	0.18	13.2	56.3	0.08	0.35
		Fall	423	0.59	0.77	0.49	29.0	59.2	0.17	0.35
		All	1730	0.62	0.77	0.45	23.5	58.0	0.15	0.36
Ohio Valley	**IMPROVE**	Winter	193	0.31	0.44	0.65	40.1	53.7	0.13	0.17
		Spring	207	0.28	0.31	0.57	13.4	44.3	0.04	0.12
		Summer	195	0.32	0.27	0.69	-16.0	28.9	-0.05	0.09
		Fall	206	0.29	0.35	0.69	19.6	38.8	0.06	0.11
		All	801	0.30	0.34	0.60	14.0	41.3	0.04	0.12
	CSN	Winter	579	0.56	1.00	0.44	79.9	93.0	0.45	0.52
		Spring	605	0.57	0.79	0.55	37.5	58.0	0.22	0.33
		Summer	658	0.84	0.88	0.53	4.4	36.6	0.04	0.31
		Fall	611	0.68	0.91	0.62	33.2	53.8	0.26	0.37

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		All	2453	0.67	0.89	0.51	33.6	56.6	0.22	0.38
Upper Midwest	**IMPROVE**	Winter	200	0.15	0.26	0.67	71.7	79.3	0.11	0.12
		Spring	211	0.16	0.21	0.73	34.7	56.2	0.05	0.09
		Summer	203	0.21	0.18	0.72	-13.6	35.1	-0.03	0.07
		Fall	202	0.25	0.48	0.71	94.2	116.0	0.24	0.29
		All	816	0.19	0.28	0.65	48.0	74.2	0.09	0.14
	CSN	Winter	326	0.40	0.90	0.54	125.0	127.0	0.50	0.51
		Spring	330	0.41	0.74	0.60	80.0	86.7	0.33	0.36
		Summer	333	0.61	0.67	0.61	10.6	38.2	0.06	0.23
		Fall	340	0.52	0.82	0.73	57.0	63.5	0.30	0.33
		All	1329	0.49	0.78	0.54	61.0	73.4	0.30	0.36
South	**IMPROVE**	Winter	224	0.21	0.32	0.40	55.6	76.1	0.12	0.16
		Spring	237	0.26	0.31	0.66	16.2	55.3	0.04	0.15
		Summer	239	0.21	0.22	0.48	3.0	47.7	0.01	0.10
		Fall	222	0.21	0.27	0.55	24.4	49.6	0.05	0.11
		All	922	0.22	0.28	0.53	23.8	56.9	0.05	0.13
	CSN	Winter	221	0.66	1.02	0.43	54.7	80.8	0.36	0.53
		Spring	250	0.52	0.74	0.30	41.0	68.4	0.21	0.36
		Summer	257	0.47	0.72	0.43	55.2	77.7	0.26	0.36
		Fall	240	0.61	0.92	0.59	51.7	70.8	0.32	0.43
		All	968	0.56	0.84	0.43	50.7	74.4	0.28	0.42
Southwest	**IMPROVE**	Winter	910	0.17	0.21	0.70	19.8	63.1	0.03	0.11
		Spring	933	0.09	0.14	0.63	54.9	92.2	0.05	0.08
		Summer	952	0.15	0.20	0.42	28.5	89.7	0.04	0.14

Region	Network	Season	N	Avg. Obs. (µg m-3)	Avg. Mod. (µg m-3)	R	NMB (%)	NME (%)	MB (µg m-3)	ME (µg m-3)
		Fall	918	0.17	0.21	0.72	21.8	68.1	0.04	0.12
		All	3713	0.15	0.19	0.63	28.0	76.1	0.04	0.11
	CSN	Winter	181	1.05	1.31	0.52	25.1	54.3	0.26	0.57
		Spring	187	0.35	0.75	0.72	115.0	118.0	0.40	0.41
		Summer	195	0.46	0.72	0.41	56.7	74.9	0.26	0.34
		Fall	189	0.72	1.03	0.65	41.8	58.4	0.30	0.43
		All	752	0.64	0.95	0.63	48.0	67.9	0.31	0.43
N. Rockies & Plains	**IMPROVE**	Winter	497	0.07	0.08	0.45	13.4	62.4	0.01	0.04
		Spring	545	0.07	0.08	0.66	13.1	56.5	0.01	0.04
		Summer	526	0.13	0.16	0.34	29.7	75.9	0.04	0.10
		Fall	522	0.16	0.23	0.53	45.3	80.6	0.07	0.13
		All	2090	0.11	0.14	0.47	30.1	72.2	0.03	0.08
	CSN	Winter	63	0.76	0.57	-0.22	-25.6	110.0	-0.20	0.84
		Spring	60	0.33	0.42	0.41	26.4	84.1	0.09	0.28
		Summer	70	0.41	0.46	0.53	12.0	57.4	0.05	0.24
		Fall	69	0.50	0.62	0.04	24.8	83.8	0.12	0.42
		All	262	0.50	0.52	0.00	3.74	87.5	0.02	0.44
Northwest	**IMPROVE**	Winter	427	0.14	0.27	0.85	91.7	122.0	0.13	0.17
		Spring	480	0.07	0.23	0.77	211.0	241.0	0.16	0.18
		Summer	432	0.13	0.34	0.75	160.0	189.0	0.21	0.25
		Fall	437	0.21	0.55	0.58	162.0	185.0	0.34	0.39
		All	1776	0.14	0.34	0.63	151.0	179.0	0.21	0.24
	CSN	Winter	167	1.49	1.98	0.47	32.7	71.3	0.49	1.07
		Spring	162	0.35	1.23	0.49	247.0	251.0	0.88	0.89

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Summer	156	0.39	1.13	0.38	193.0	198.0	0.74	0.77
		Fall	160	0.92	1.72	0.43	87.1	101.0	0.80	0.93
		All	645	0.80	1.52	0.49	90.9	115.0	0.72	0.92
West	**IMPROVE**	Winter	467	0.18	0.16	0.91	-7.1	46.2	-0.01	0.08
		Spring	469	0.09	0.11	0.68	17.3	64.6	0.02	0.06
		Summer	471	0.16	0.21	0.57	35.7	76.3	0.06	0.12
		Fall	502	0.20	0.25	0.72	25.6	60.9	0.05	0.12
		All	1909	0.16	0.18	0.68	17.9	61.2	0.03	0.10
	CSN	Winter	221	1.37	1.10	0.69	-19.7	39.2	-0.27	0.54
		Spring	235	0.47	0.73	0.69	54.8	70.4	0.26	0.33
		Summer	244	0.50	0.71	0.79	42.0	49.4	0.21	0.25
		Fall	226	0.99	1.06	0.62	7.4	35.2	0.07	0.35
		All	926	0.82	0.89	0.70	9.1	44.2	0.07	0.36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IMPROVE
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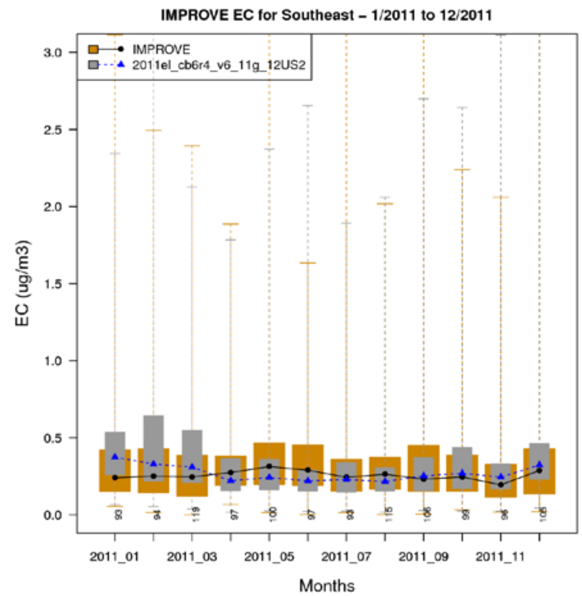
EC (ug/m3)
Months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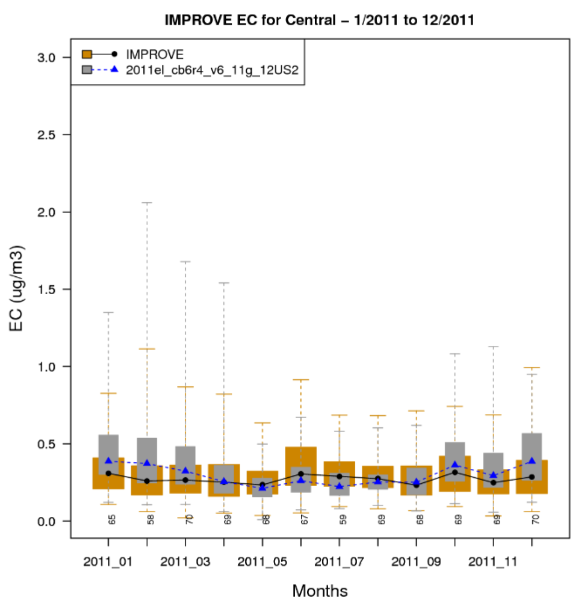
EC (ug/m3)
Months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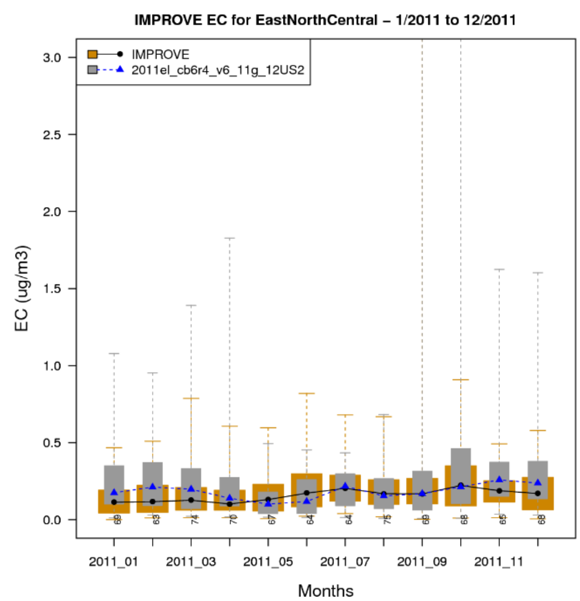
EC (ug/m3)
Months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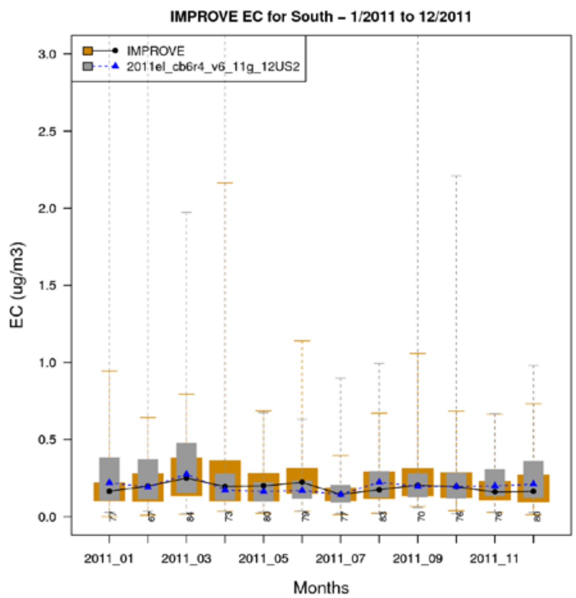
EC (ug/m3)
Months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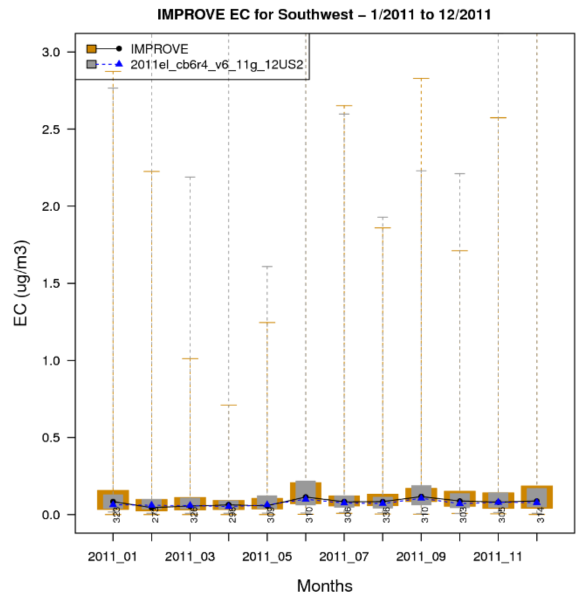
EC (ug/m3)
Months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IMPROVE
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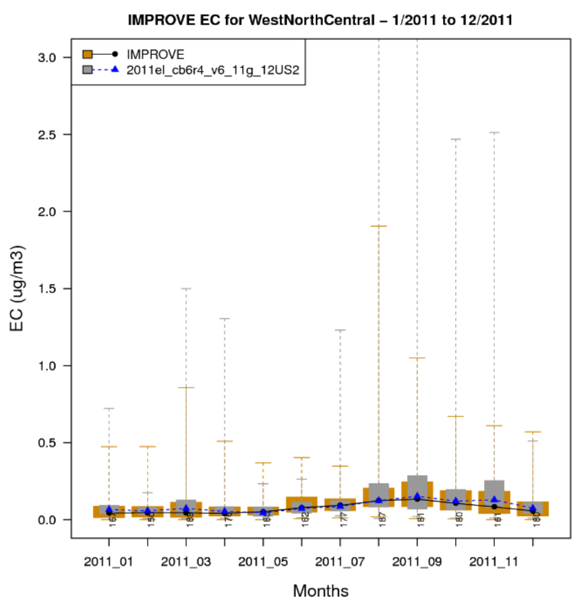
EC (ug/m3)
Months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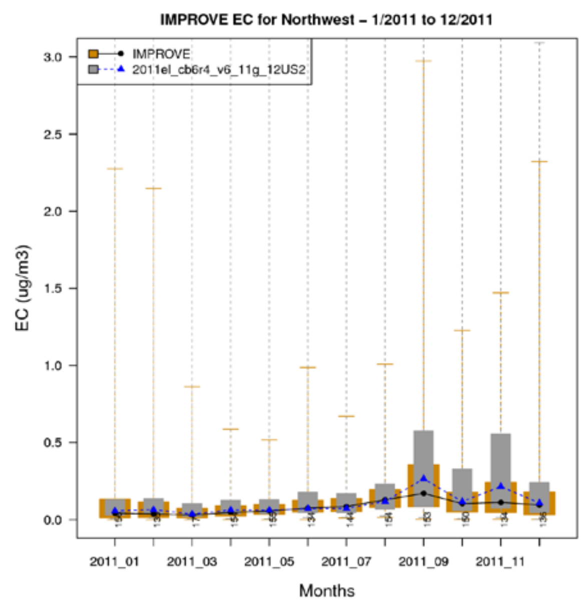
EC (ug/m3)
Months


IMPROVE EC for Northwest – 1/2011 to 12/2011
IMPROVE
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EC (ug/m3)
Months

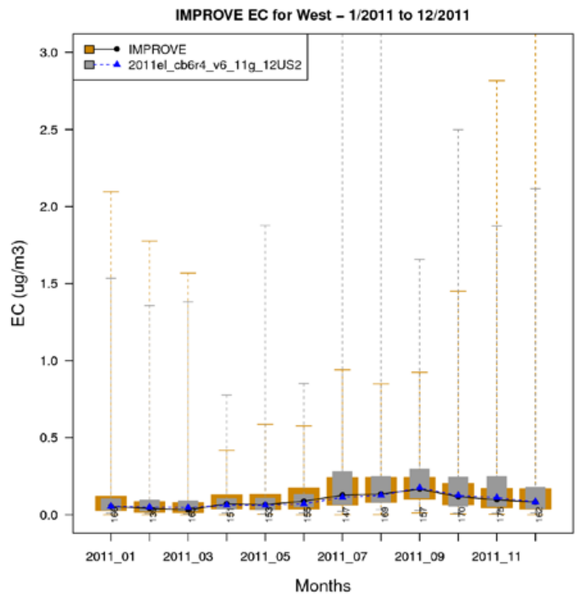
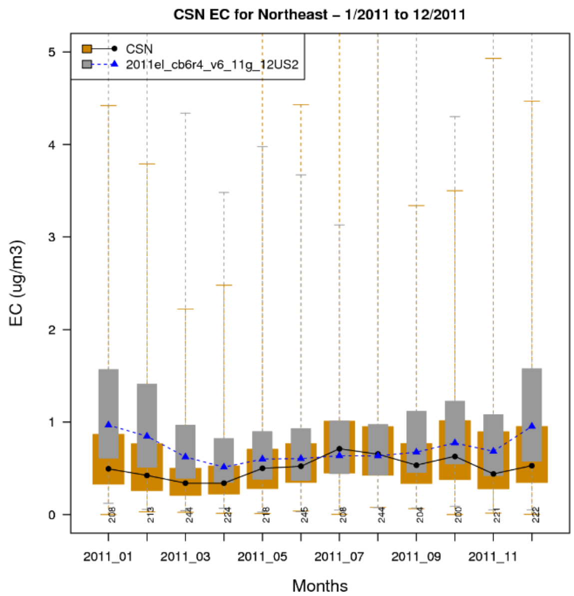


Figure 20. Boxplot comparisons of model predictions and IMPROVE elemental carbon observations for each climate region by month.


CSN EC for Northeast – 1/2011 to 12/2011
CSN
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EC (ug/m3)
0
1
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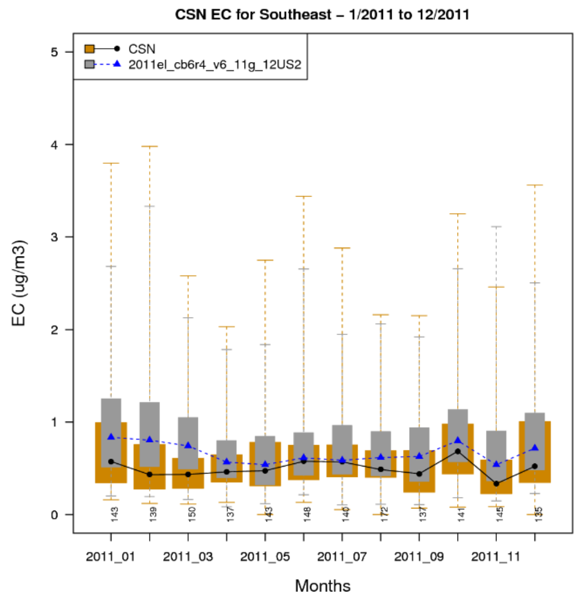
3
4
5
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months


CSN EC for Southeast – 1/2011 to 12/2011
CSN
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EC (ug/m3)
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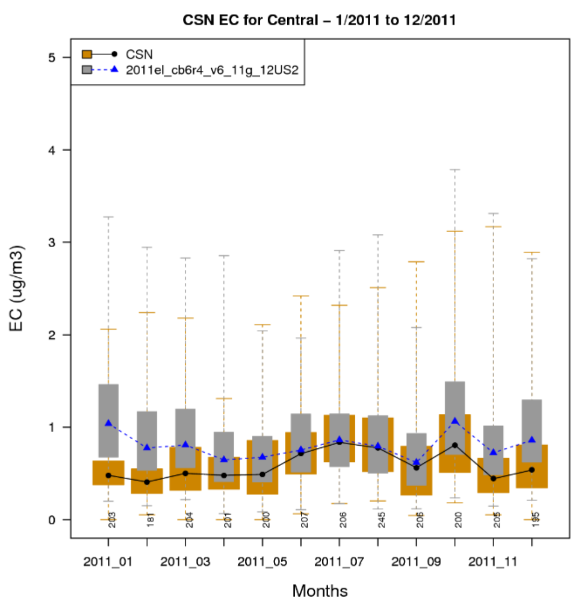
1
2
3
4
5
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months


CSN EC for Central – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
EC (ug/m3)
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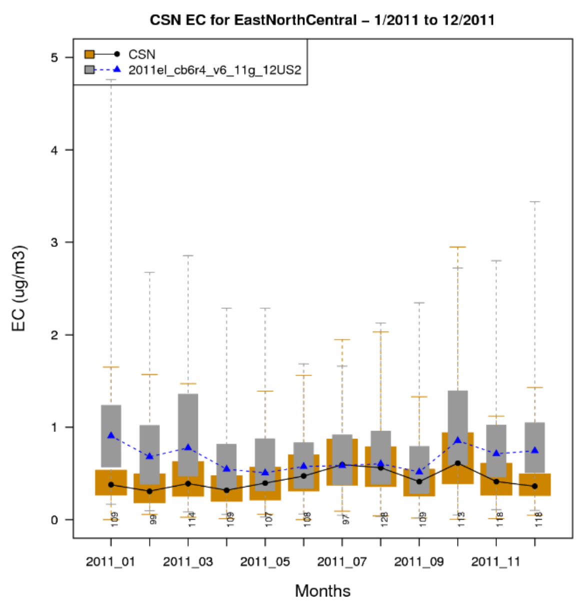
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months


CSN EC for EastNorthCentral – 1/2011 to 12/2011
CSN
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EC (ug/m3)
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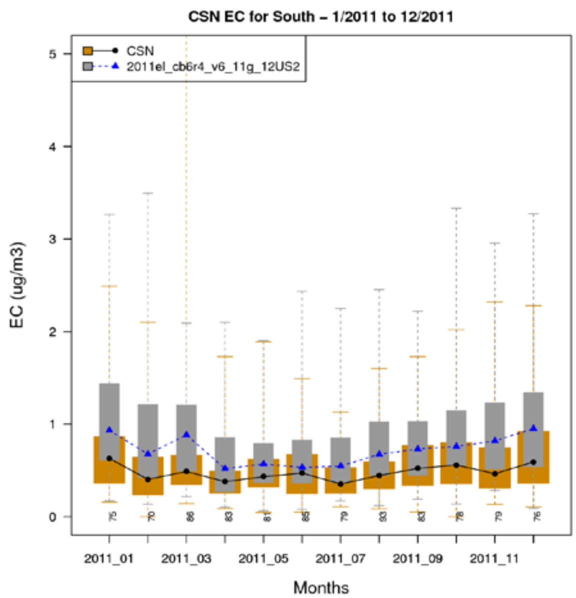
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months


CSN EC for South – 1/2011 to 12/2011
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EC (ug/m3)
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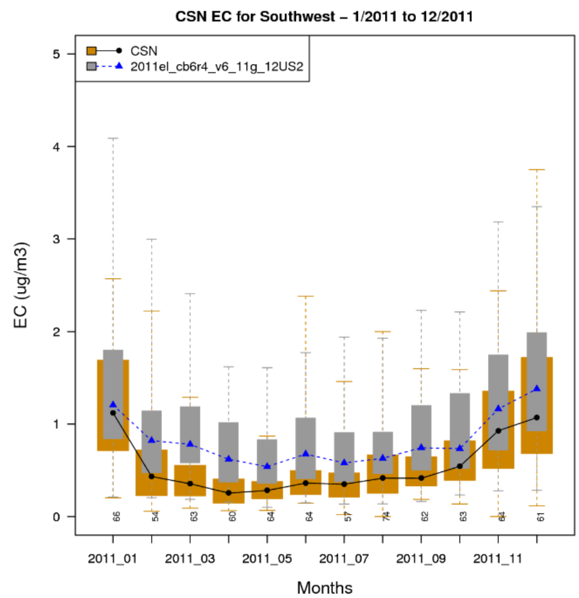
5
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months


CSN EC for Southwest – 1/2011 to 12/2011
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2011_01
2011_03
2011_05
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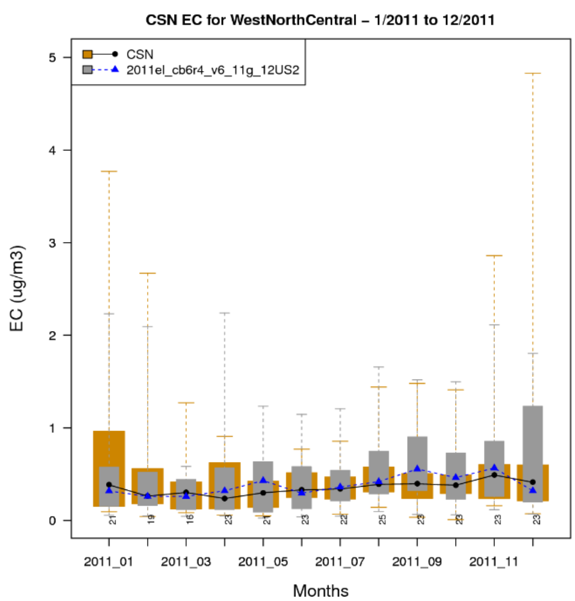
2011_09
2011_11
Months


CSN EC for WestNorthCentral – 1/2011 to 12/2011
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EC (ug/m3)
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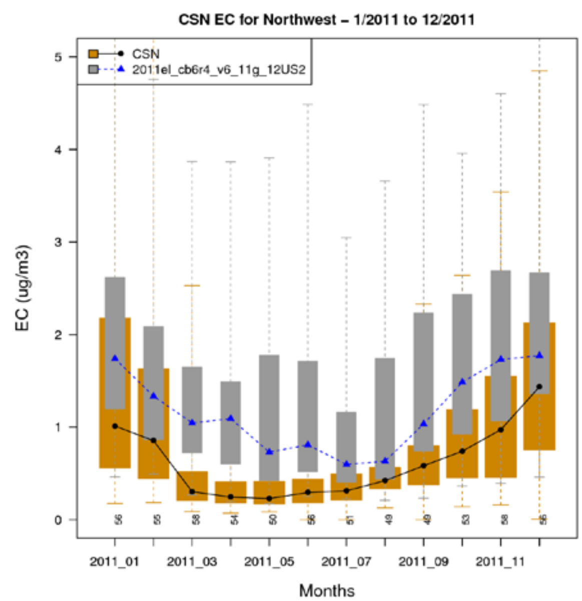
2011_05
2011_07
2011_09
2011_11
Months


CSN EC for Northwest – 1/2011 to 12/2011
CSN
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EC (ug/m3)
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2011_05
2011_07
2011_09
2011_11
Months

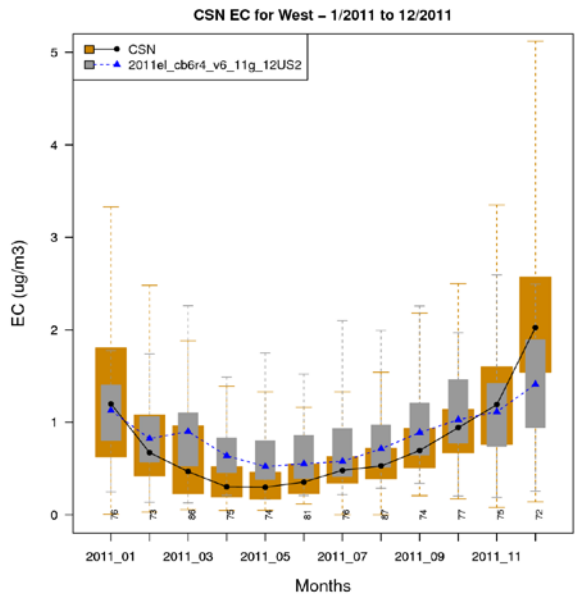


Figure 21. Boxplot comparisons of model predictions and CSN elemental carbon observations for each climate region by month.

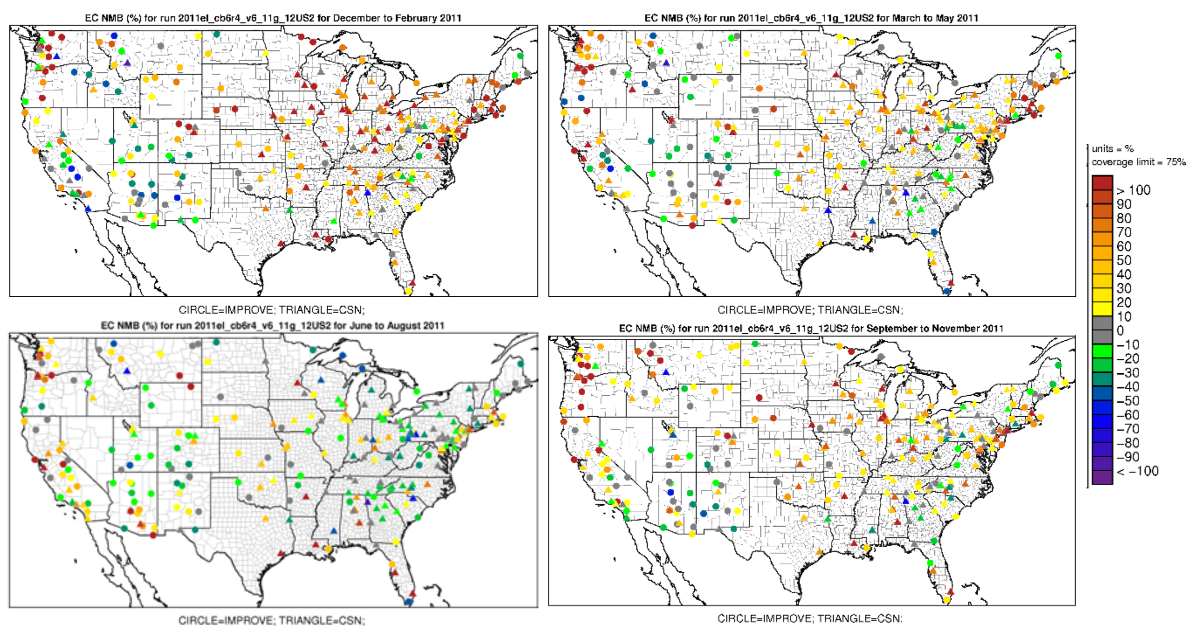


Figure 22. Spatial plot of elemental carbon NMB by season and network.

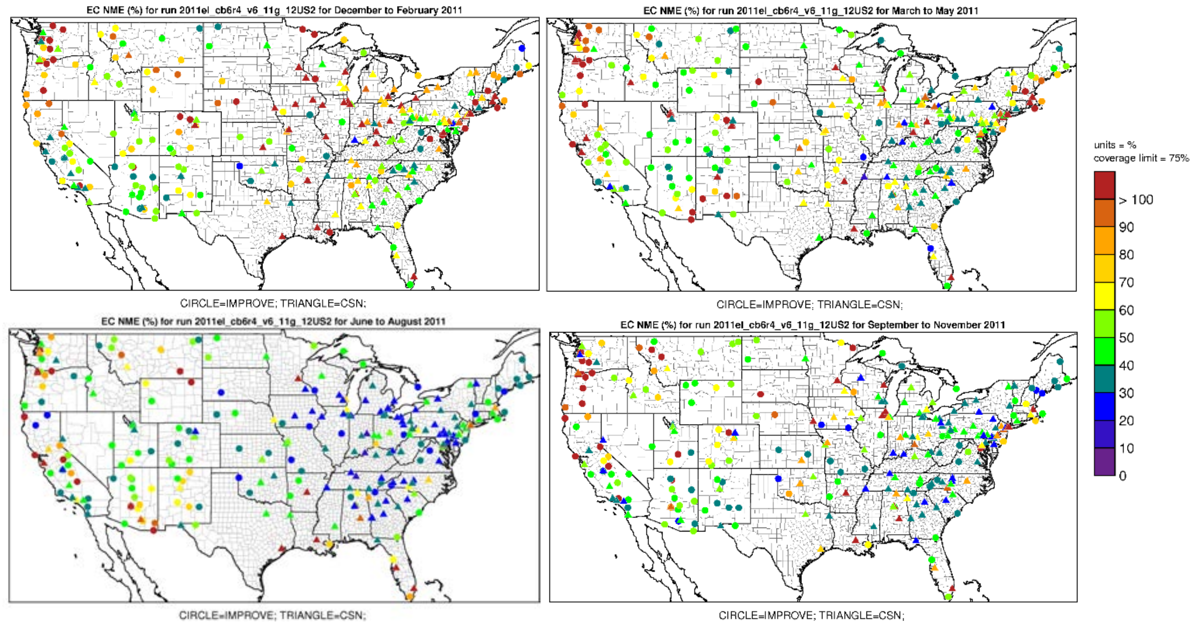


Figure 23. Spatial plot of elemental carbon NME by season and network.

7. Total $PM_{2.5}$

Table 7-1 summarizes model performance statistics for total $PM_{2.5}$. Boxplot comparisons of model predictions and observations (IMPROVE and CSN) by month for each climate region are shown in Figures 24 and 25. Nationwide spatial plots of NMB and NME for each season are shown in Figures 26 and 27.

PM2.5 is generally overpredicted across most regions during the winter season and underpredicted across most regions during the summer season. Model performance varies across regions during the spring and fall seasons, though a moderate overprediction is observed most often.

Table 7-1. Model performance statistics for PM2.5 by region, network, and season.

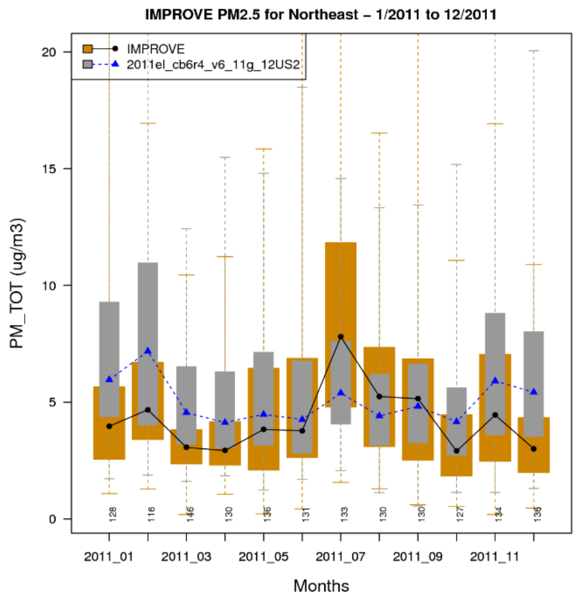
Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
Northeast	**IMPROVE**	Winter	380	4.50	7.23	0.78	60.7	67.1	2.73	3.02
		Spring	412	3.90	5.23	0.62	34.2	49.3	1.33	1.92
		Summer	394	6.71	5.40	0.72	-19.5	34.4	-1.31	2.31
		Fall	391	4.63	5.41	0.67	16.7	35.4	0.78	1.64
		All	1577	4.93	5.80	0.61	17.7	44.9	0.87	2.21
	CSN	Winter	674	10.90	15.20	0.63	39.8	53.4	4.34	5.81

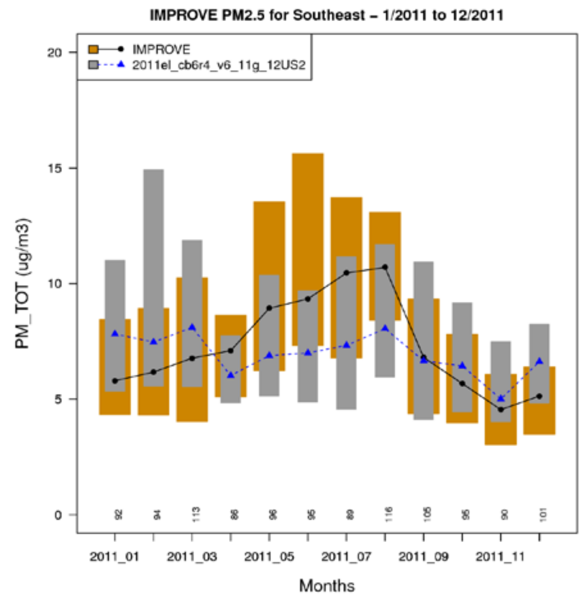
Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Spring	712	7.93	9.33	0.59	17.7	38.4	1.40	3.05
		Summer	719	12.70	9.69	0.72	-23.8	32.4	-3.02	4.12
		Fall	683	8.46	9.88	0.57	16.7	38.5	1.42	3.25
		All	2788	10.00	11.00	0.58	9.7	40.4	0.97	4.04
Southeast	**IMPROVE**	Winter	287	6.53	9.48	0.73	45.3	58.1	2.96	3.79
		Spring	295	8.39	8.56	0.53	2.0	39.4	0.17	3.30
		Summer	300	11.40	8.99	0.57	-20.8	37.3	-2.36	4.23
		Fall	290	6.36	7.80	0.70	22.7	44.3	1.44	2.81
		All	1172	8.19	8.71	0.57	6.3	43.2	0.52	3.54
	CSN	Winter	437	9.93	12.6	0.67	26.6	40.6	2.65	4.03
		Spring	458	11.2	10.8	0.31	-3.4	30.9	-0.38	3.46
		Summer	473	15.6	12.7	0.52	-18.4	32.1	-2.87	5.02
		Fall	445	8.74	10.40	0.67	18.4	35.6	1.61	3.11
		All	1813	11.40	11.60	0.57	1.7	34.2	0.19	3.92
Ohio Valley	**IMPROVE**	Winter	161	7.83	9.32	0.71	19.0	35.7	1.49	2.79
		Spring	176	7.80	8.42	0.56	8.0	41.2	0.62	3.21
		Summer	167	11.40	8.51	0.73	-25.4	30.3	-2.90	3.46
		Fall	176	6.50	7.64	0.72	17.5	36.9	1.14	2.40
		All	680	8.35	8.45	0.62	1.2	35.5	0.10	2.96
	CSN	Winter	586	11.80	13.40	0.64	13.7	33.4	1.62	3.94
		Spring	626	10.70	12.20	0.62	14.2	36.6	1.51	3.91
		Summer	651	15.3	11.9	0.69	-22.2	28.8	-3.40	4.42
		Fall	612	8.98	10.00	0.66	11.7	34.7	1.05	3.11
		All	2475	11.70	11.90	0.61	1.1	32.8	0.13	3.85

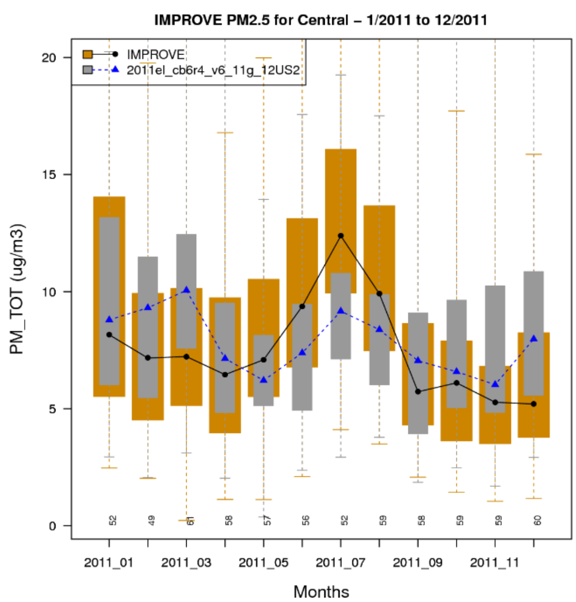
Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
Upper Midwest	IMPROVE	Winter	171	6.15	7.32	0.69	19.0	42.6	1.17	2.62
		Spring	183	5.49	6.55	0.82	19.4	37.3	1.06	2.05
		Summer	173	6.59	5.75	0.81	-12.8	27.4	-0.85	1.80
		Fall	173	5.28	7.22	0.66	36.7	57.6	1.94	3.04
		All	700	5.87	6.71	0.66	14.2	40.4	0.83	2.37
	CSN	Winter	333	11.10	13.30	0.68	20.4	37.1	2.26	4.10
		Spring	337	9.30	12.30	0.78	32.0	39.2	2.98	3.65
		Summer	333	11.70	9.43	0.66	-19.4	31.0	-2.27	3.63
		Fall	340	8.27	10.70	0.78	29.9	39.4	2.47	3.26
		All	1343	10.10	11.40	0.67	13.6	36.3	1.37	3.66
South	IMPROVE	Winter	219	5.83	6.91	0.56	18.5	41.4	1.08	2.41
		Spring	243	8.40	7.52	0.62	-10.5	40.2	-0.88	3.38
		Summer	249	8.99	6.75	0.65	-25.0	33.6	-2.25	3.03
		Fall	222	5.20	5.67	0.58	9.0	35.5	0.47	1.85
		All	933	7.19	6.73	0.59	-6.5	37.4	-0.47	2.69
	CSN	Winter	223	10.90	13.20	0.40	20.3	47.5	2.22	5.20
		Spring	248	12.60	10.10	0.26	-19.5	41.0	-2.46	5.15
		Summer	253	12.40	10.60	0.68	-14.5	29.2	-1.80	3.61
		Fall	238	9.30	11.40	0.53	22.0	43.3	2.05	4.03
		All	962	11.30	11.20	0.36	-0.75	39.5	-0.08	4.48
Southwest	IMPROVE	Winter	901	2.51	2.50	0.50	-0.4	49.5	-0.01	1.24
		Spring	936	4.27	2.52	0.46	-41.1	51.2	-1.75	2.19
		Summer	953	5.61	3.49	0.50	-37.9	45.6	-2.13	2.56
		Fall	905	3.56	3.04	0.62	-14.6	38.9	-0.52	1.38

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		All	3695	4.01	2.89	0.51	-28.0	46.3	-1.12	1.86
	CSN	Winter	183	11.90	11.90	0.32	-0.3	54.8	-0.03	6.53
		Spring	189	6.09	6.76	0.32	11.0	46.5	0.67	2.83
		Summer	188	7.96	6.13	0.29	-23.0	37.9	-1.84	3.02
		Fall	186	7.50	8.37	0.33	11.5	45.3	0.87	3.40
		All	746	8.34	8.26	0.40	-1.0	47.1	-0.08	3.93
N. Rockies & Plains	**IMPROVE**	Winter	469	1.86	2.24	0.67	20.4	49.7	0.38	0.93
		Spring	497	2.73	2.83	0.67	3.8	44.0	0.10	1.20
		Summer	491	4.09	3.53	0.42	-13.6	43.1	-0.56	1.76
		Fall	495	3.65	4.04	0.64	10.5	45.4	0.38	1.66
		All	1952	3.10	3.17	0.59	2.4	44.9	0.07	1.39
	CSN	Winter	67	11.20	8.04	0.02	-28.2	55.3	-3.15	6.19
		Spring	68	8.60	7.62	0.73	-11.4	35.7	-0.98	3.07
		Summer	72	9.26	6.21	0.69	-32.9	38.1	-3.05	3.53
		Fall	68	9.02	7.97	0.45	-11.7	44.1	-1.05	3.98
		All	275	9.51	7.44	0.40	-21.8	43.9	-2.07	4.18
Northwest	**IMPROVE**	Winter	457	2.05	3.47	0.54	69.1	104.0	1.42	2.14
		Spring	511	1.86	2.93	0.59	57.9	84.0	1.08	1.56
		Summer	463	3.27	3.33	0.46	1.9	56.9	0.06	1.86
		Fall	470	3.89	6.08	0.53	56.5	92.9	2.20	3.61
		All	1901	2.75	3.94	0.51	43.2	82.9	1.19	2.28
	CSN	Winter	164	14.00	21.10	0.52	50.7	72.1	7.11	10.10
		Spring	168	4.75	10.90	0.56	129.0	134.0	6.12	6.37
		Summer	171	6.00	8.61	0.20	43.5	70.4	2.61	4.22

Region	Network	Season	N	Avg. Obs. (µg m^{-3})	Avg. Mod. (µg m^{-3})	R	NMB (%)	NME (%)	MB (µg m^{-3})	ME (µg m^{-3})
		Fall	165	8.43	15.80	0.48	87.3	100.0	7.36	8.44
		All	668	8.25	14.00	0.59	69.9	87.9	5.77	7.25
West	**IMPROVE**	Winter	432	3.48	2.62	0.83	-24.6	49.0	-0.86	1.71
		Spring	439	3.63	2.53	0.43	-30.3	47.5	-1.10	1.73
		Summer	449	5.47	3.65	0.39	-33.2	53.4	-1.82	2.92
		Fall	462	4.52	3.95	0.64	-12.6	43.3	-0.57	1.95
		All	1782	4.29	3.20	0.59	-25.3	48.5	-1.08	2.08
	CSN	Winter	221	18.20	12.70	0.47	-30.0	44.8	-5.44	8.14
		Spring	242	8.25	8.14	0.55	-1.4	37.2	-0.11	3.01
		Summer	246	10.60	7.06	0.52	-33.4	40.1	-3.54	4.25
		Fall	227	14.00	11.30	0.59	-19.7	36.8	-2.77	5.16
		All	936	12.60	9.69	0.55	-23.1	40.3	-2.92	5.08


IMPROVE PM2.5 for Northeast – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
Months


IMPROVE PM2.5 for Southeast – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
Months


IMPROVE PM2.5 for Central – 1/2011 to 12/2011
IMPROVE
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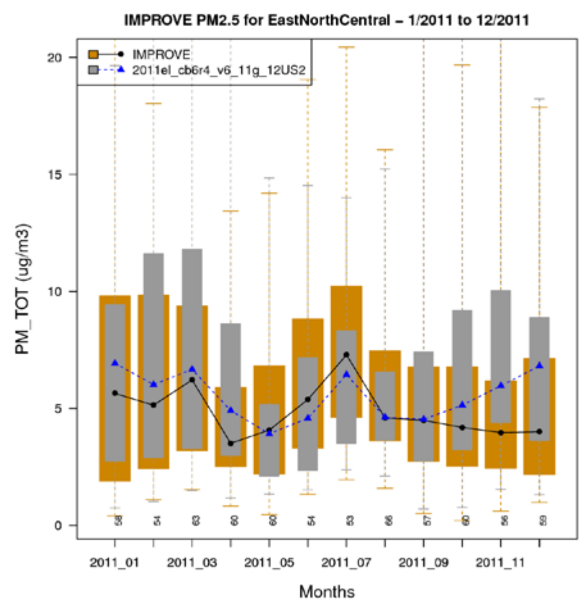
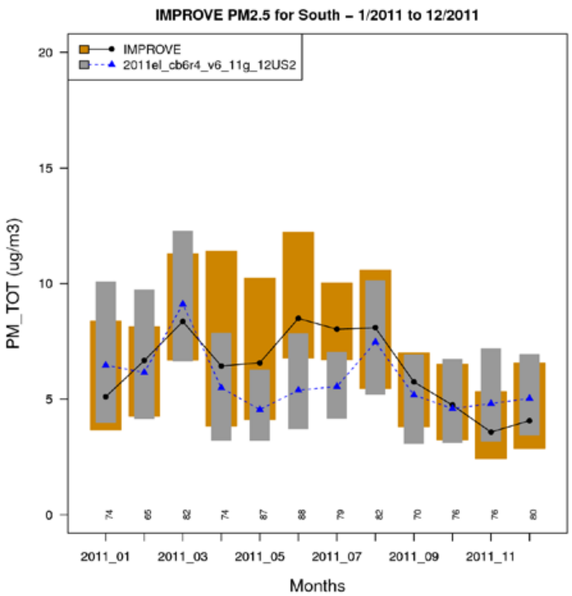
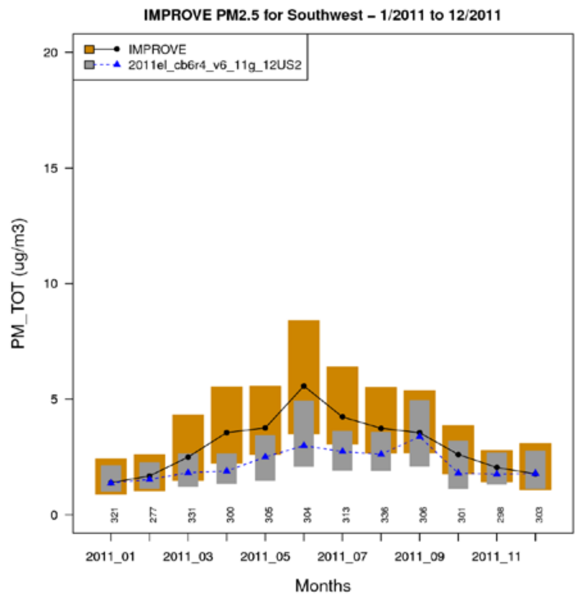
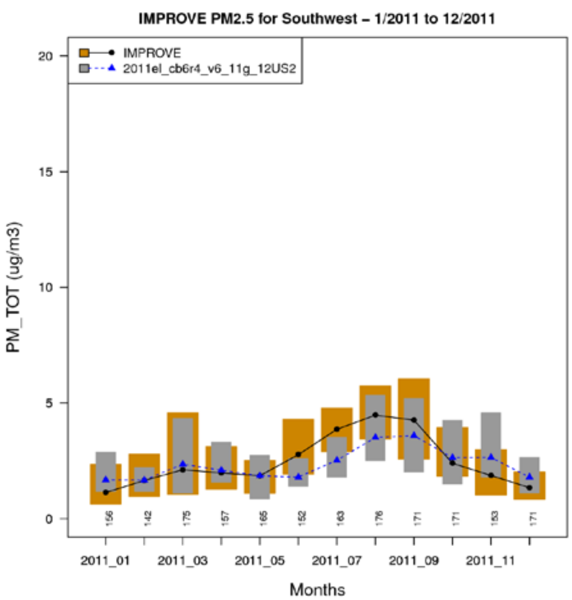
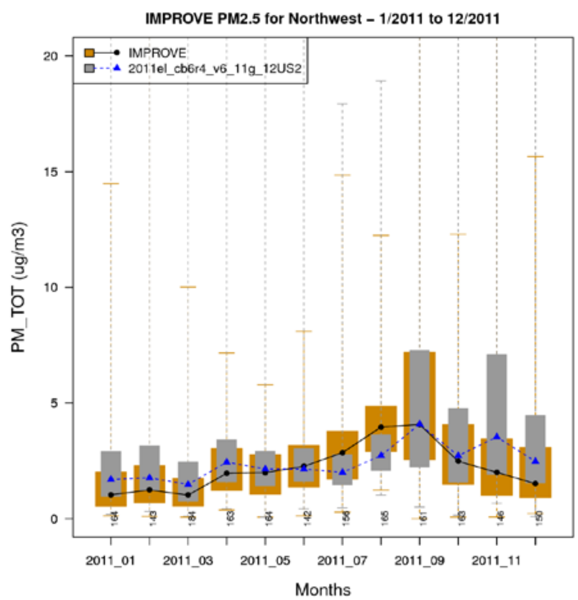
PM_TOT (ug/m3)
Months


IMPROVE PM2.5 for EastNorthCentral – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
Months


IMPROVE PM2.5 for South – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
0
5
10
15
20
74 65 82 74 87 88 79 82 70 76 76 80
2011_01 2011_03 2011_05 2011_07 2011_09 2011_11
Months


IMPROVE PM2.5 for Southwest – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
0
5
10
15
20
321 277 331 300 305 304 313 336 306 301 298 303
2011_01 2011_03 2011_05 2011_07 2011_09 2011_11
Months


IMPROVE PM2.5 for Southwest – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
0
5
10
15
20
156 142 175 157 165 152 163 176 171 171 153 171
2011_01 2011_03 2011_05 2011_07 2011_09 2011_11
Months


IMPROVE PM2.5 for Northwest – 1/2011 to 12/2011
IMPROVE
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
0
5
10
15
20
2011_01 2011_03 2011_05 2011_07 2011_09 2011_11
Months

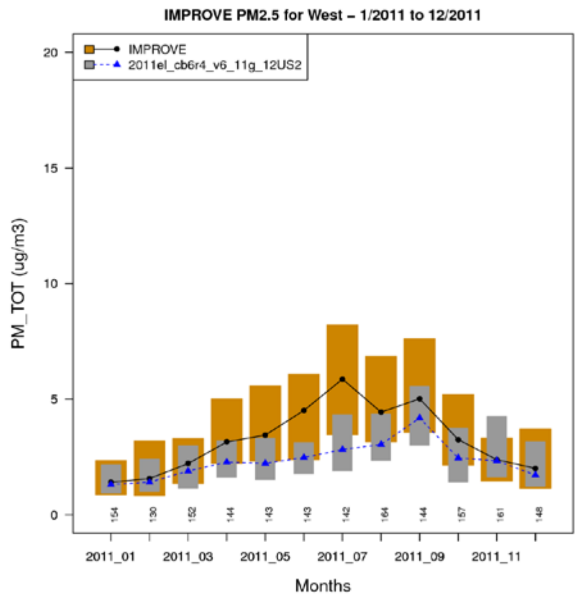
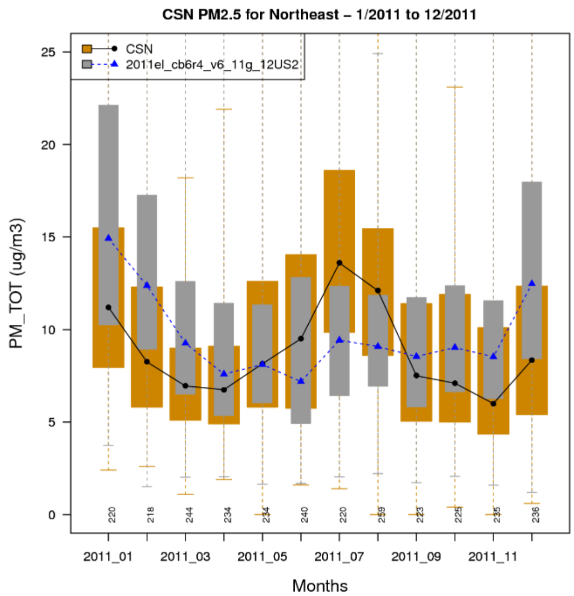
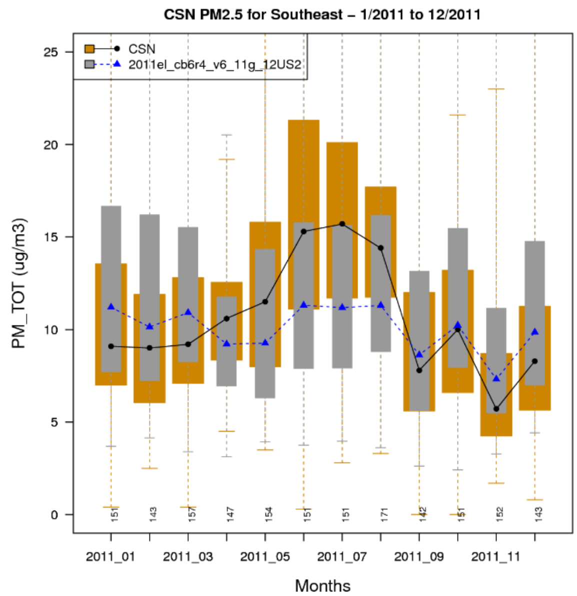
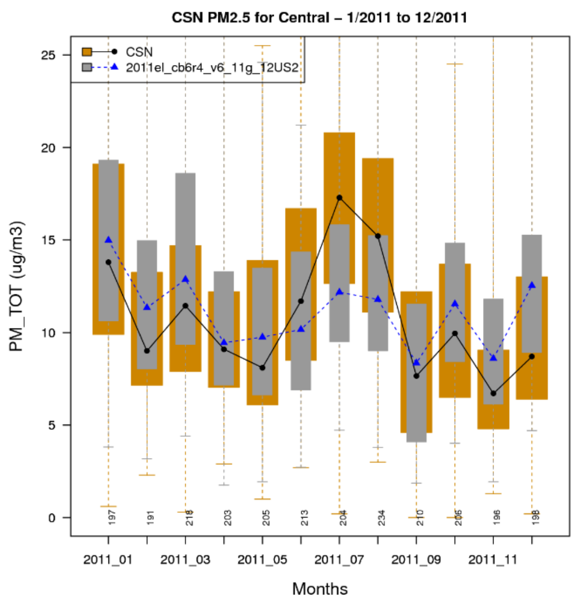
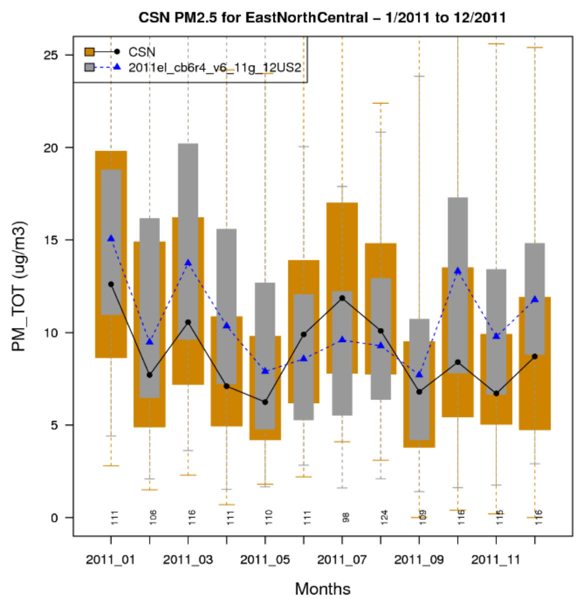


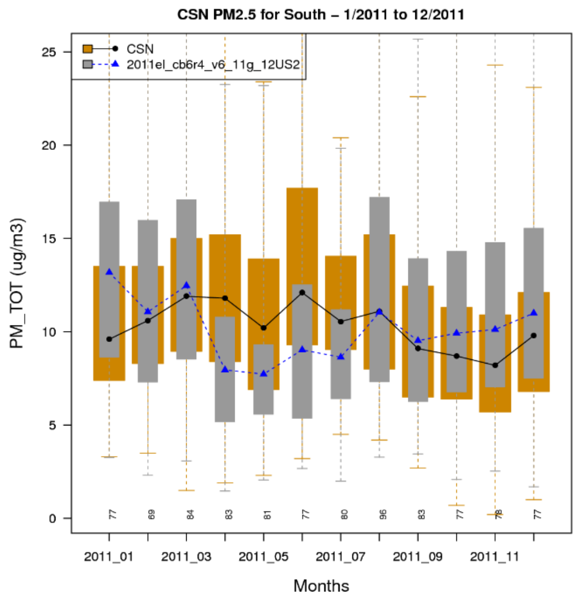
Figure 24. Boxplot comparisons of model predictions and IMPROVE PM2.5 observations for each climate region by month.

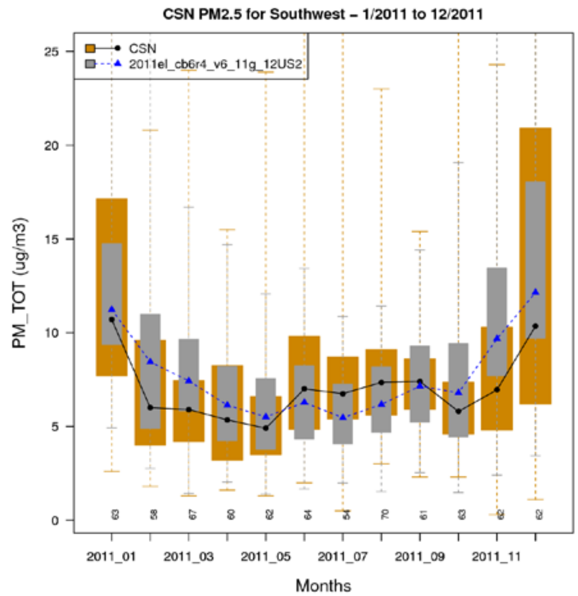

CSN PM2.5 for Northeast – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
0
5
10
15
20
25
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months

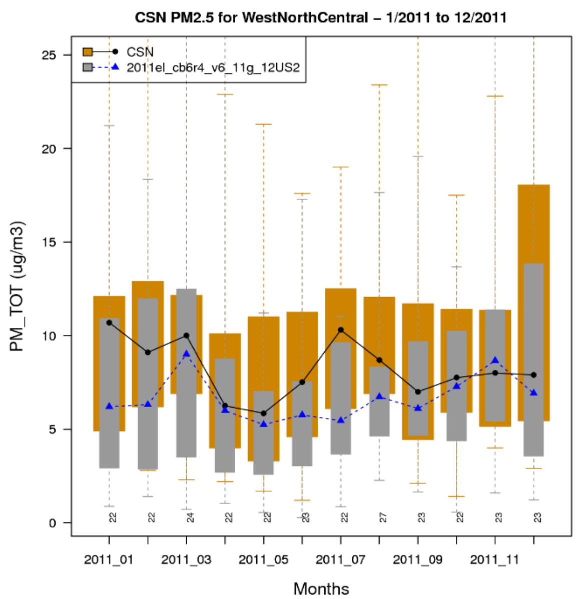

CSN PM2.5 for Southeast – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
0
5
10
15
20
25
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months

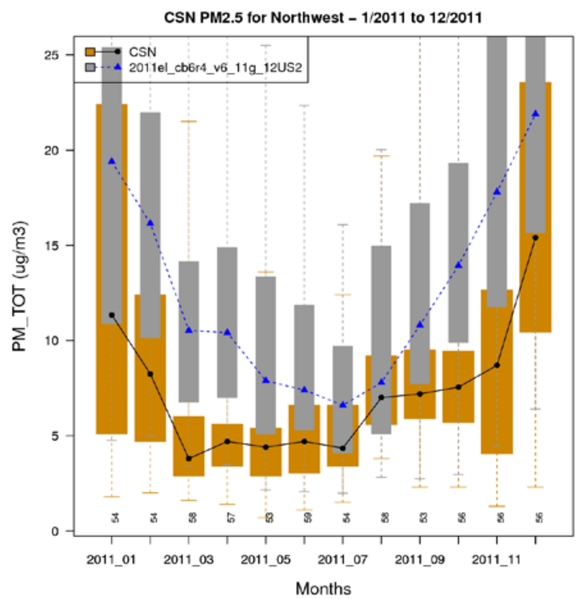

CSN PM2.5 for Central – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
0
5
10
15
20
25
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months


CSN PM2.5 for EastNorthCentral – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
0
5
10
15
20
25
2011_01
2011_03
2011_05
2011_07
2011_09
2011_11
Months


CSN PM2.5 for South – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
Months


CSN PM2.5 for Southwest – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
Months


CSN PM2.5 for WestNorthCentral – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
Months


CSN PM2.5 for Northwest – 1/2011 to 12/2011
CSN
2011el_cb6r4_v6_11g_12US2
PM_TOT (ug/m3)
Months

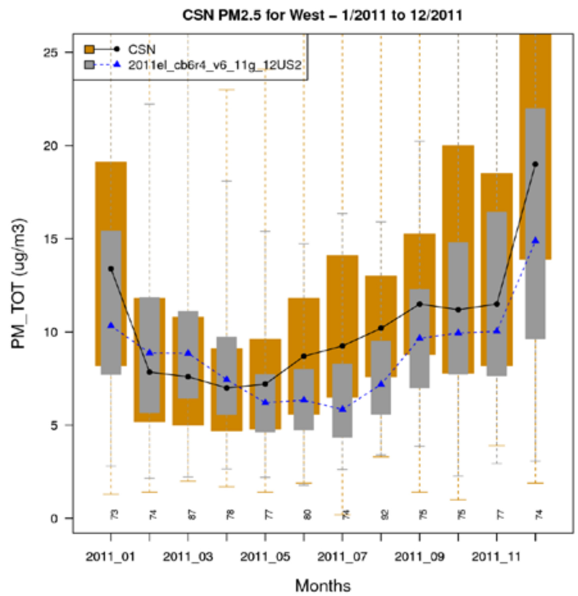


Figure 25. Boxplot comparisons of modeled predictions and CSN $PM_{2.5}$ observations by region by month.

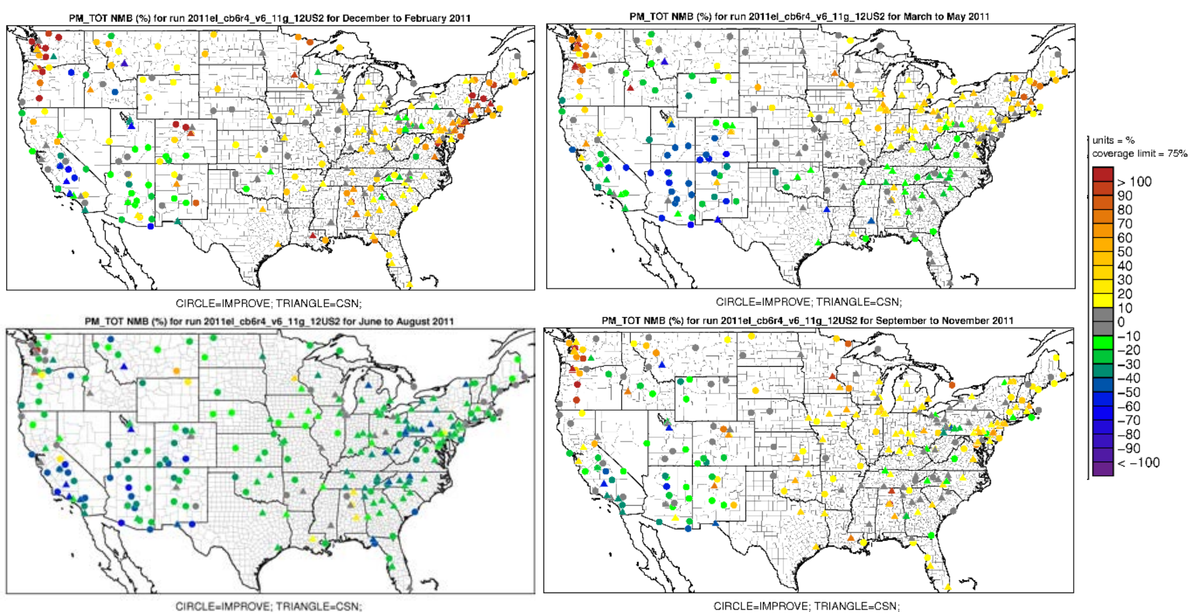


Figure 26. Spatial plot of $PM_{2.5}$ NMB by season and network.

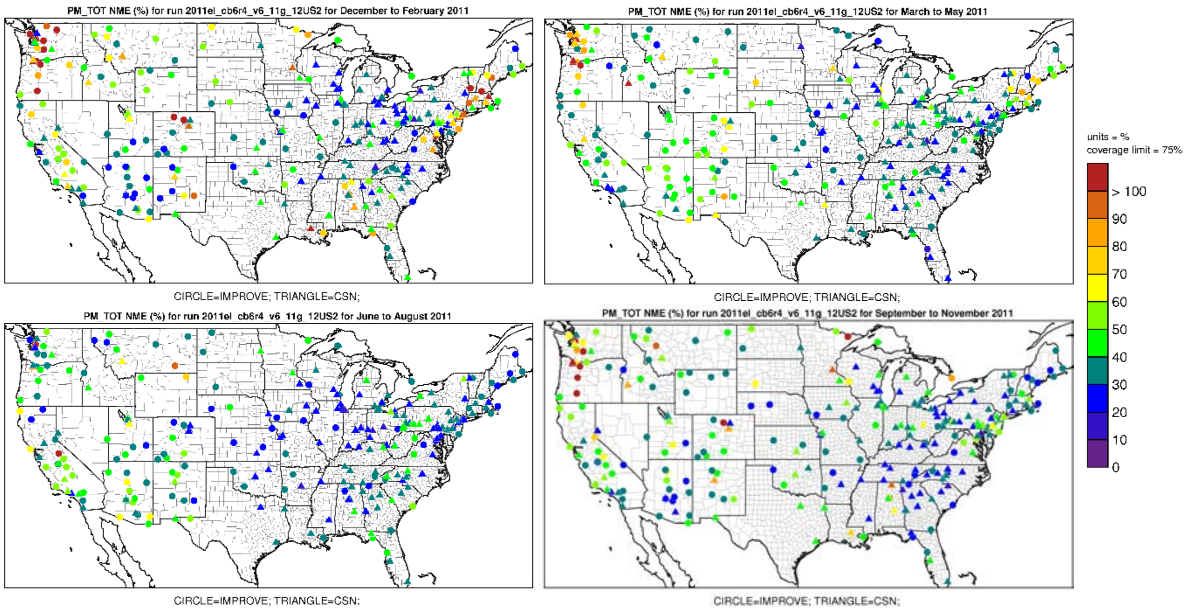


Figure 27. Spatial plot of $PM_{2.5}$ NME by season and network.

8. Performance on 20% Most-Impaired Days

Spatial plots summarizing IMPROVE observations and model NMB on the 20% most-impaired days are shown in Figures 28 through 34.

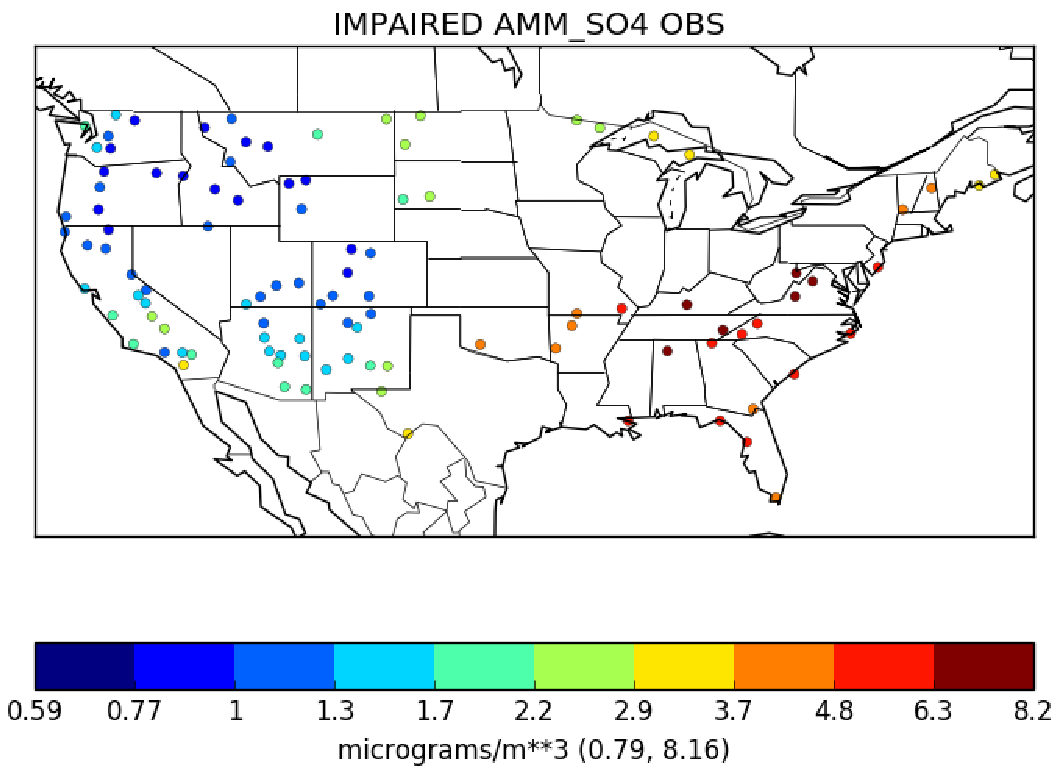
For ammonium sulfate, predictions are biased low across all regions, with the most significant percentage underpredictions occurring in the southwest and western US regions. Some isolated overpredictions are observed in a few Class I areas near the outer domain boundaries.

Predictions of ammonium nitrate are significantly underpredicted across most of the western US, especially in the Southwest. However, the model significantly overpredicts ammonium nitrate across an isolated area of the Northern Plains and Northwest, primarily in WA, OR, MT, and the Dakotas. In the eastern US, performance is mixed with a high positive bias in the northeast and a negative bias in the southeast.

A moderate to high positive bias of OC is observed across most regions, with the exception of the west and Northern Plains, where moderate underpredictions are shown. The model performs similarly for EC, though the model shows a slight underprediction in the southwestern US.

On the 20% most-impaired days, model performance for total $PM_{2.5}$ is overall biased low across most regions (corresponding closely to the sulfate performance). A slight overprediction of $PM_{2.5}$ on those days is observed in the Northern Plains and Upper Midwest, primarily along the Canadian border (corresponding closely to the nitrate performance).

Crustal $PM_{2.5}$ is generally overpredicted in the east and underpredicted in the western US. Coarse PM is generally underpredicted across much of the country. However, some overpredictions are observed in portions of the desert southwest (NM) and northwest (OR and WA).



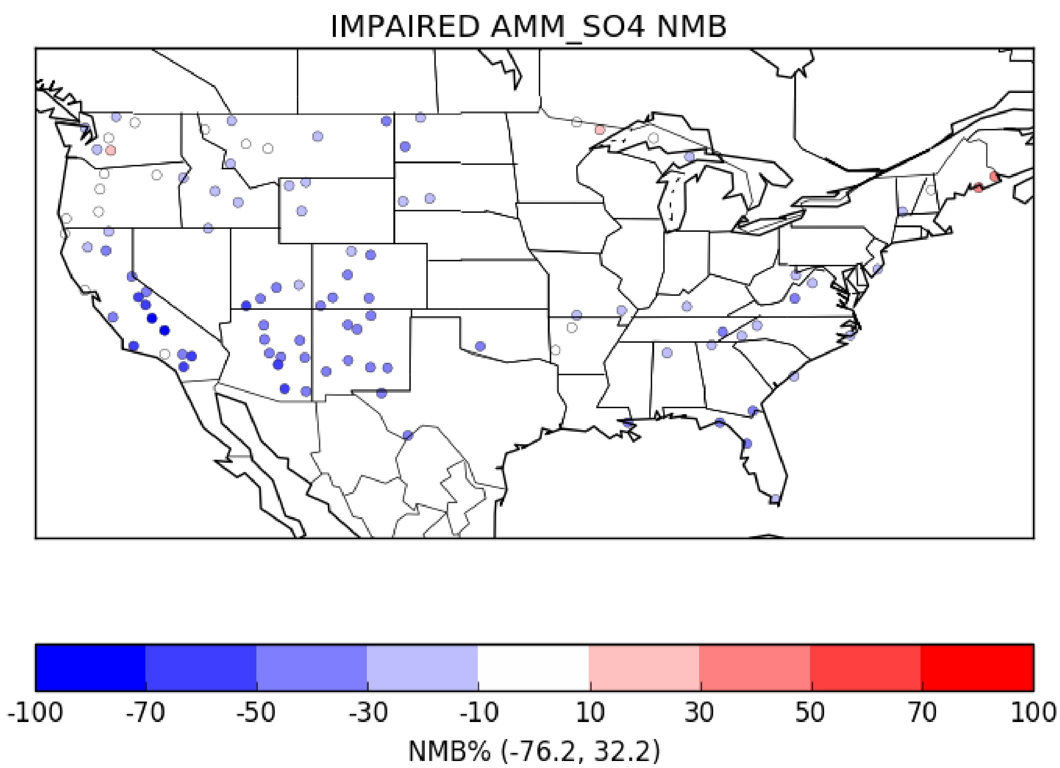


Figure 28. Observed ammonium sulfate (top) and modeled NMB (bottom) for ammonium sulfate on the 20% most-impaired days at IMPROVE monitor locations.

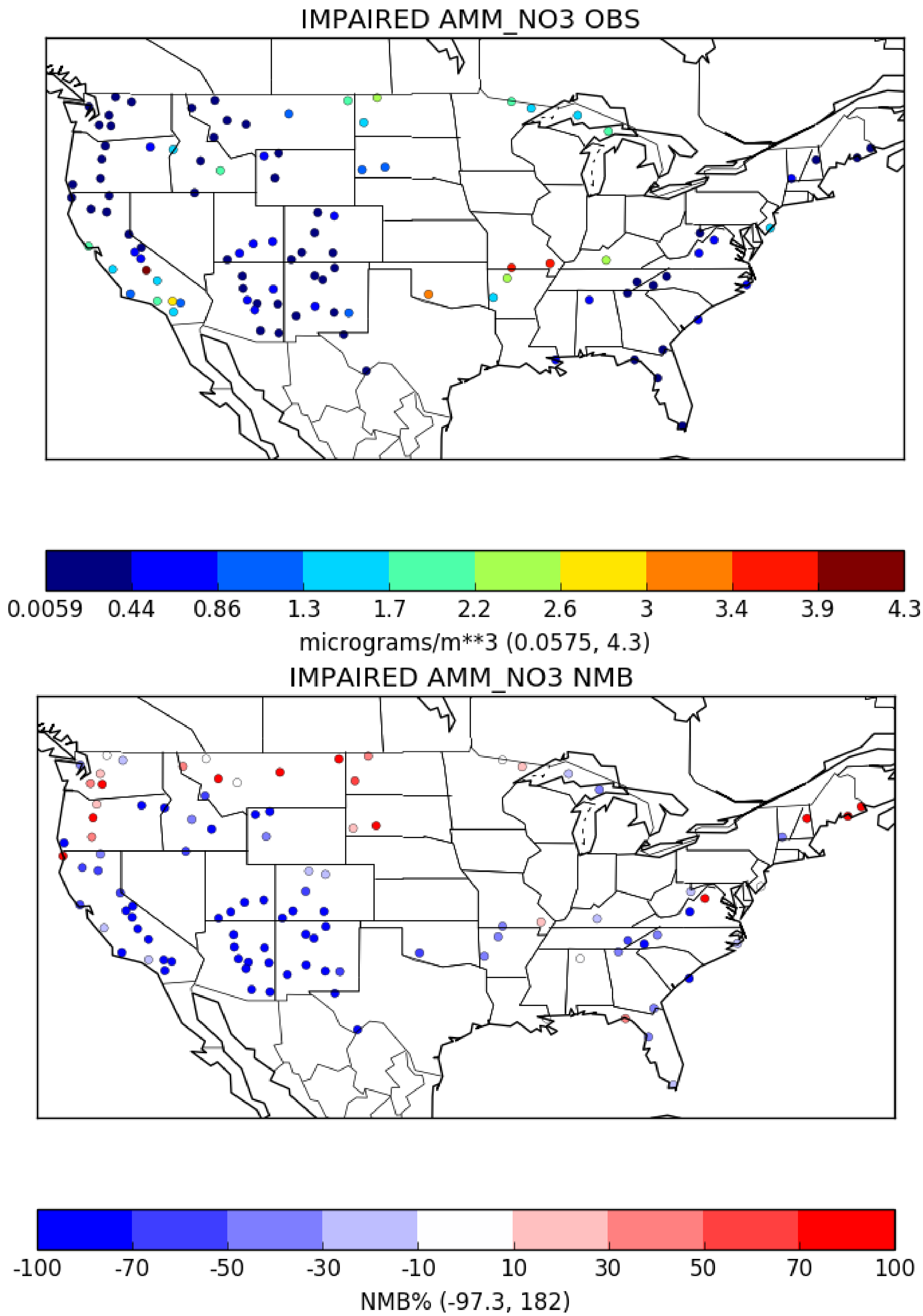


Figure 29. Observed ammonium nitrate (top) and modeled NMB (bottom) for ammonium nitrate on the 20% most-impaired days at IMPROVE monitor locations.

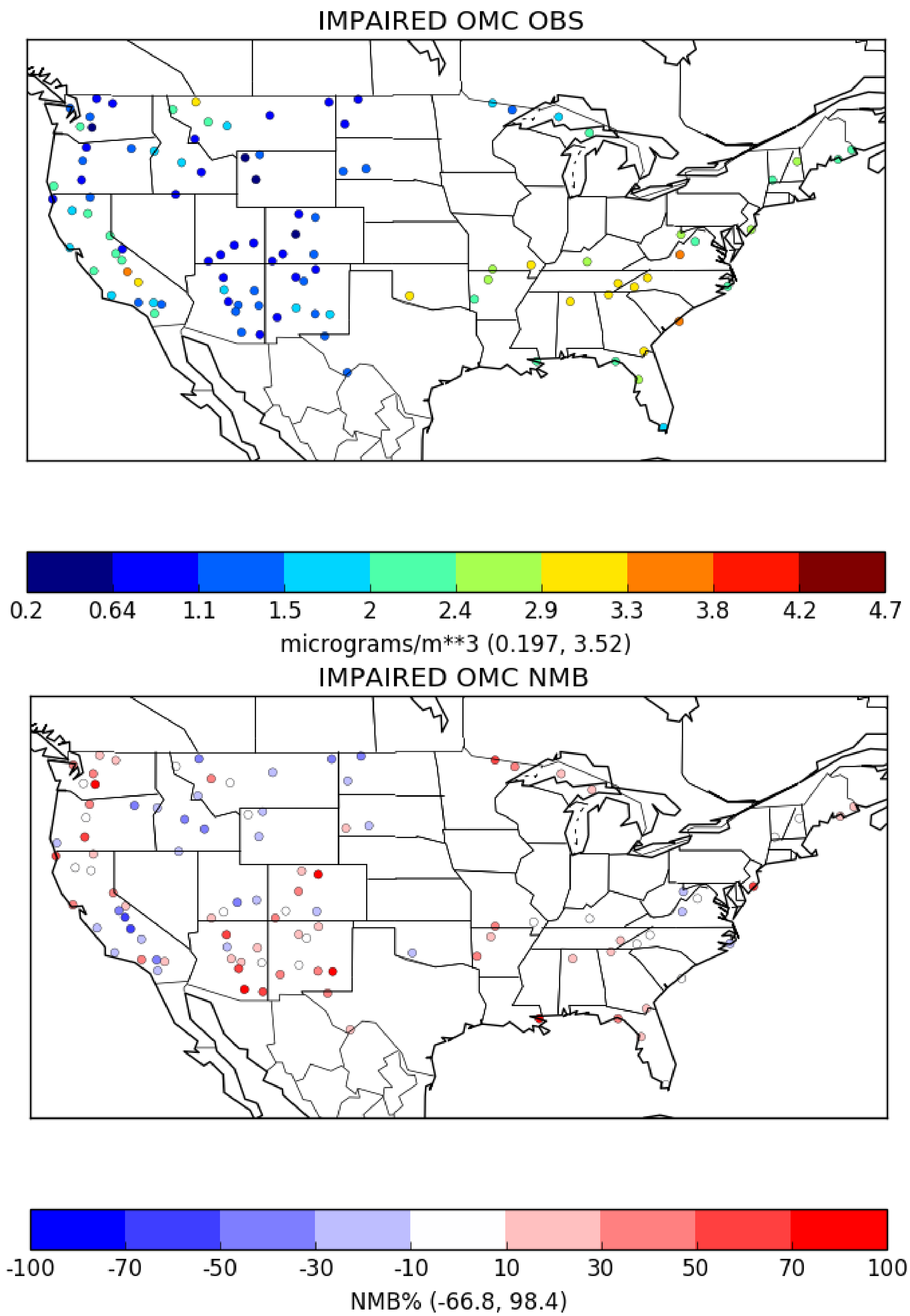


Figure 30. Observed OC (top) and modeled NMB (bottom) for OC on the 20% most-impaired days at IMPROVE monitor locations.

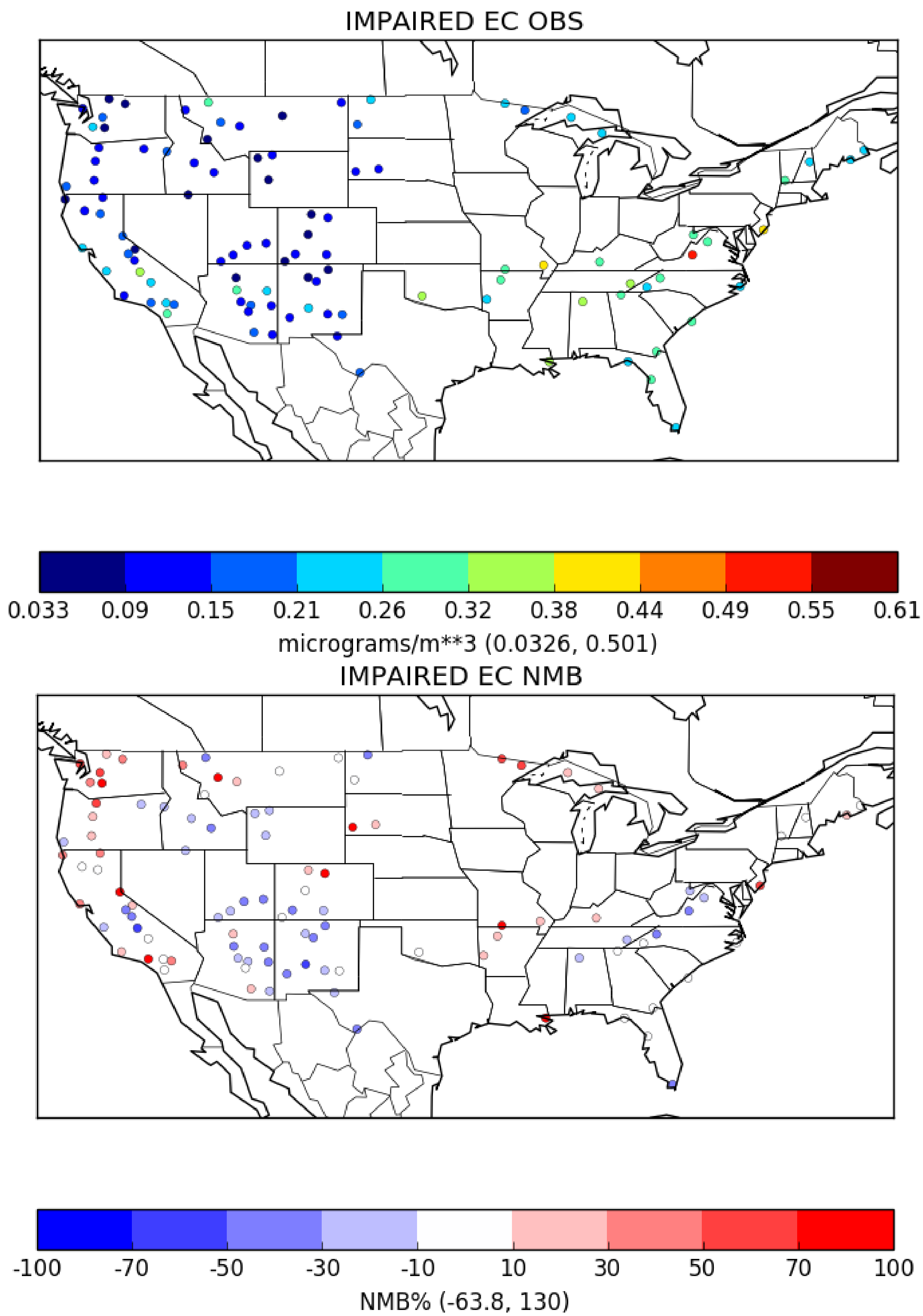
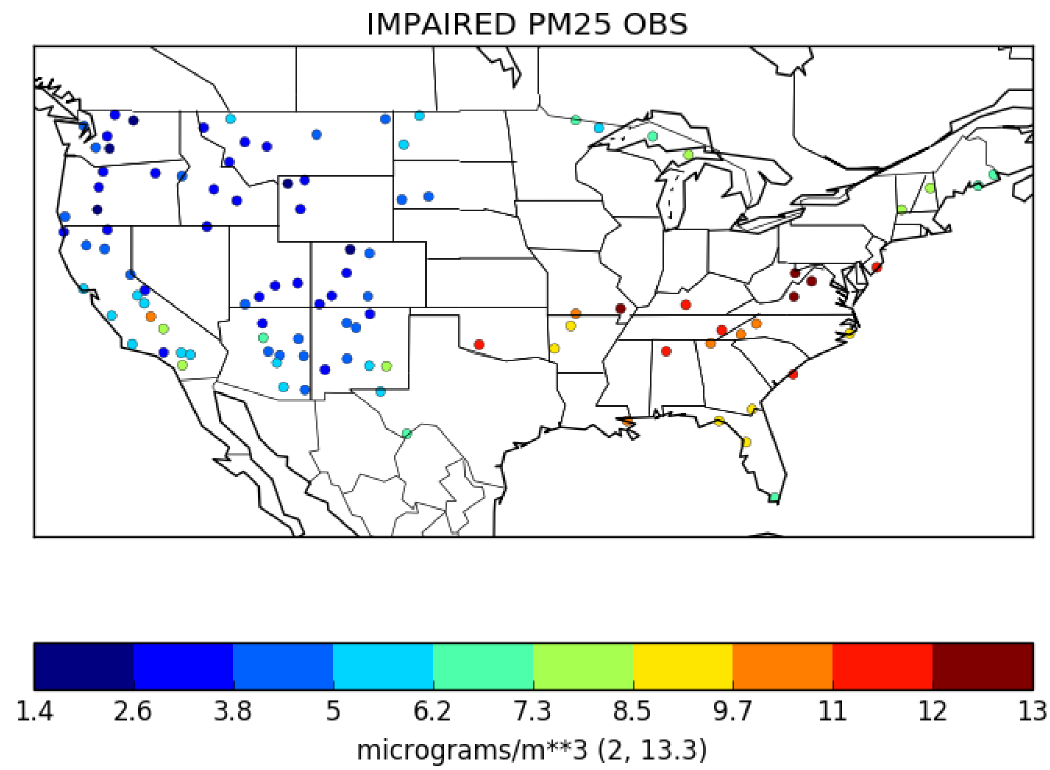


Figure 31. Observed EC (top) and modeled NMB (bottom) for EC on the 20% most-impaired days at IMPROVE monitor locations.



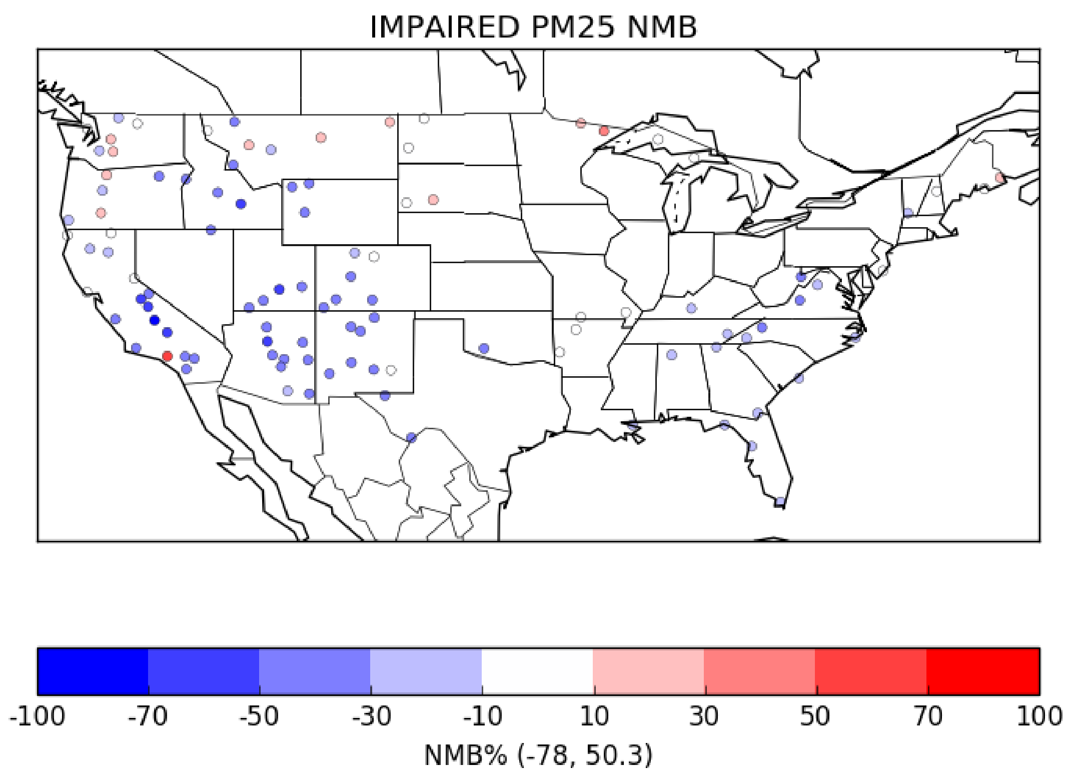
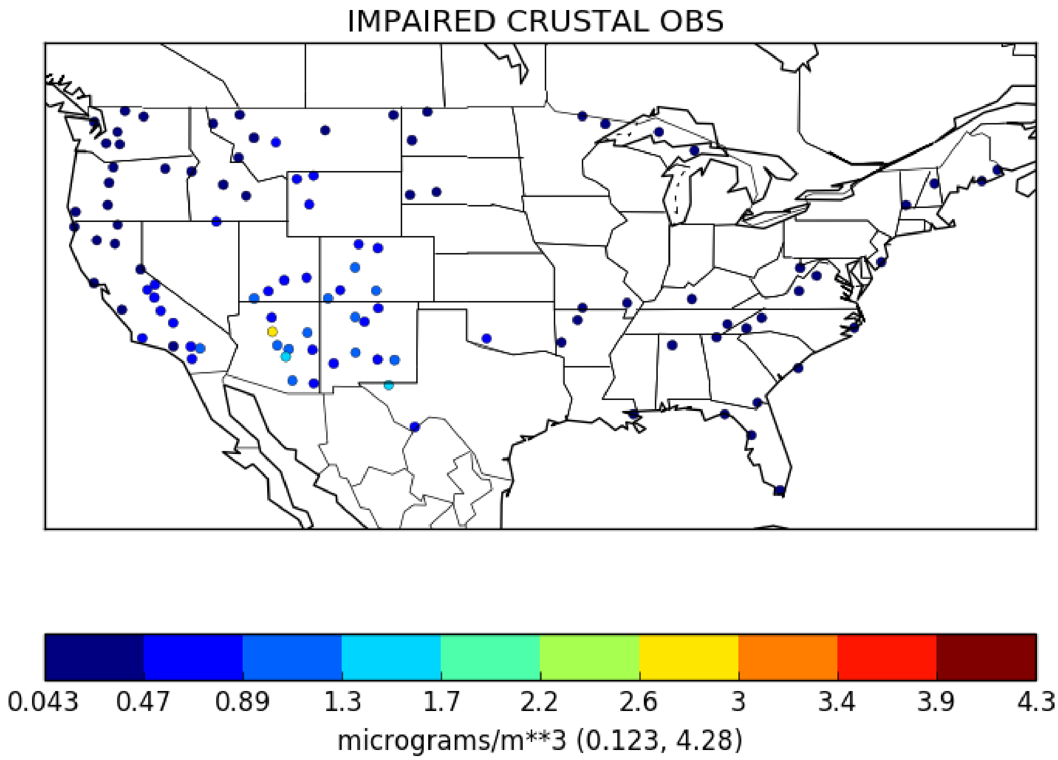


Figure 32. Observed $PM_{2.5}$ (top) and modeled NMB (bottom) for $PM_{2.5}$ on the 20% most-impaired days at IMPROVE monitor locations.



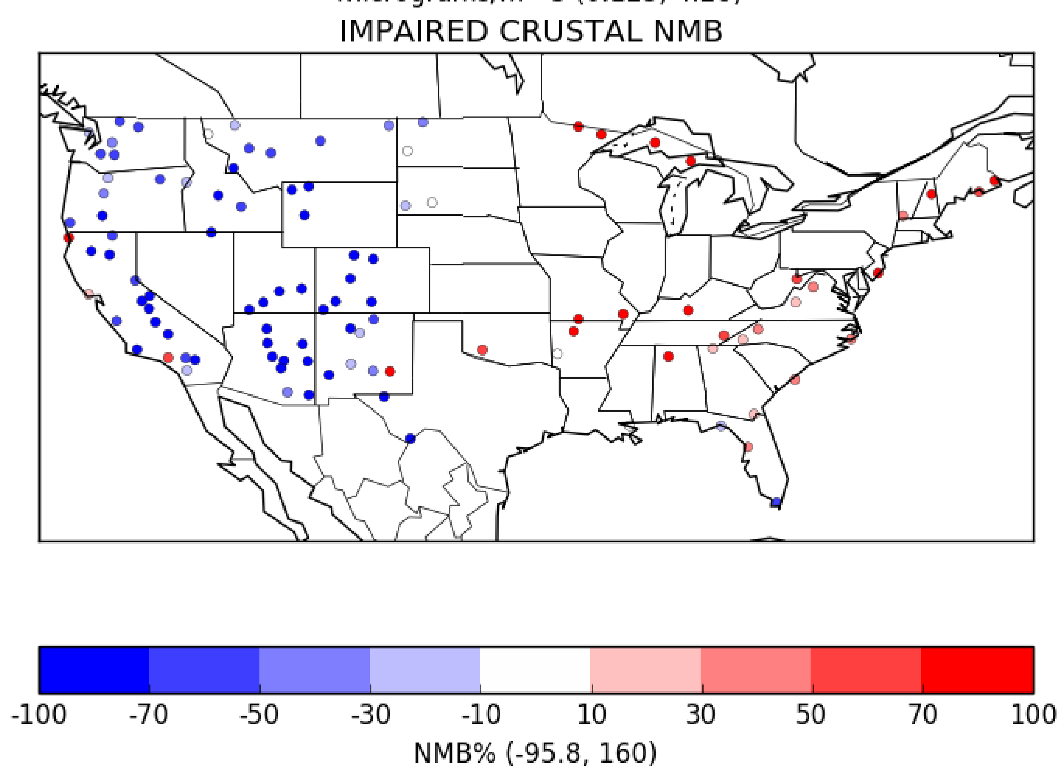


Figure 33. Observed Crustal $PM_{2.5}$ (top) and modeled NMB (bottom) for the 20% most-impaired days at IMPROVE monitor locations.

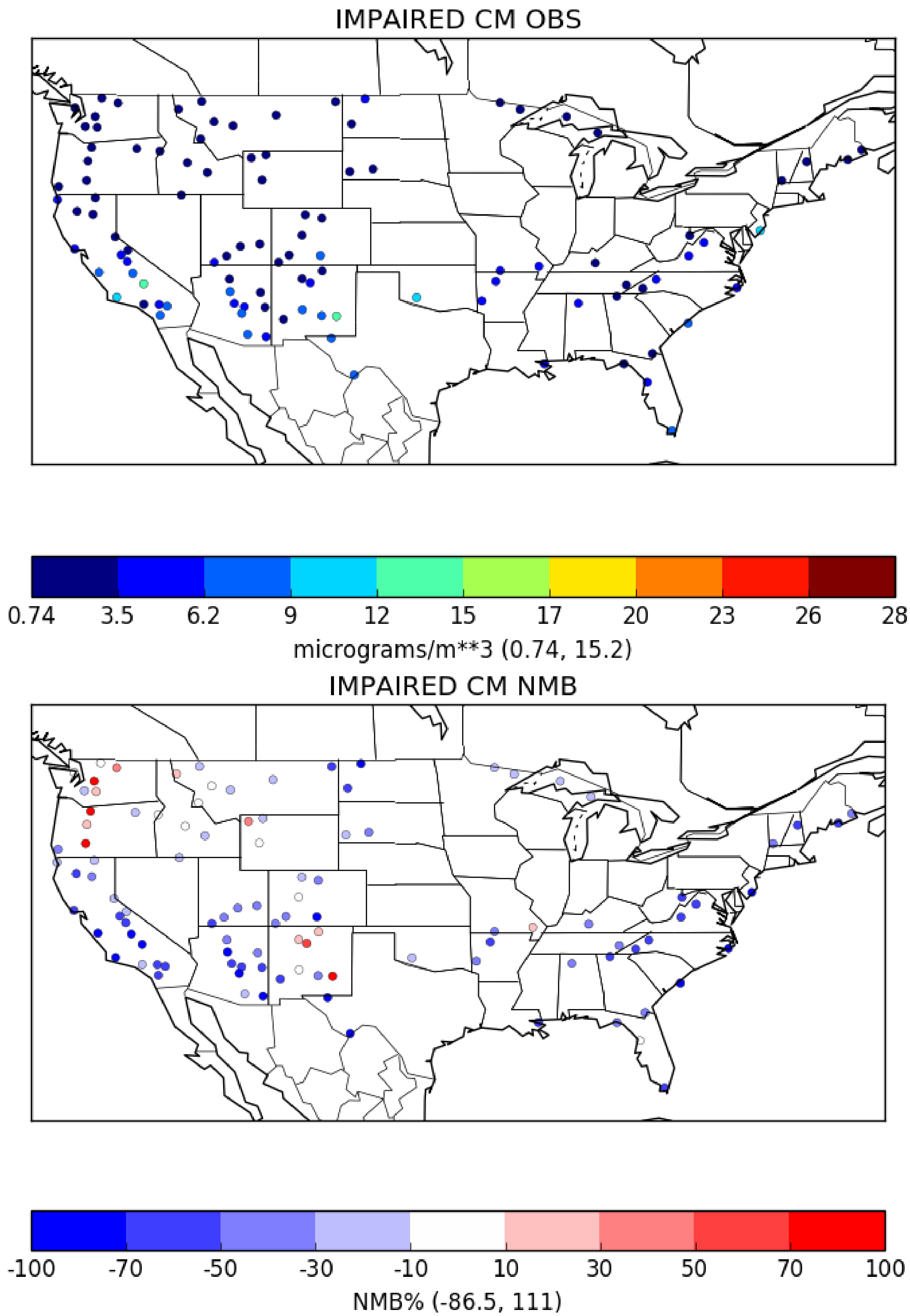


Figure 34. Observed Coarse PM (top) and modeled NMB (bottom) for the 20% most-impaired days at IMPROVE monitor locations.

9. PM2.5 Composition and Contributions to Light Extinction

Figures 35 – 138 display stacked bar charts detailing the composition of $PM_{2.5}$ on the 20% most impaired, worst, and clearest days for both modeled and observed concentration (µg/m3) and light extinction ($bext^{-1}$) at each IMPROVE monitoring site. The plots on the left display the amount of total particle mass using concentrations of coarse mass, crustal (soil), ammonium nitrate (NO3), ammonium sulfate (SO4), elemental carbon (EC), organic mass carbon (OMC), and sea salt. The amount of light extinction due to each aforementioned species is displayed in the rightmost plot.

Note that in all of the plots, sea salt is the observed value at the IMPROVE site (modeled sea salt was not used) and the Rayleigh scattering in the extinction plots is site specific Rayleigh scattering for that site, which does not vary by day (not modeled or observed).

Northwest

- Mount Rainier National Park (WA)(MORA1)
- Glacier Peak Wilderness (WA) and North Cascades National Park (WA)(NOCA1)
- Olympic National Park (WA)(OLYM1)
- Pasayten Wilderness (WA)(PASA1)
- Alpine Lake Wilderness (WA)(SNPA1)
- Goat Rocks Wilderness (WA) and Mount Adams Wilderness (WA)(WHPA1)

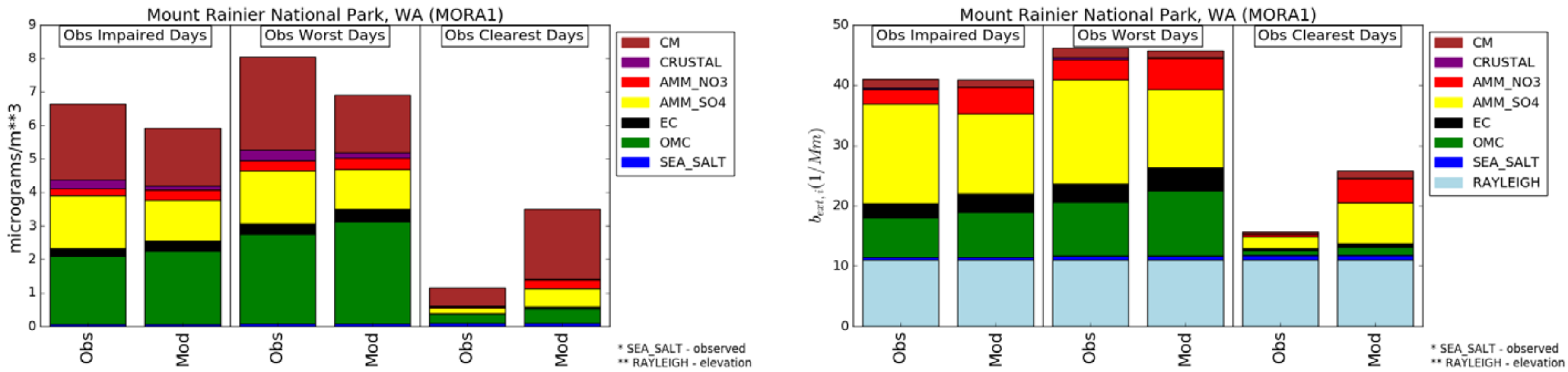


Figure 35: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Mount Rainier National Park (WA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

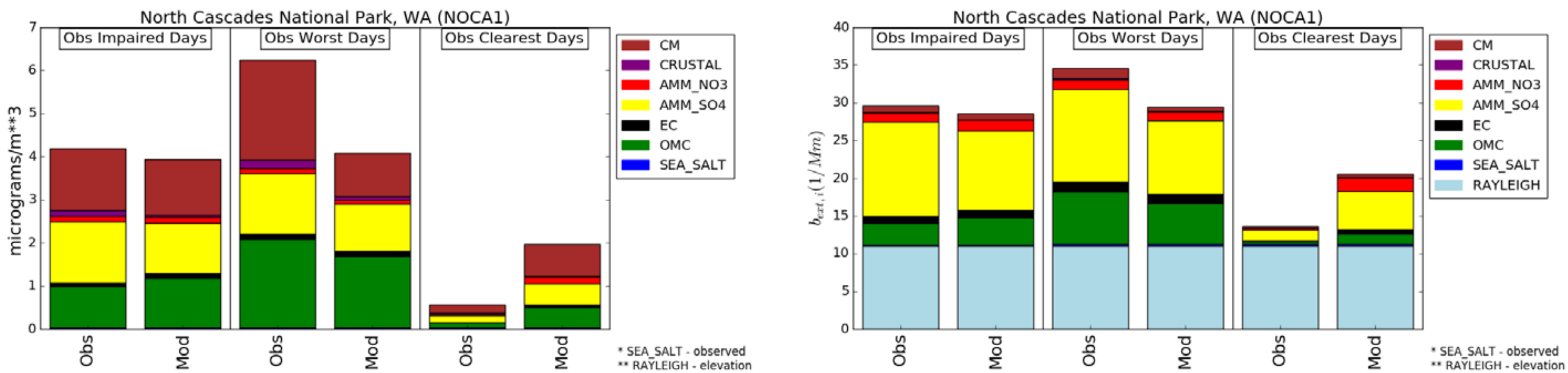


Figure 36: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Glacier Peak Wilderness (WA) and North Cascades National Park (WA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

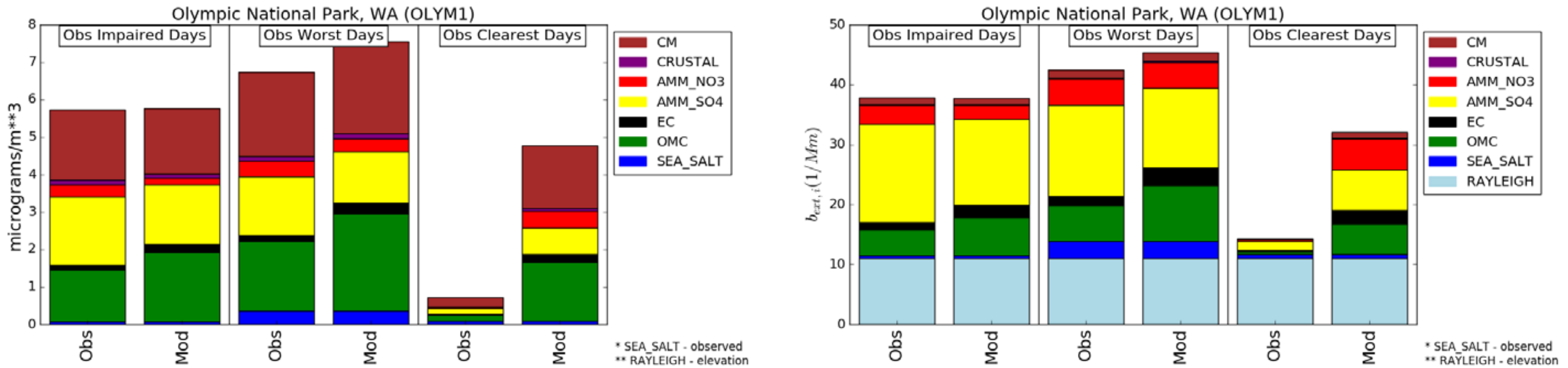


Figure 37: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Olympic National Park (WA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

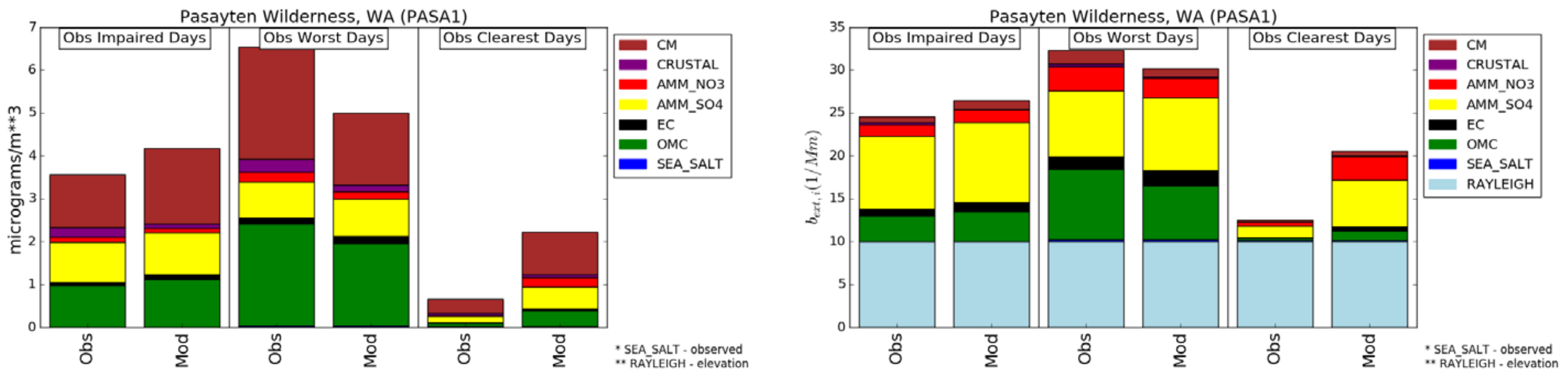


Figure 38: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Pasayten Wilderness (WA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

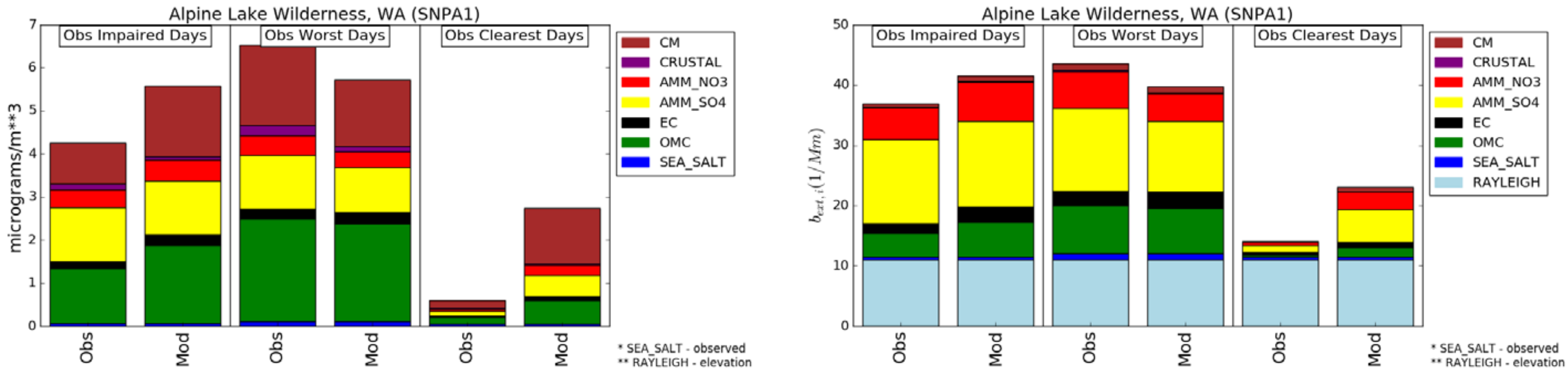


Figure 39: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Alpine Lake Wilderness (WA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

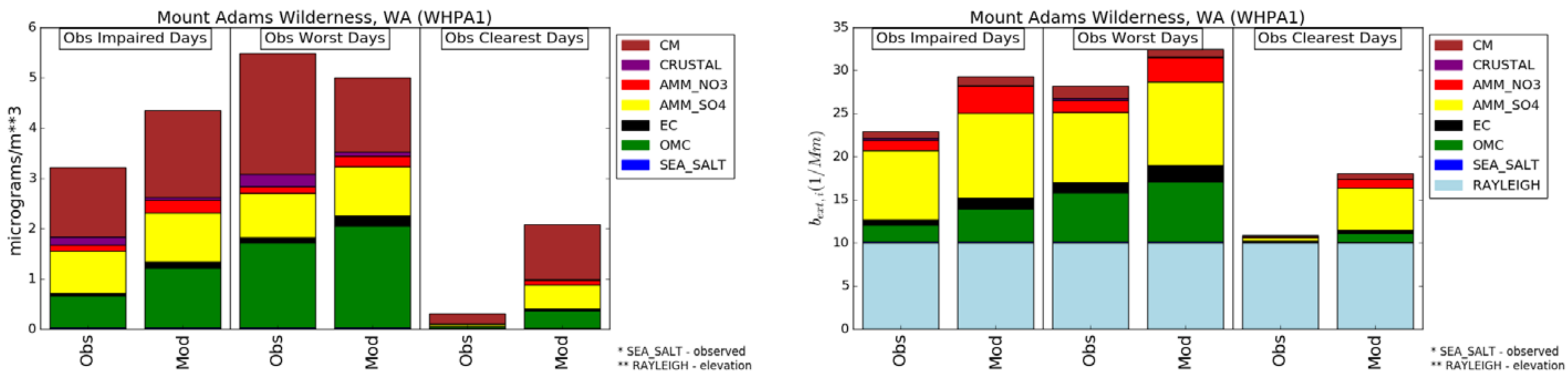


Figure 40: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Goat Rocks Wilderness (WA) and Mount Adams Wilderness (WA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Oregon and Northern California

- Desolation Wilderness (CA) and Mokelumne Wilderness (CA)(BLIS1)
- Crater Lake National Park (OR), Diamond Peak Wilderness (OR), Gearhart Mountain Wilderness (OR), and Mountain Lakes Wilderness (OR)(CRLA1)
- Kalmiopsis Wilderness (OR)(KALM1)
- Lava Beds National Monument (CA) and South Warner Wilderness (CA)(LABE1)
- Caribou Wilderness (CA), Lassen Volcanic National Park (CA), and Thousand Lakes Wilderness (CA)(LAVO1)
- Mount Hood Wilderness (OR)(MOHO1)
- Redwood National Park (CA)(REDW1)
- Mount Jefferson Wilderness (OR), Mount Washington Wilderness (OR), and Three Sisters Wilderness (OR)(THSI1)
- Marble Mountain Wilderness (CA) and Yolla Bolly Middle Eel Wilderness (CA)(TRIN1)

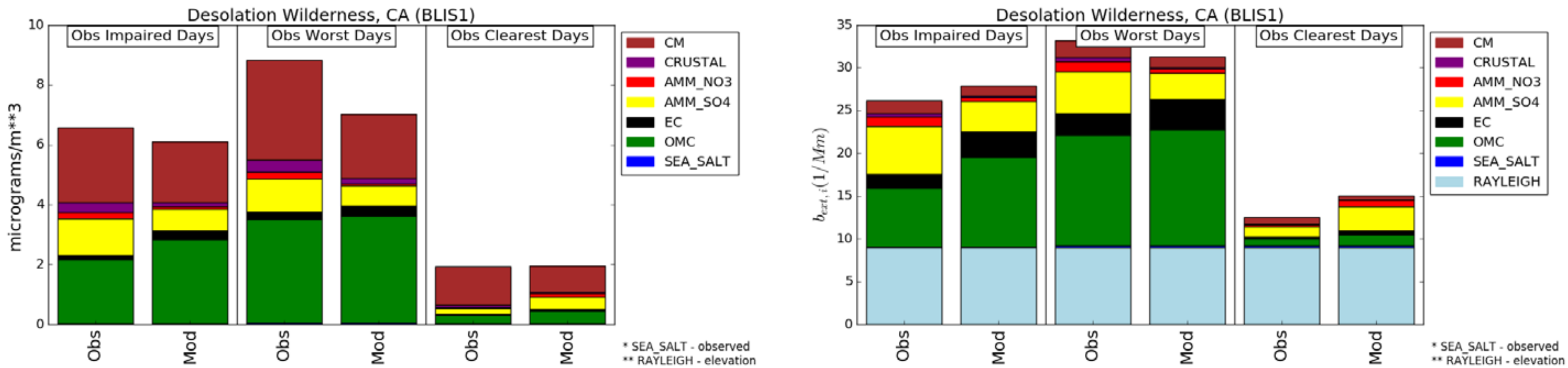


Figure 41: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Desolation Wilderness (CA) and Mokelumne Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

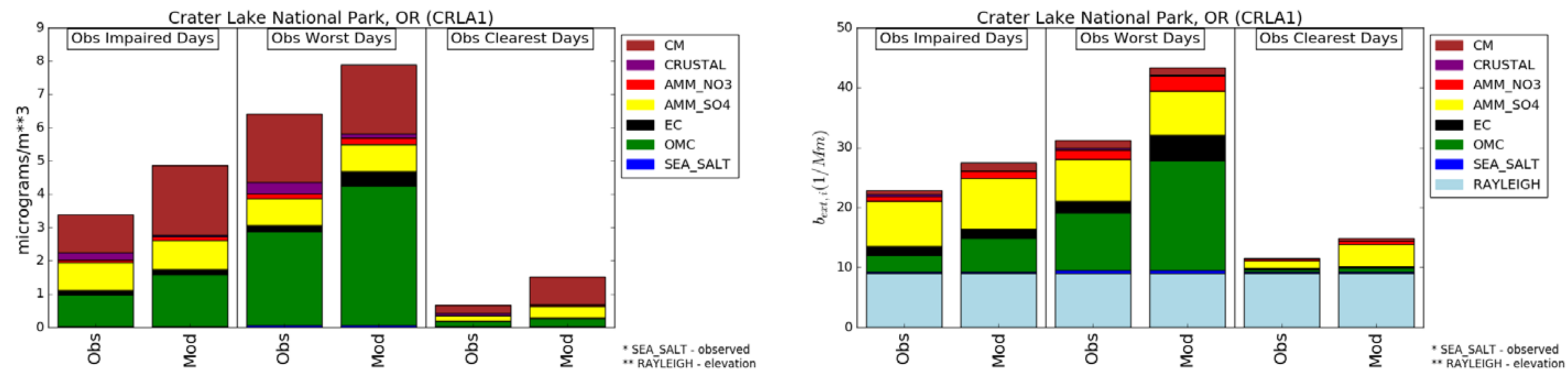


Figure 42: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Crater Lake National Park (OR), Diamond Peak Wilderness (OR), Gearhart Mountain Wilderness (OR), and Mountain Lakes Wilderness (OR) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

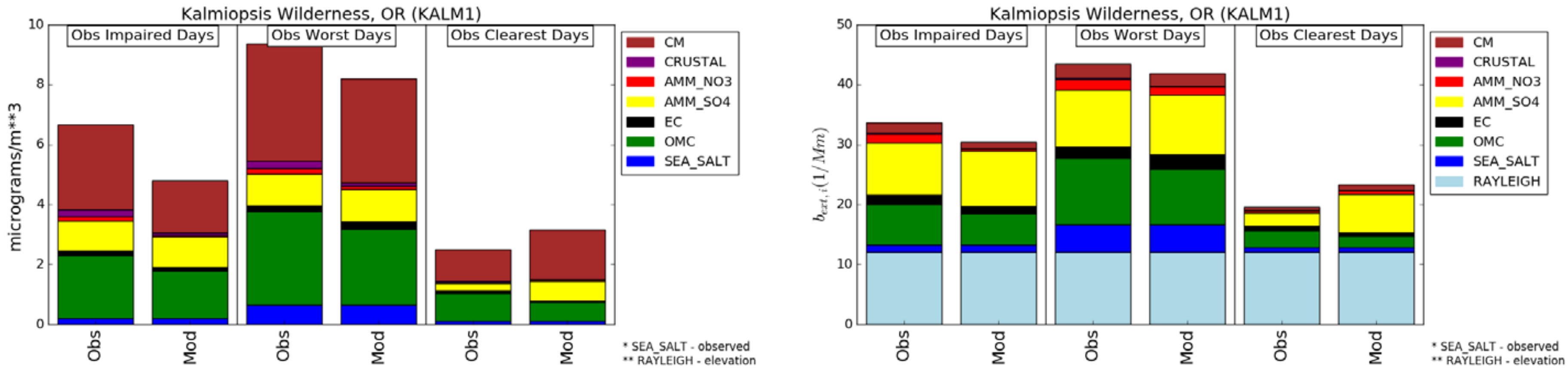


Figure 43: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Kalmiopsis Wilderness (OR) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

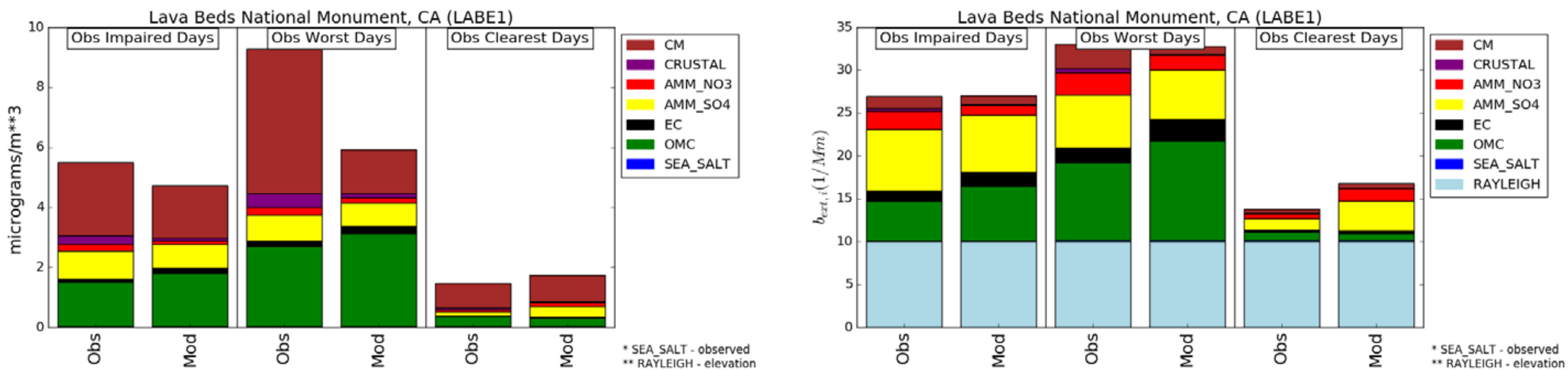


Figure 44: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Lava Beds National Monument (CA) and South Warner Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

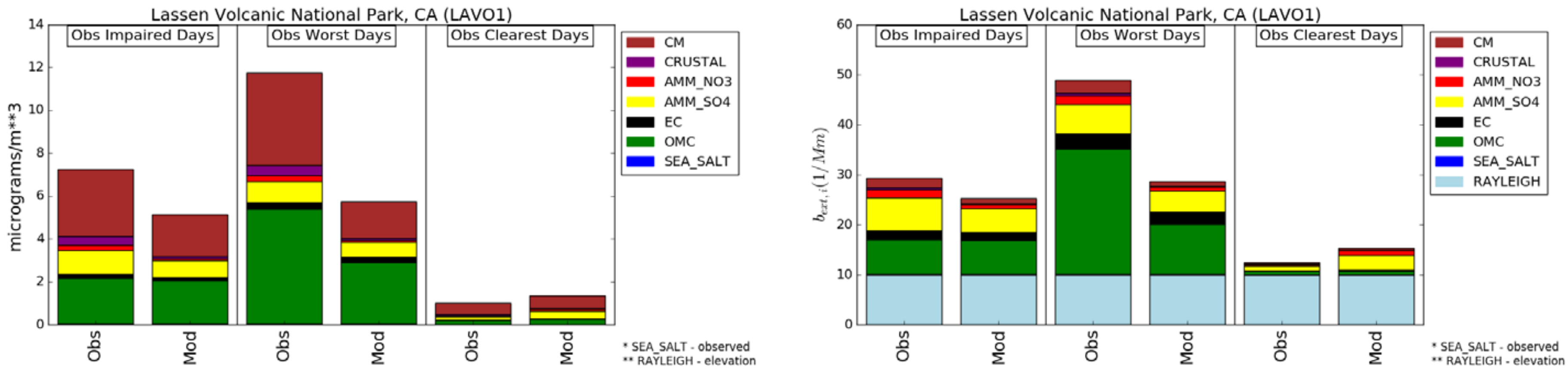


Figure 45: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Caribou Wilderness (CA), Lassen Volcanic National Park (CA), and Thousand Lakes Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

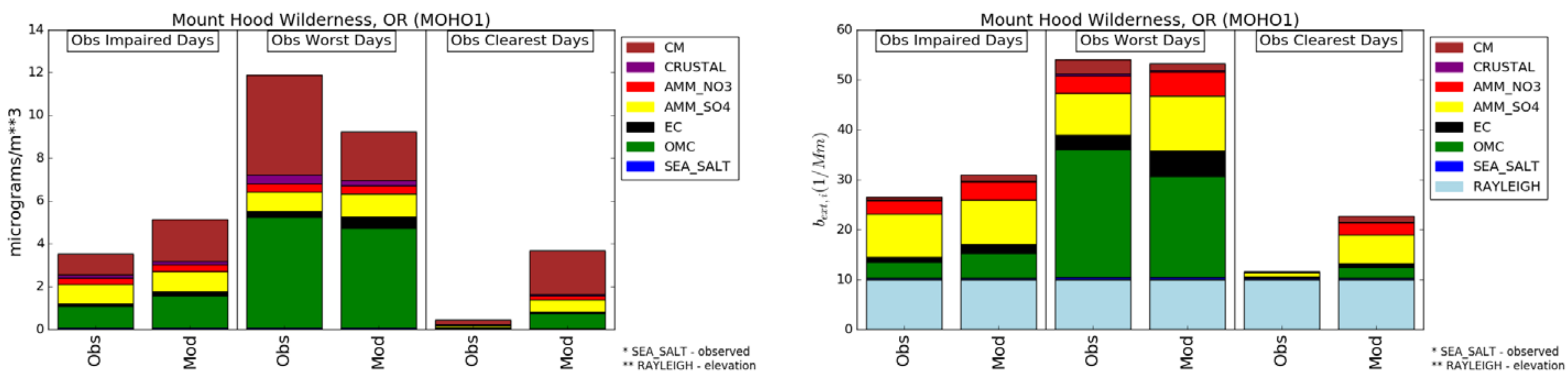


Figure 46: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Mount Hood Wilderness (OR) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

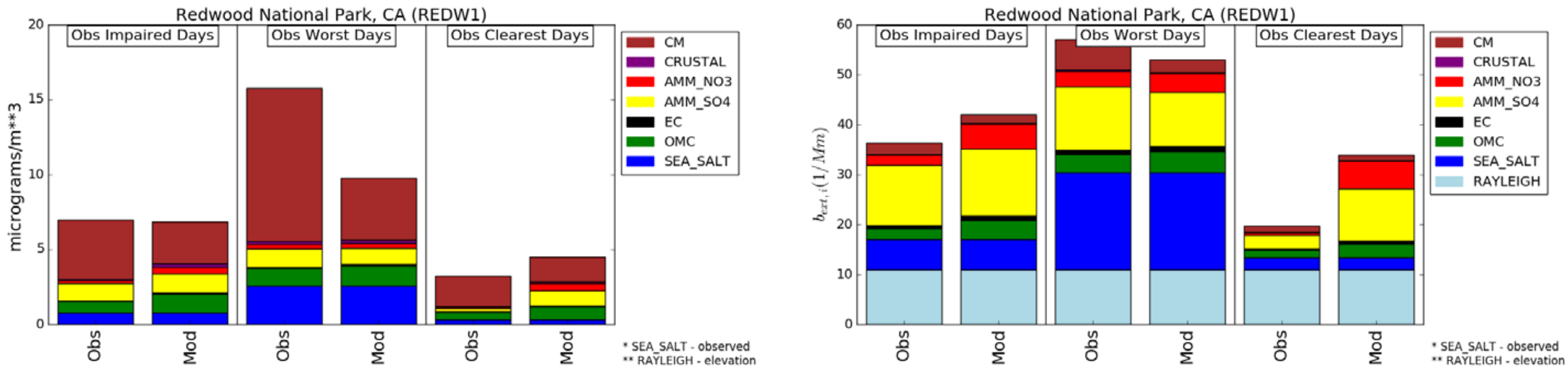


Figure 47: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Redwood National Park (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

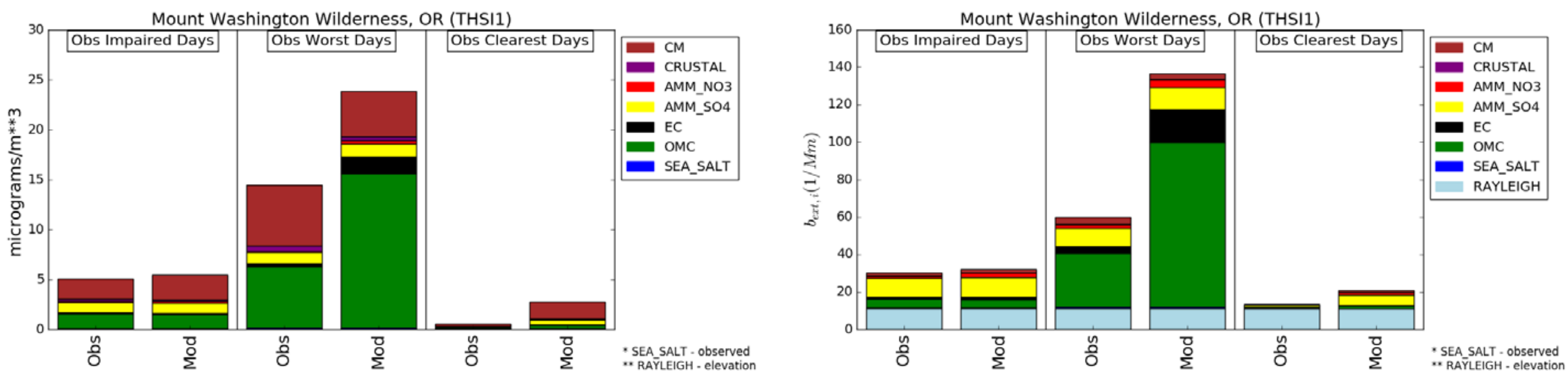
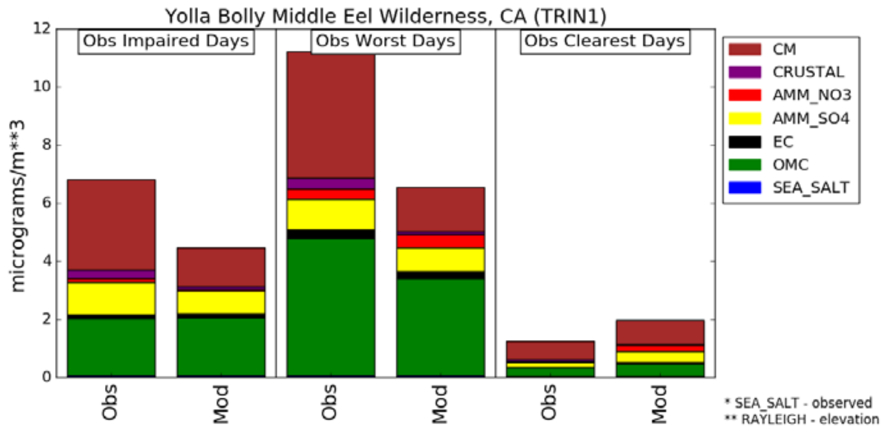


Figure 48: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Mount Jefferson Wilderness (OR), Mount Washington Wilderness (OR), and Three Sisters Wilderness (OR) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.



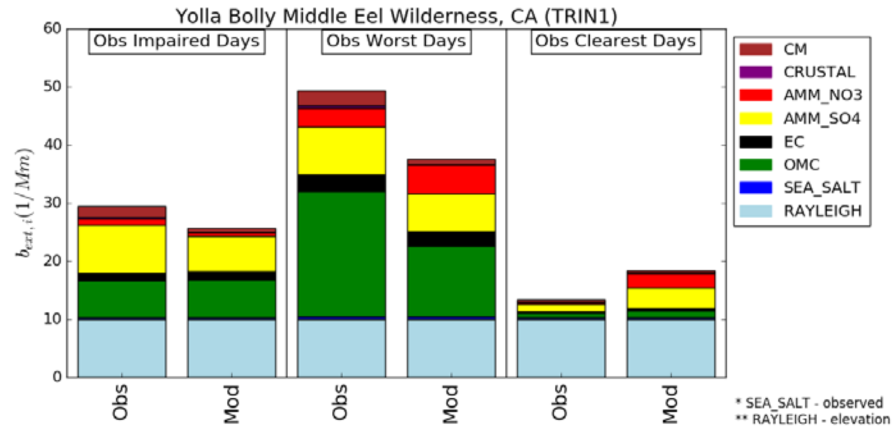


Figure 49: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Marble Mountain Wilderness (CA) and Yolla Bolly Middle Eel Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

California Coast

- Pinnacles National Monument (CA) and Ventana Wilderness (CA)(PINN1)
- Point Reyes NS (CA)(PORE1)
- San Rafael Wilderness (CA)(RAFA1)

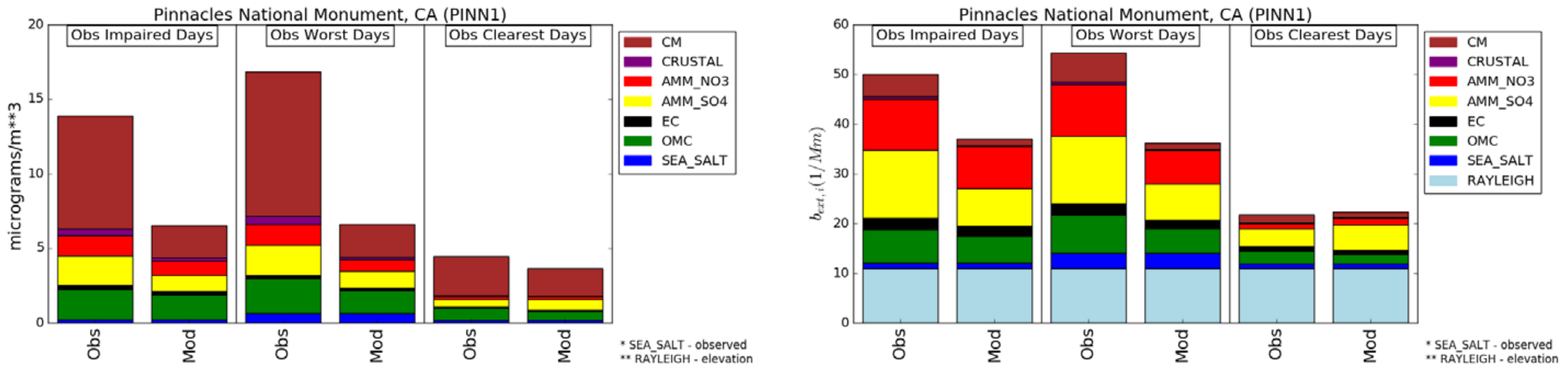


Figure 50: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Pinnacles National Monument (CA) and Ventana Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

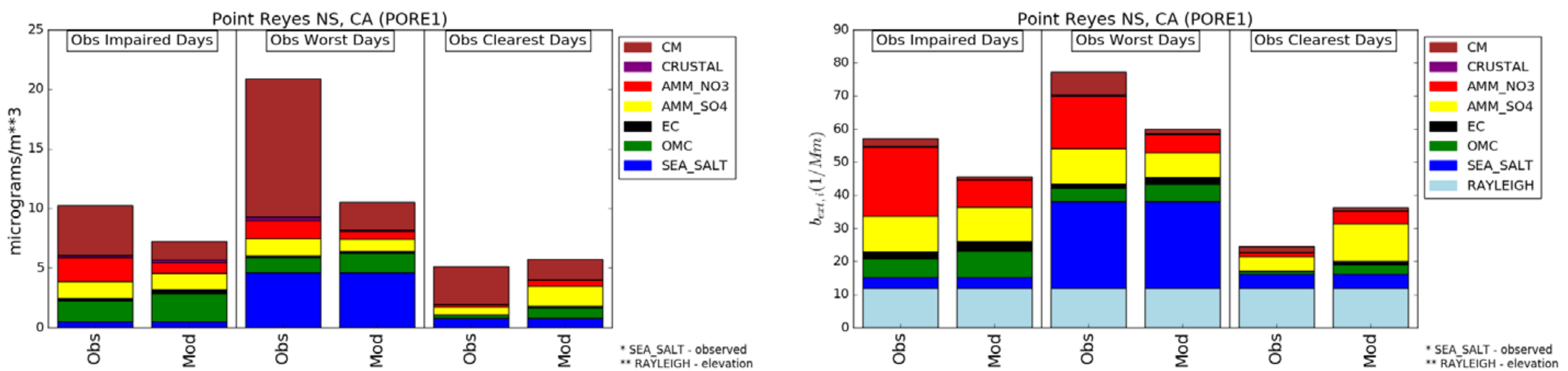


Figure 51: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Point Reyes NS (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

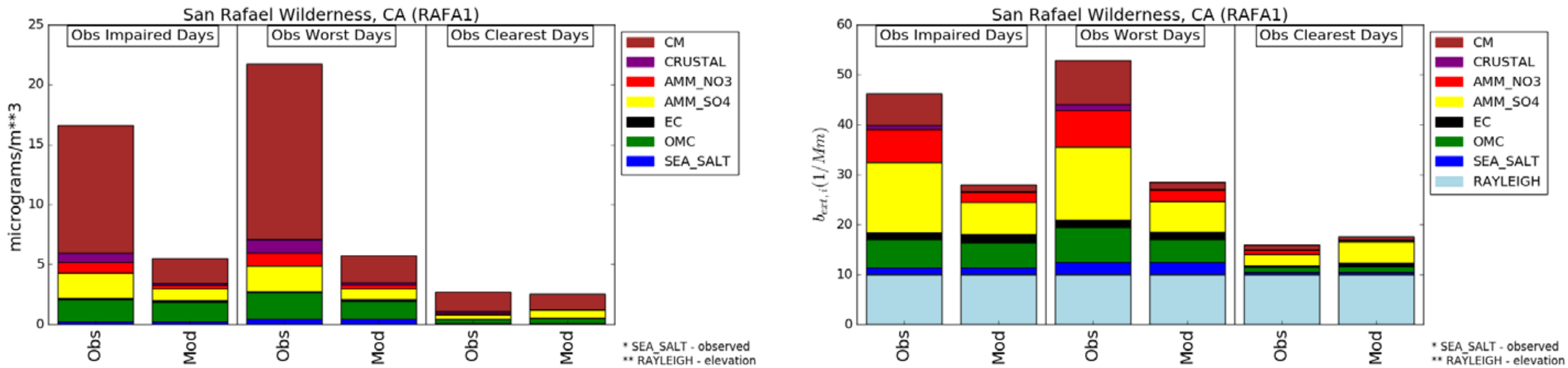


Figure 52: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the San Rafael Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Sierra Nevada

- Dome Land Wilderness (CA)(DOME1)
- Hoover Wilderness (CA)(HOOV1)
- Ansel Adams Wilderness (Minarets) (CA), John Muir Wilderness (CA), and Kaiser Wilderness (CA)(KAIS1)
- Kings Canyon National Park (CA) and Sequoia National Park (CA)(SEQU1)
- Emigrant Wilderness (CA) and Yosemite National Park (CA)(YOSE1)

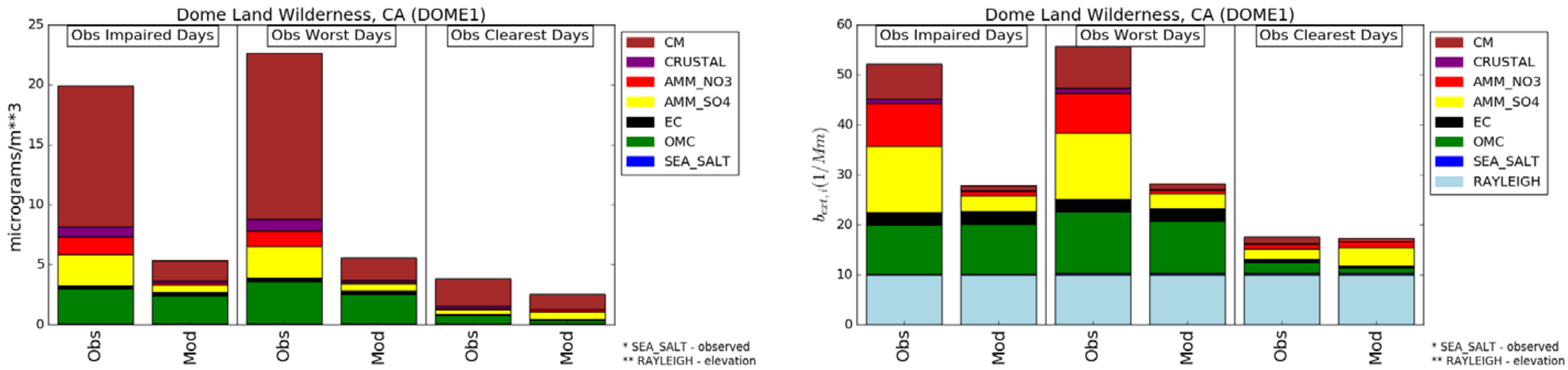


Figure 53: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Dome Land Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

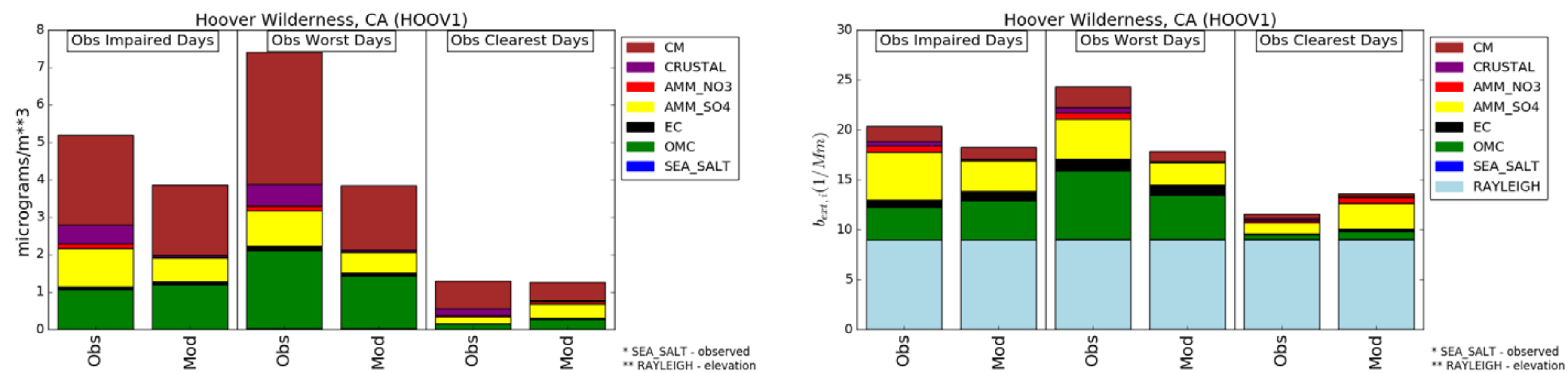


Figure 54: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Hoover Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

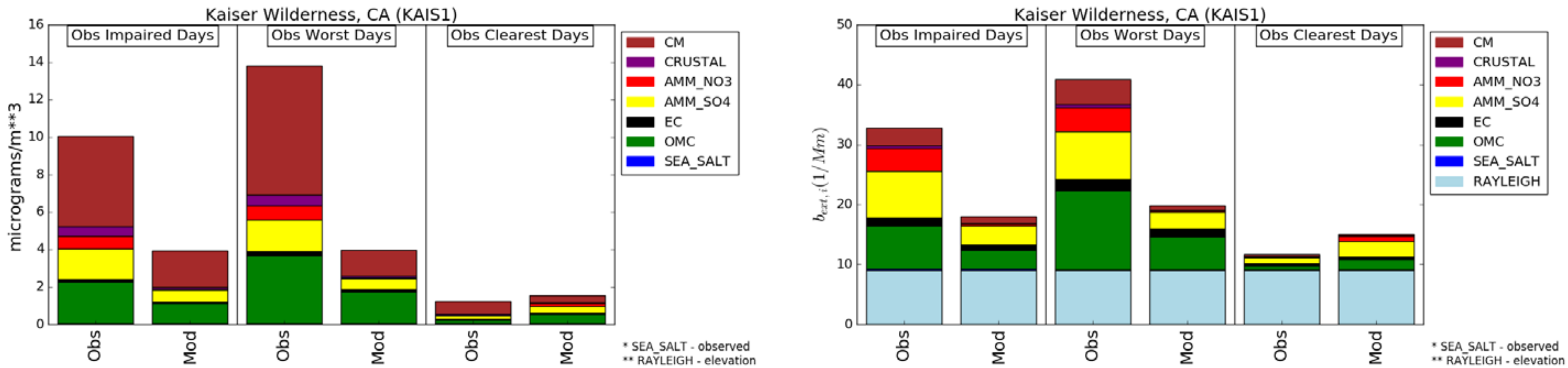


Figure 55: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Ansel Adams Wilderness (Minarets) (CA), John Muir Wilderness (CA), and Kaiser Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

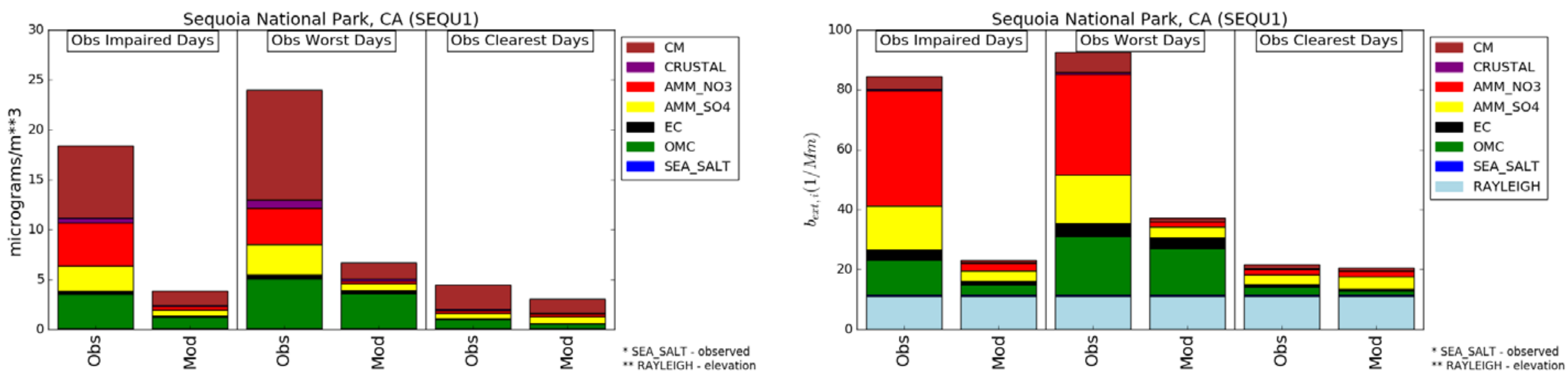
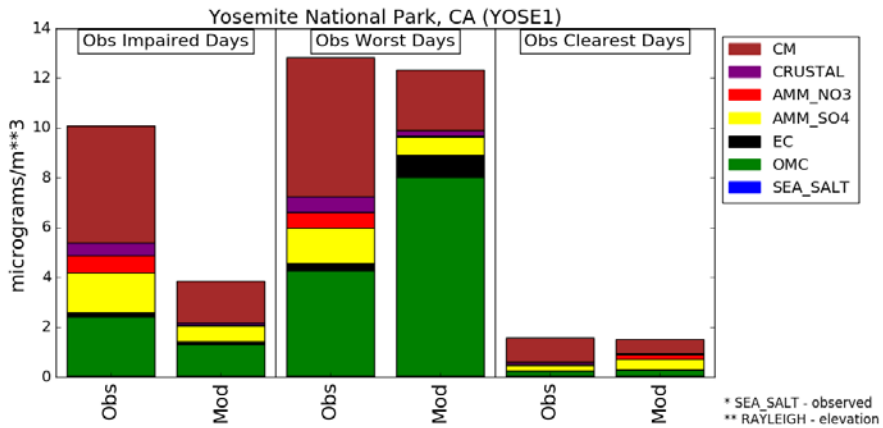


Figure 56: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Kings Canyon National Park (CA) and Sequoia National Park (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.



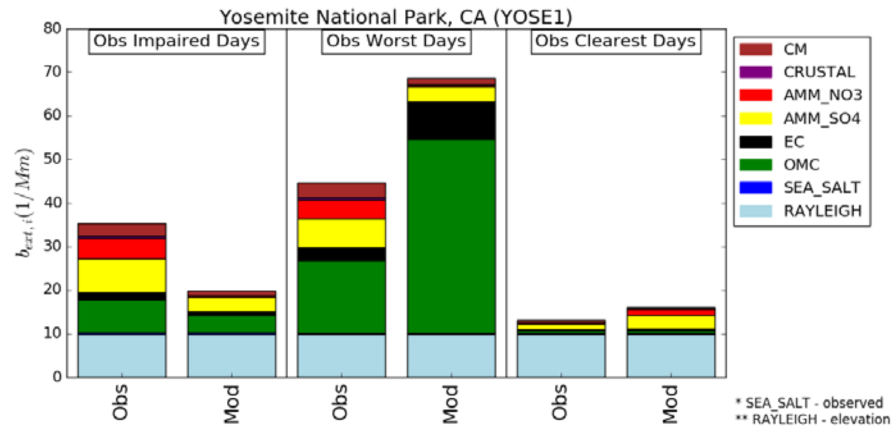


Figure 57: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Emigrant Wilderness (CA) and Yosemite National Park (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Southern California

- Agua Tibia Wilderness (CA)(AGTI1)
- Joshua Tree National Monument (CA)(JOSH1)
- Cucamonga Wilderness (CA) and San Gabriel Wilderness (CA)(SAGA1)
- San Gorgonio Wilderness (CA) and San Jacinto Wilderness (CA)(SAGO1)

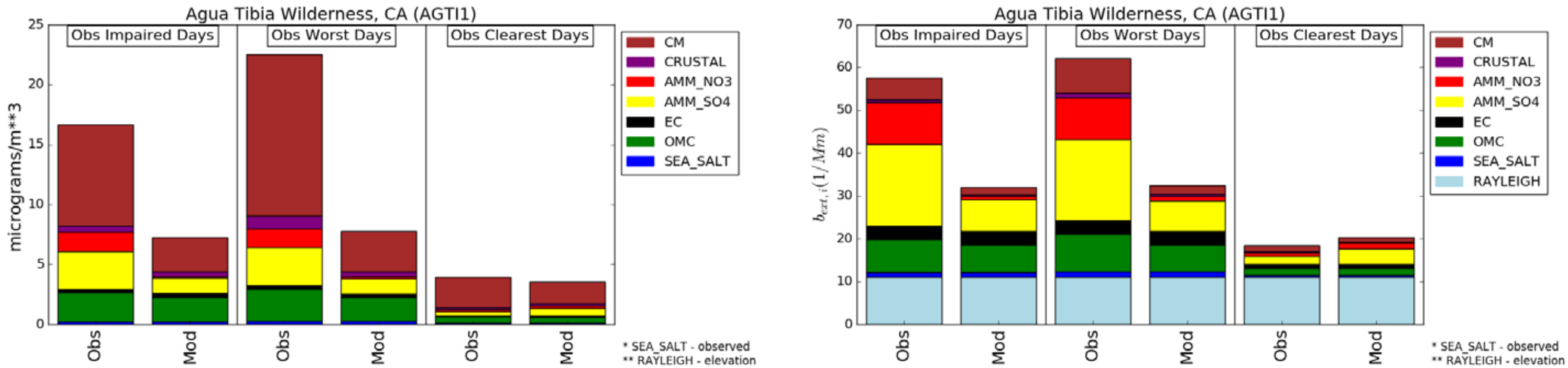


Figure 58: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Agua Tibia Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

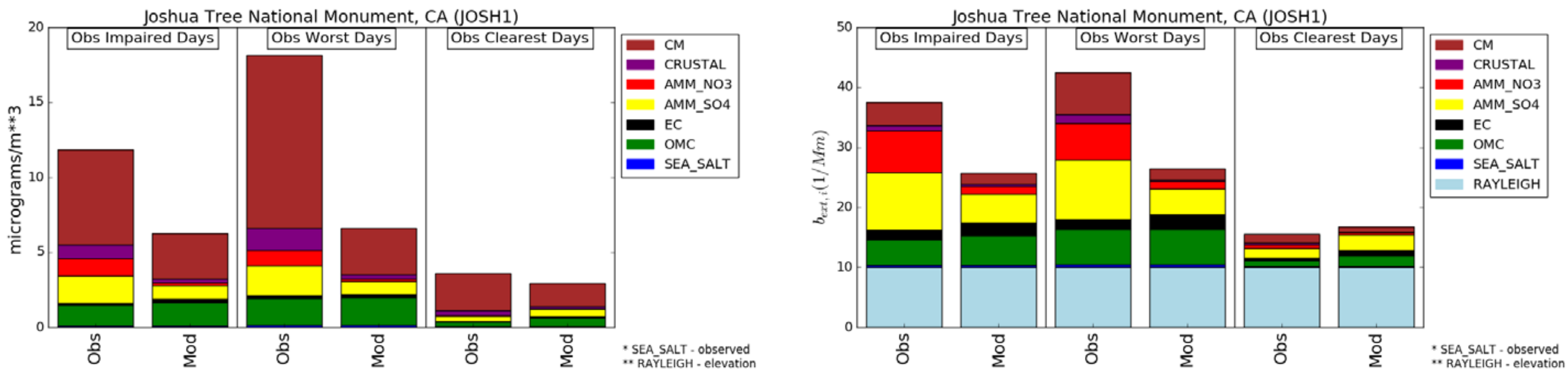


Figure 59: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Joshua Tree National Monument (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

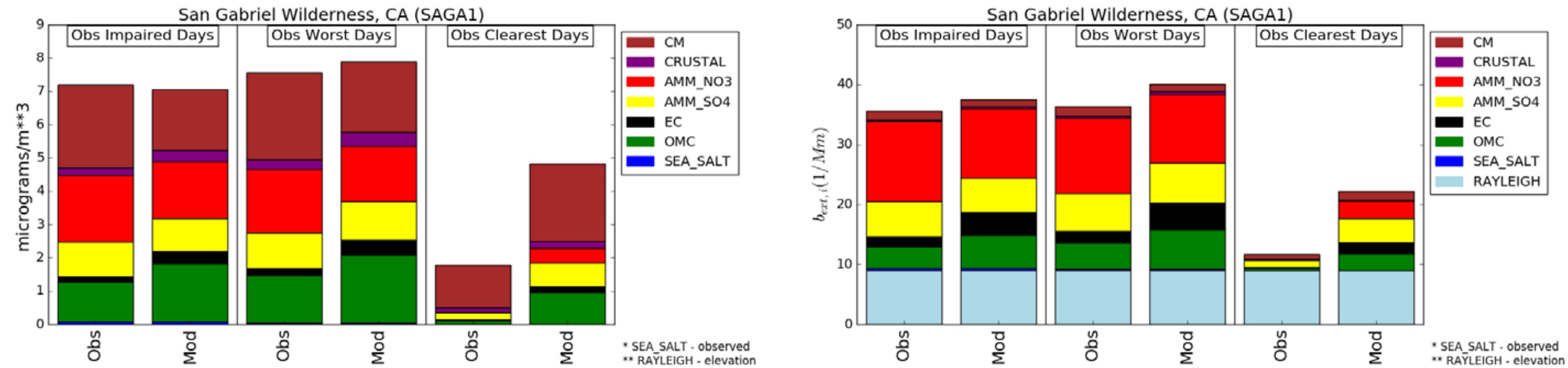


Figure 60: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Cucamonga Wilderness (CA) and San Gabriel Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

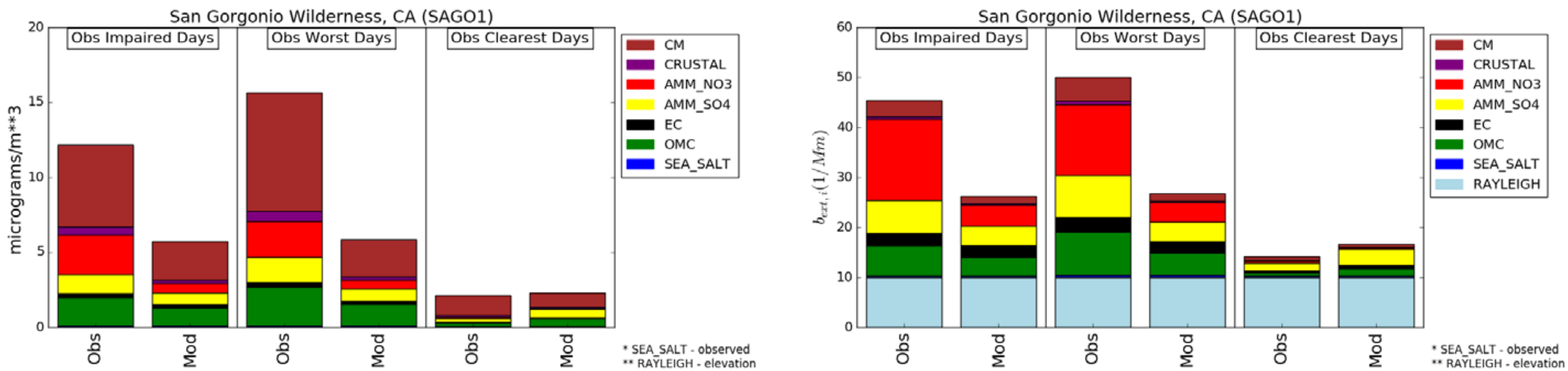


Figure 61: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the San Gorgonio Wilderness (CA) and San Jacinto Wilderness (CA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Northern Rocky Mountains

- Bridger Wilderness (WY) and Fitzpatrick Wilderness (WY)(BRID1)
- Cabinet Mountains Wilderness (MT)(CABI1)
- Gates of the Mountains Wilderness (MT)(GAMO1)
- Glacier National Park (MT)(GLAC1)
- Bob Marshall Wilderness (MT), Mission Mountains Wilderness (MT), and Scapegoat Wilderness (MT)(MONT1)
- North Absaroka Wilderness (WY) and Washakie Wilderness (WY)(NOAB1)
- Anaconda-Pintler Wilderness (MT) and Selway-Bitterroot Wilderness (MT)(SULA1)
- Grand Teton National Park (WY), Red Rock Lakes (WY), Teton Wilderness (WY), and Yellowstone National Park (WY)(YELL2)

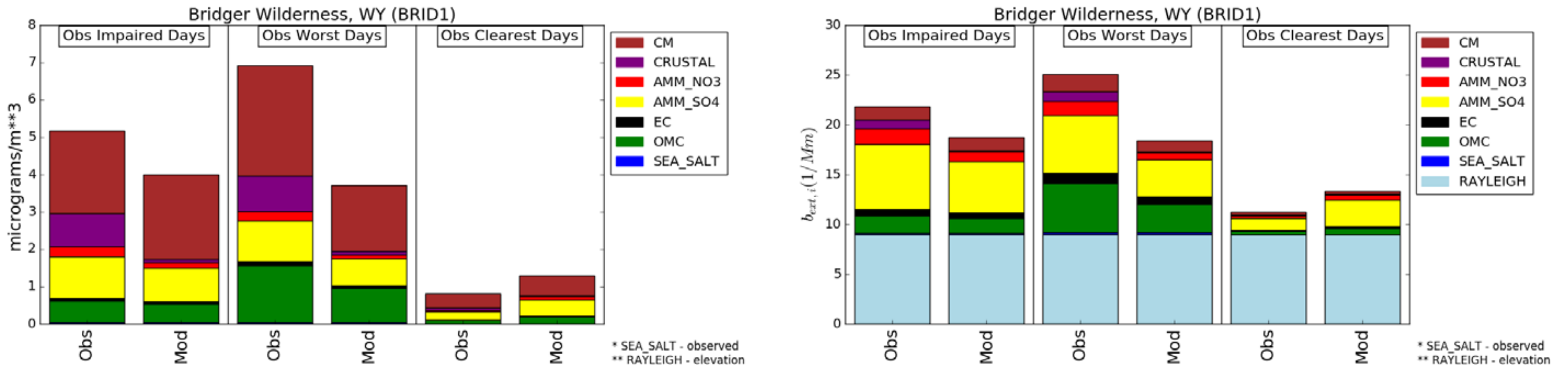


Figure 62: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Bridger Wilderness (WY) and Fitzpatrick Wilderness (WY) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

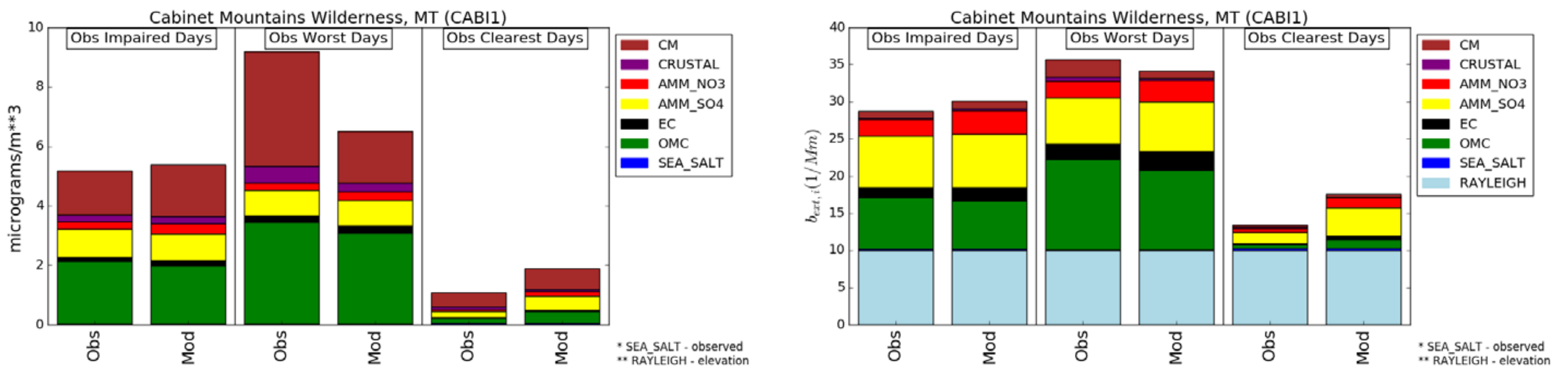


Figure 63: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Cabinet Mountains Wilderness (MT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

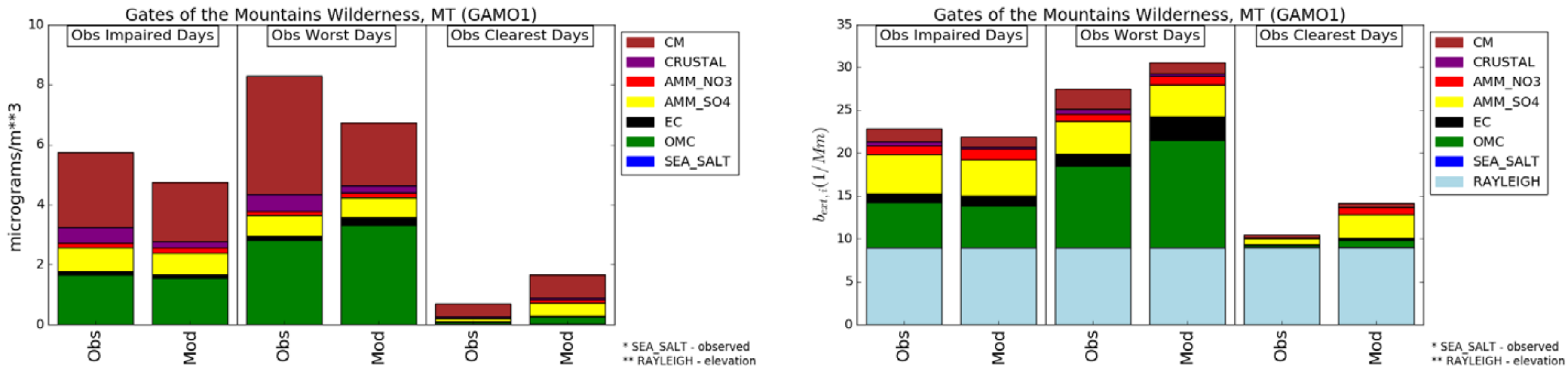


Figure 64: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Gates of the Mountains Wilderness (MT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

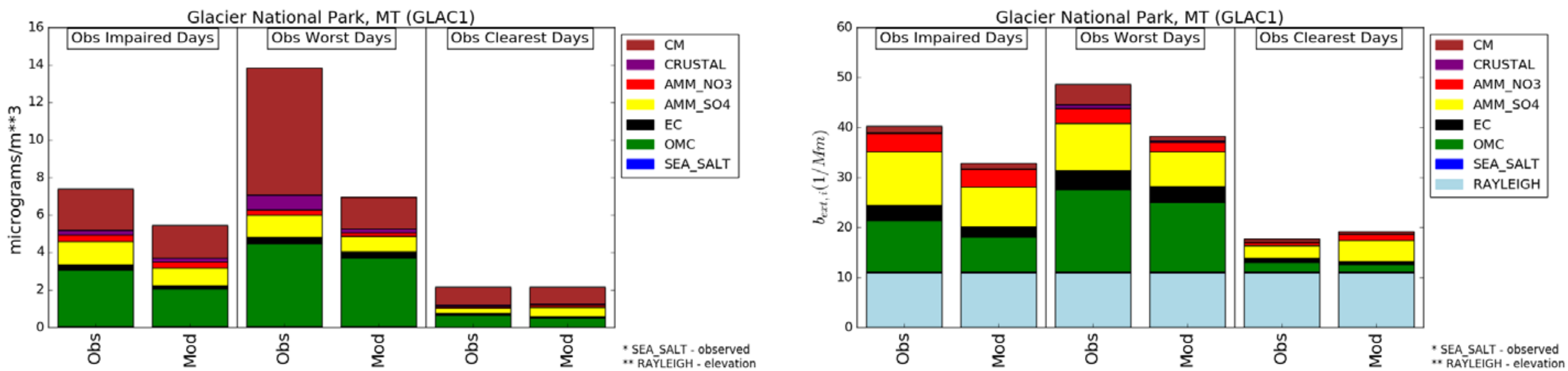


Figure 65: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Glacier National Park (MT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

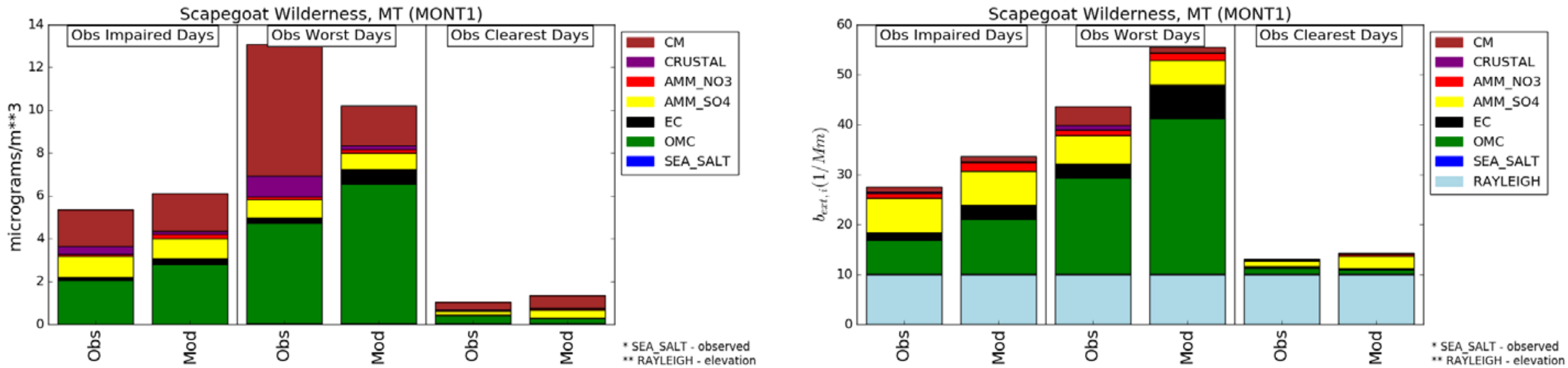


Figure 66: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Bob Marshall Wilderness (MT), Mission Mountains Wilderness (MT), and Scapegoat Wilderness (MT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

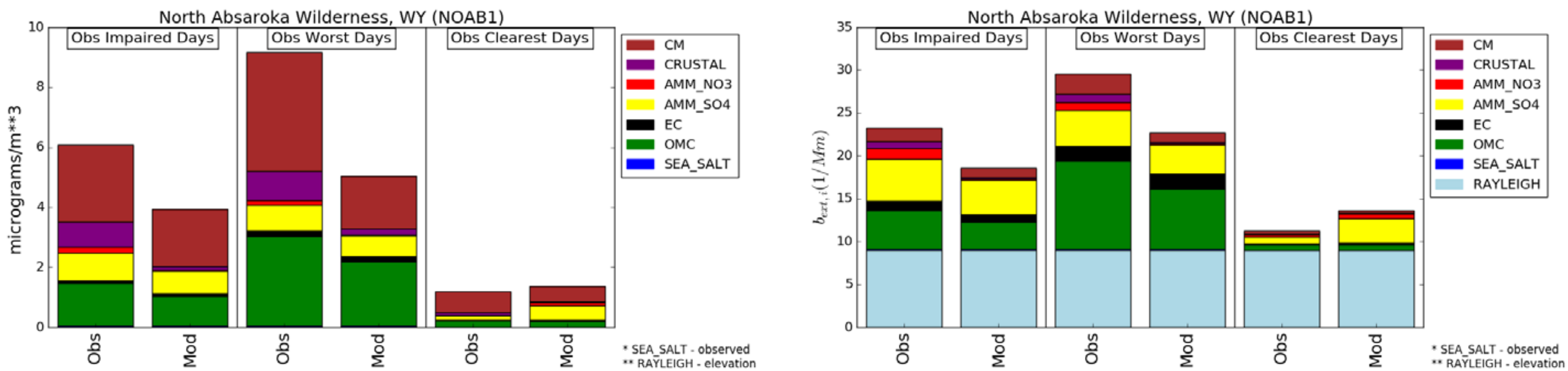


Figure 67: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the North Absaroka Wilderness (WY) and Washakie Wilderness (WY) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

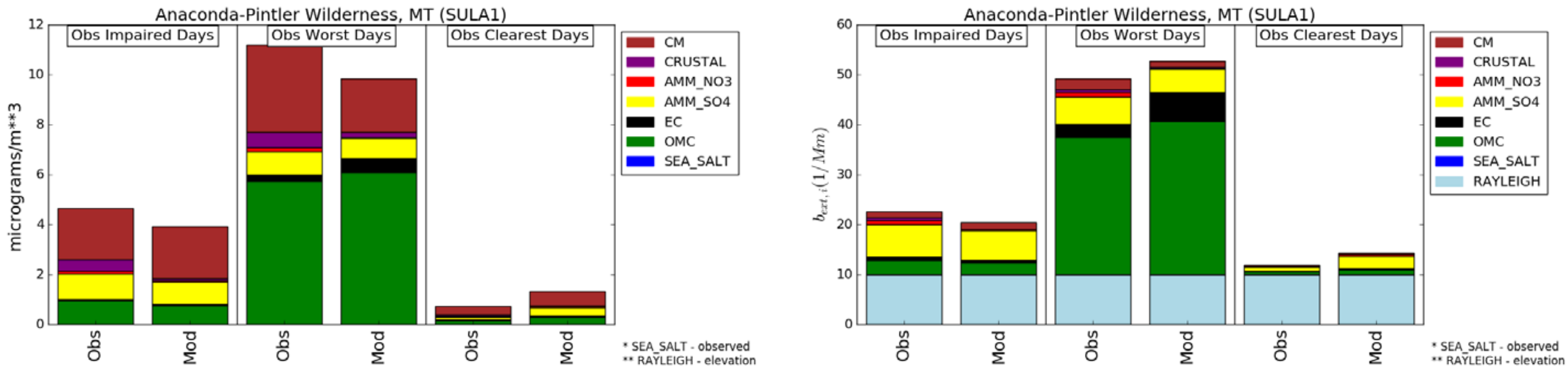


Figure 68: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Anaconda-Pintler Wilderness (MT) and Selway-Bitterroot Wilderness (MT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

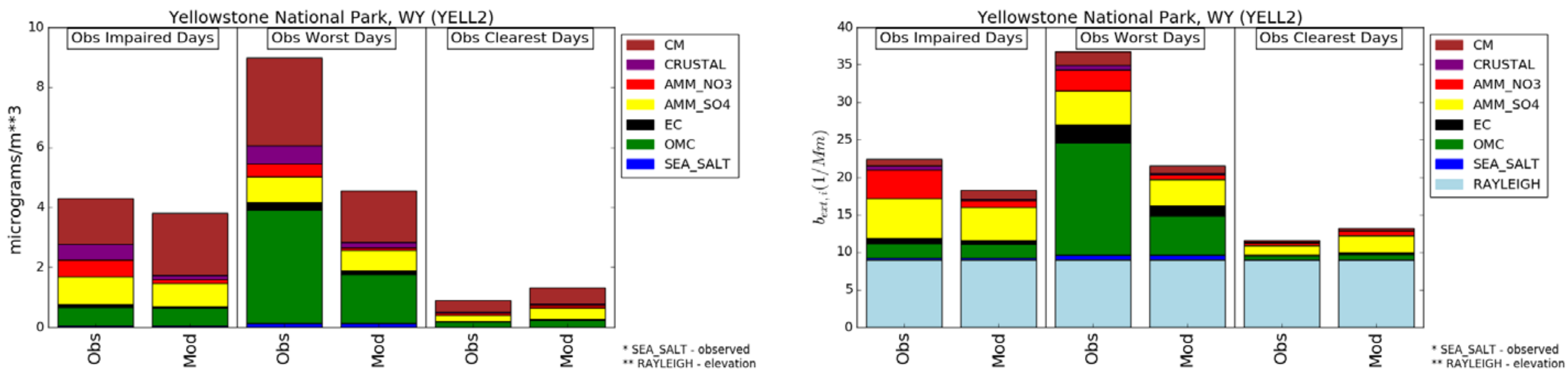


Figure 69: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Grand Teton National Park (WY), Red Rock Lakes (WY), Teton Wilderness (WY), and Yellowstone National Park (WY) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Hells Canyon

- Craters of the Moon National Monument (ID)(CRMO1)
- Hells Canyon Wilderness (OR)(HECA1)
- Sawtooth Wilderness (ID)(SAWT1)
- Eagle Cap Wilderness (OR) and Strawberry Mountain Wilderness (OR)(STAR1)

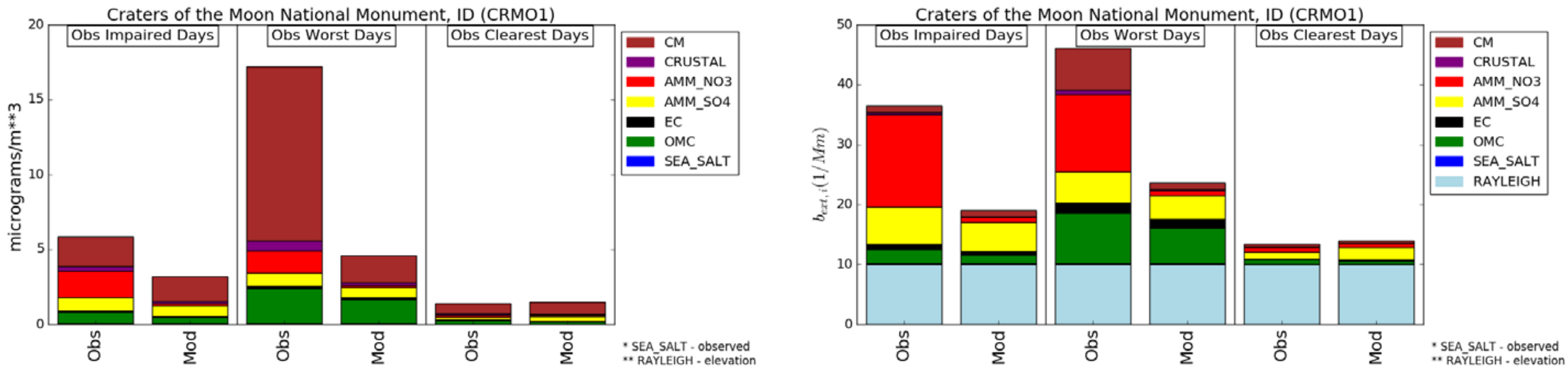


Figure 70: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Craters of the Moon National Monument (ID) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

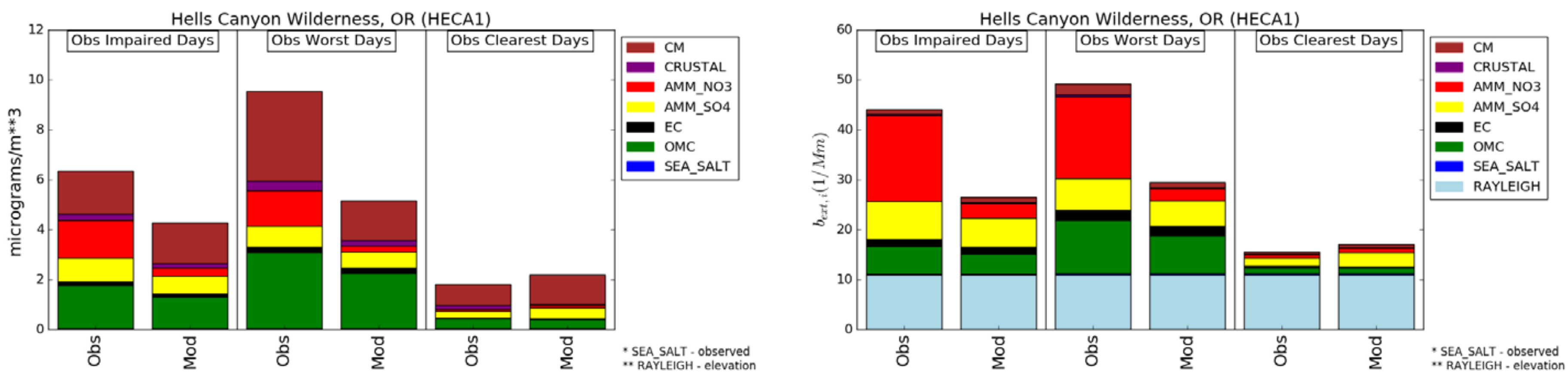


Figure 71: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Hells Canyon Wilderness (OR) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

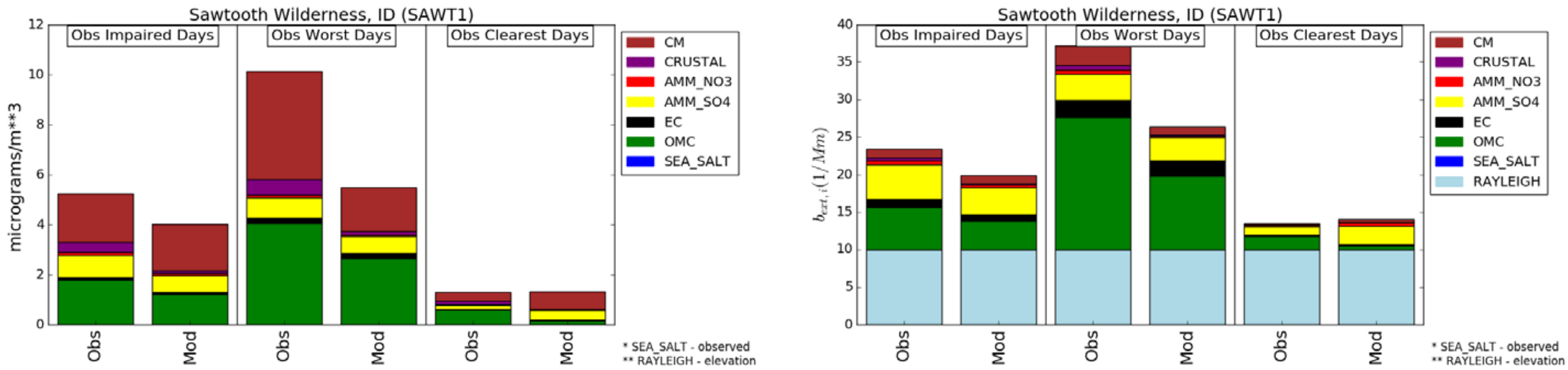


Figure 72: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Sawtooth Wilderness (ID) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

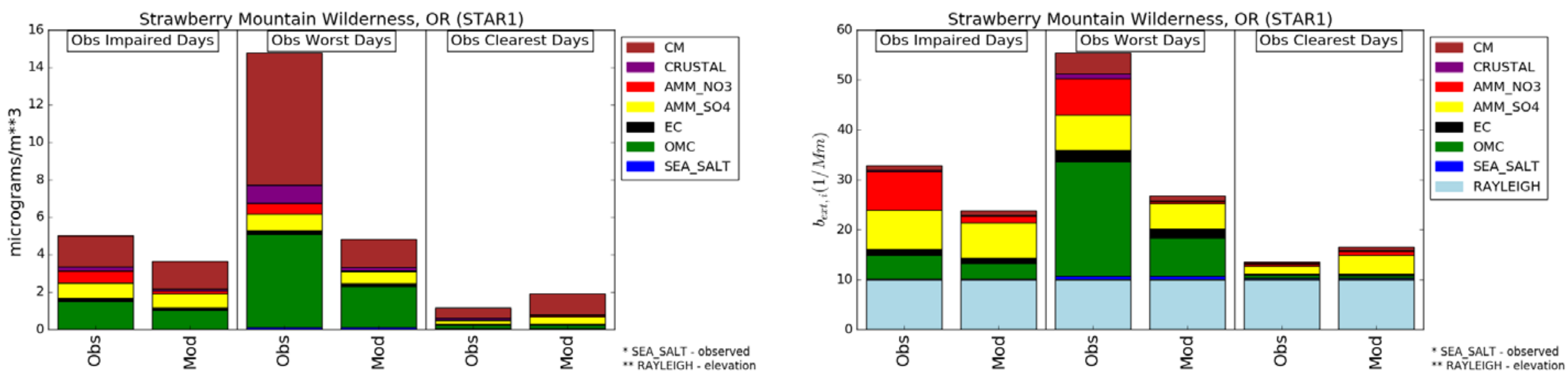
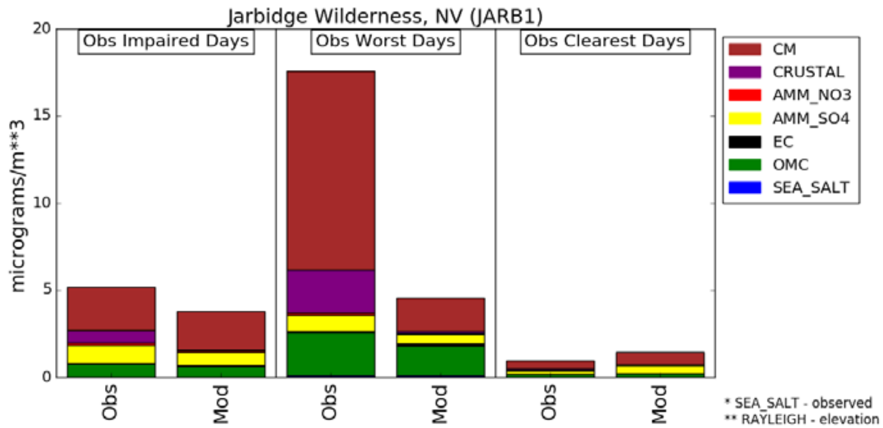


Figure 73: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Eagle Cap Wilderness (OR) and Strawberry Mountain Wilderness (OR) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Great Basin

- Jarbidge Wilderness (NV)(JARB1)



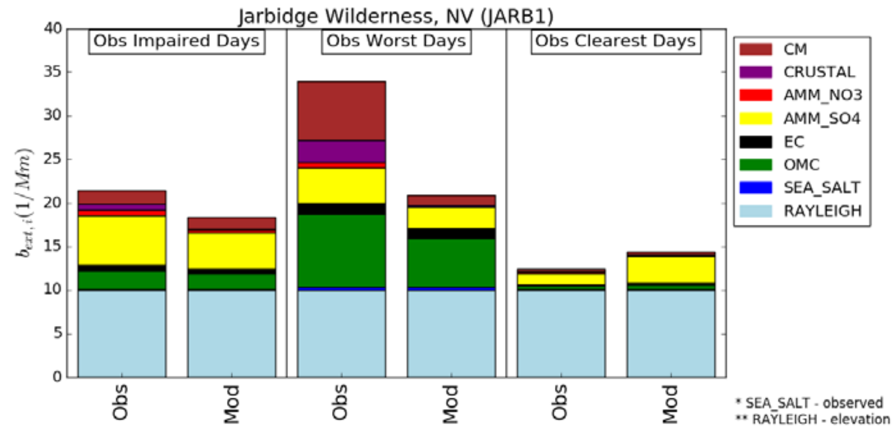


Figure 74: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Jarbidge Wilderness (NV) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Central Rocky Mountains

- Great Sand Dunes National Monument (CO)(GRSA1)
- Mount Zirkel Wilderness (CO) and Rawah Wilderness (CO)(MOZI1)
- Rocky Mountain National Park (CO)(ROMO1)
- Pecos Wilderness (NM) and Wheeler Peak Wilderness (NM)(WHPE1)
- Eagles Nest Wilderness (CO), Flat Tops Wilderness (CO), Maroon Bells-Snowmass Wilderness (CO), and West Elk Wilderness (CO)(WHRI1)

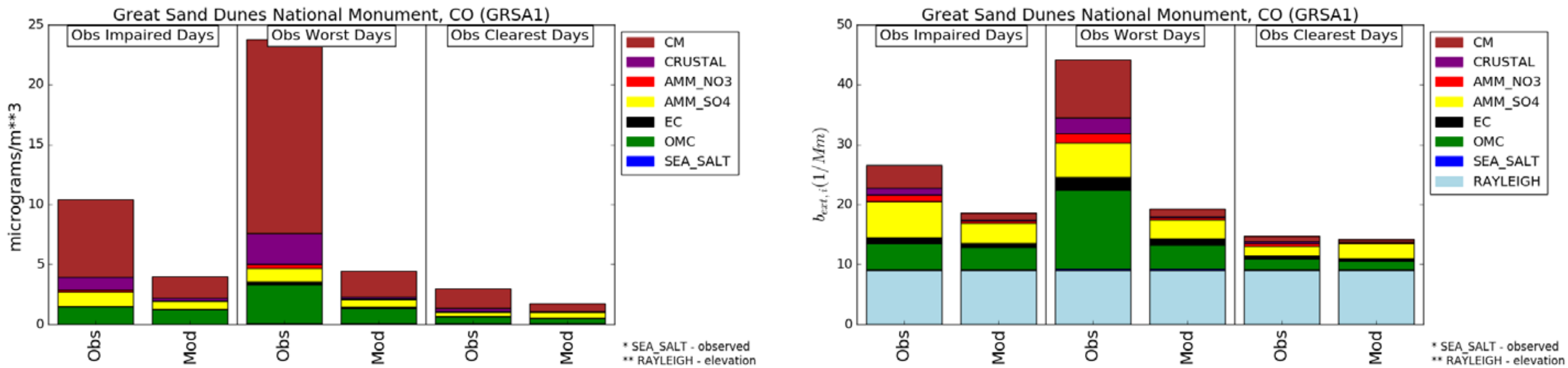


Figure 75: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Great Sand Dunes National Monument (CO) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

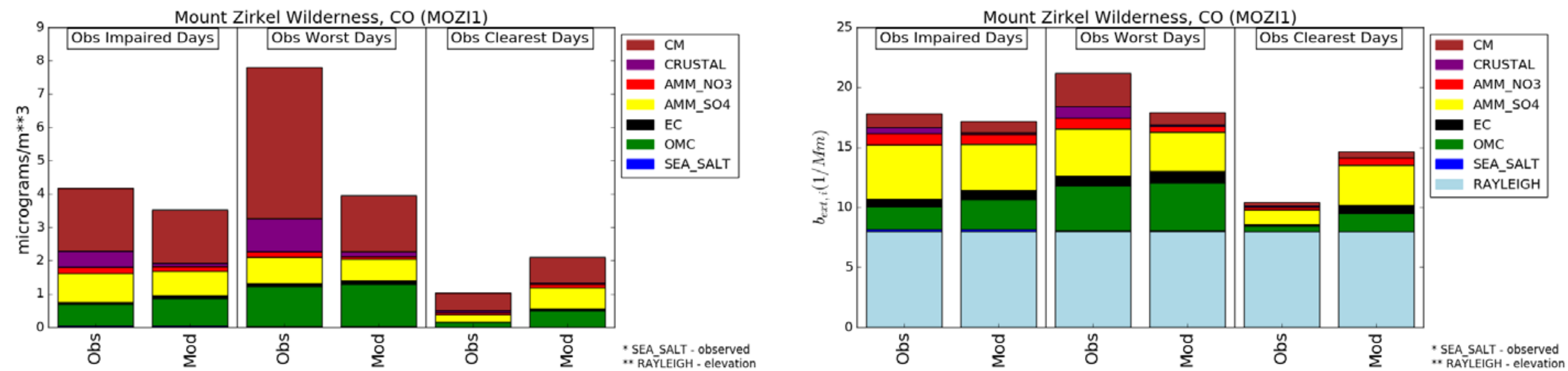


Figure 76: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Mount Zirkel Wilderness (CO) and Rawah Wilderness (CO) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

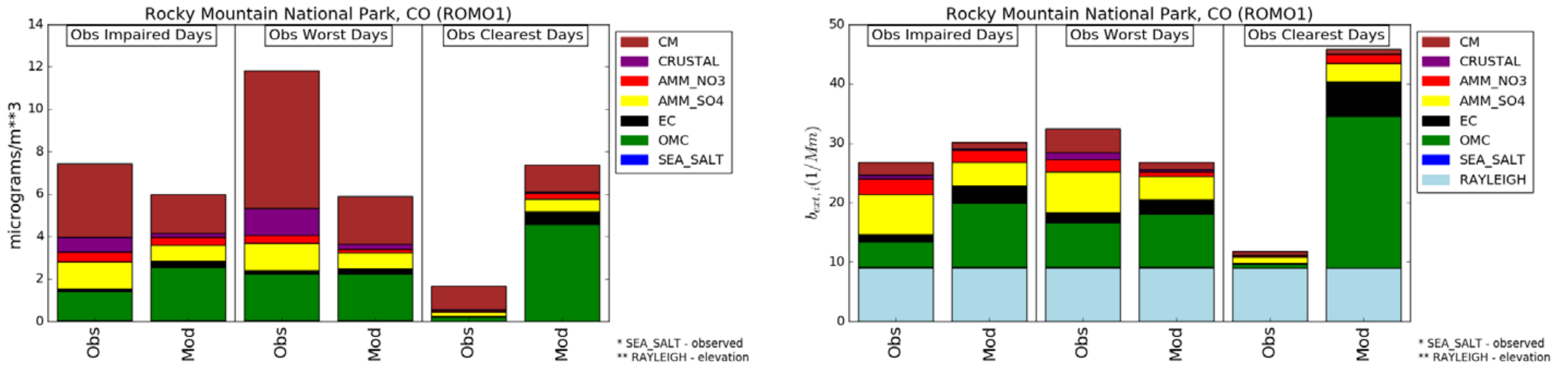


Figure 77: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Rocky Mountain National Park (CO) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

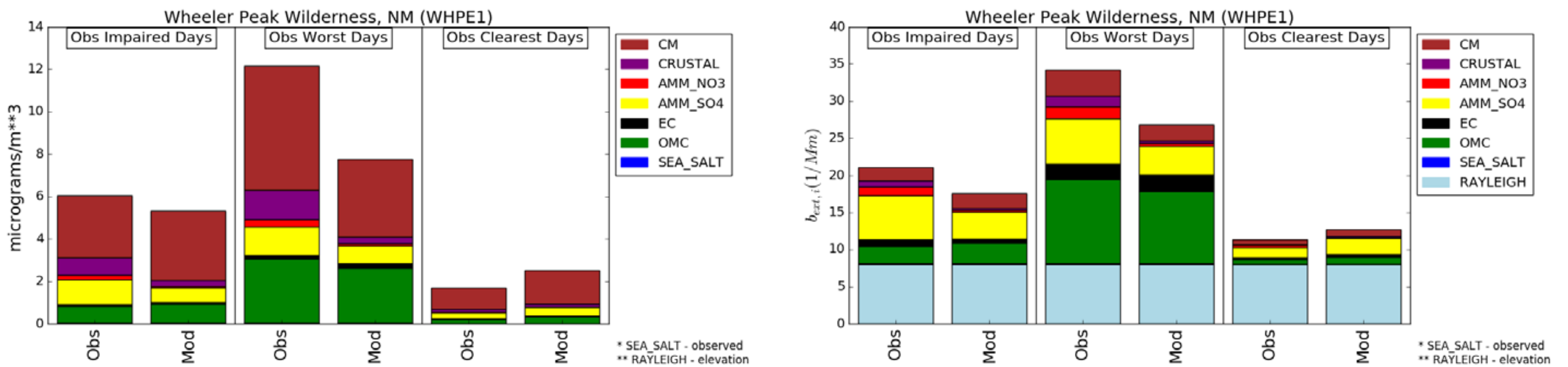
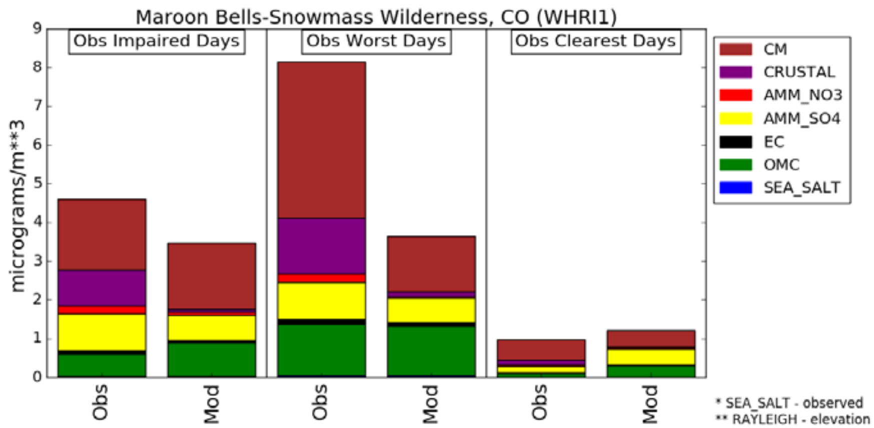


Figure 78: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Pecos Wilderness (NM) and Wheeler Peak Wilderness (NM) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.



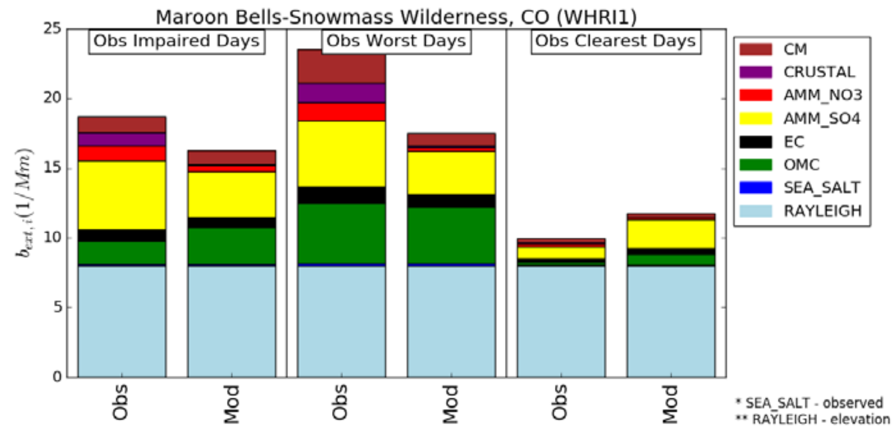


Figure 79: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Eagles Nest Wilderness (CO), Flat Tops Wilderness (CO), Maroon Bells-Snowmass Wilderness (CO), and West Elk Wilderness (CO) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Colorado Plateau

- Bandelier National Monument (NM)(BAND1)
- Bryce Canyon National Park (UT)(BRCA1)
- Arches National Park (UT) and Canyonlands National Park (UT)(CANY1)
- Capitol Reef National Park (UT)(CAPI1)
- Grand Canyon National Park (AZ)(GRCA2)
- Mesa Verde National Park (CO)(MEVE1)
- San Pedro Parks Wilderness (NM)(SAPE1)
- Black Canyon of the Gunnison National Monument (CO), La Garita Wilderness (CO), and Weminuche Wilderness (CO)(WEMI1)
- Zion National Park (UT)(ZICA1)

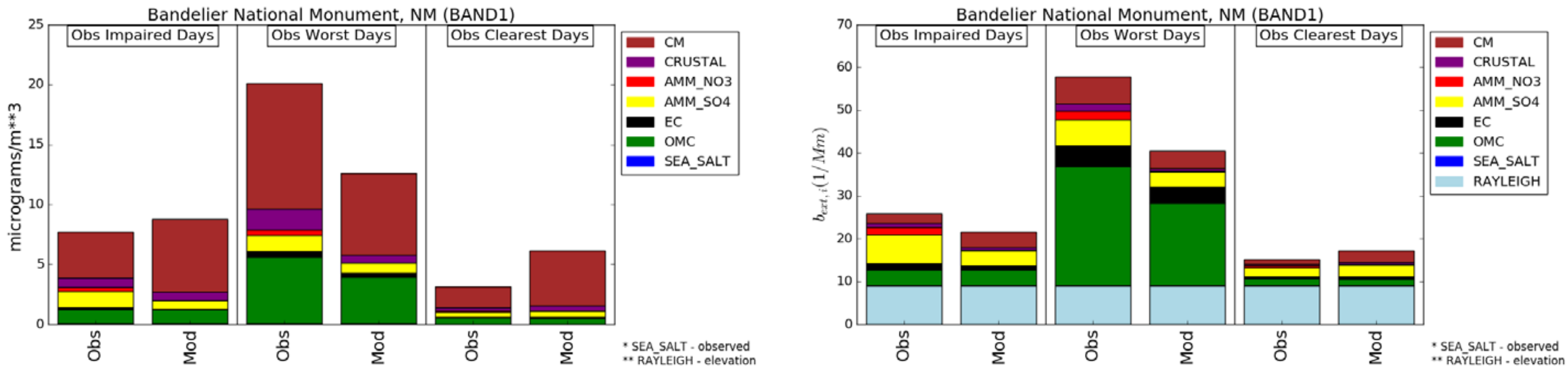


Figure 80: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Bandelier National Monument (NM) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

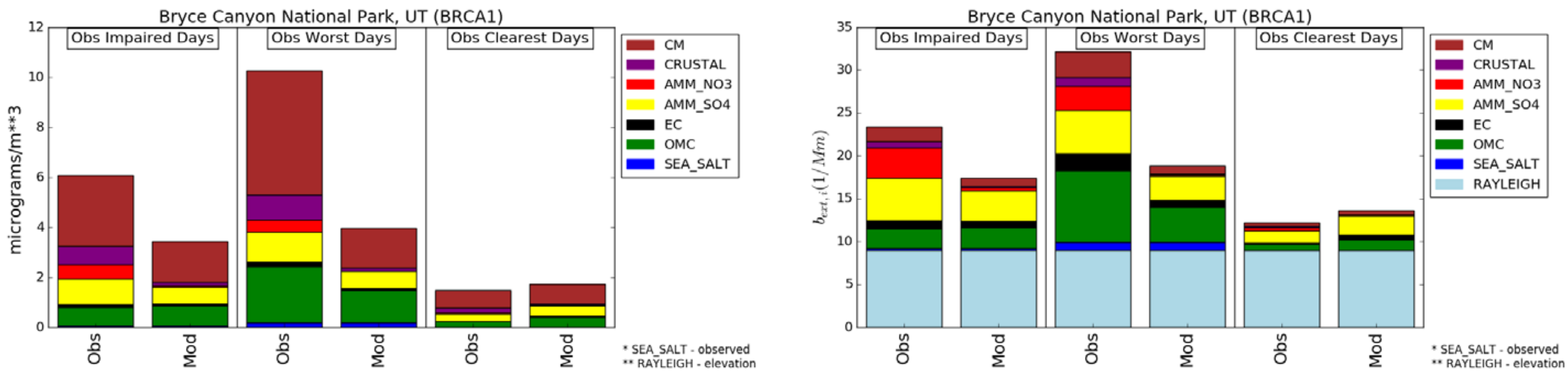


Figure 81: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Bryce Canyon National Park (UT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

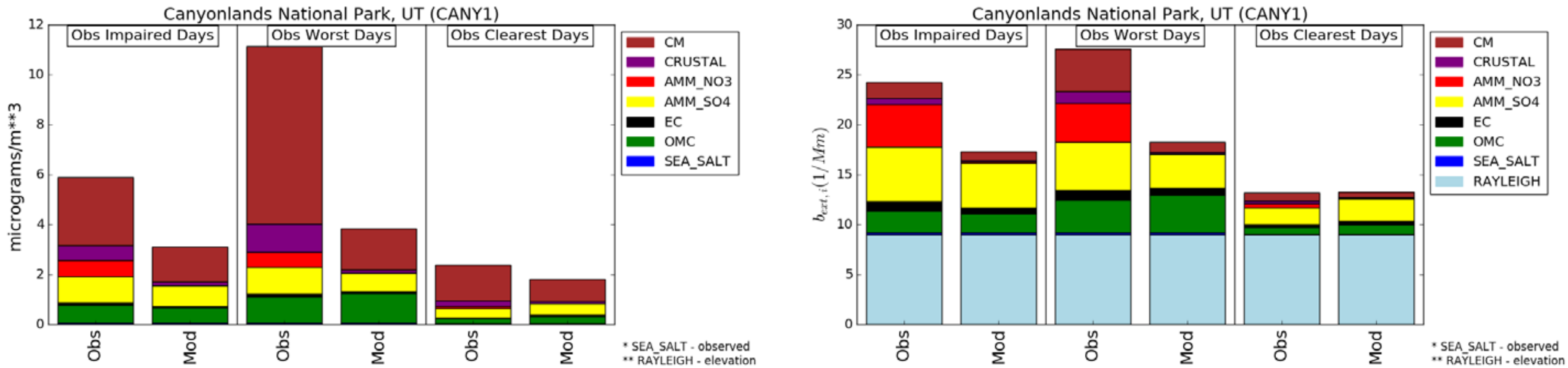


Figure 82: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Arches National Park (UT) and Canyonlands National Park (UT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

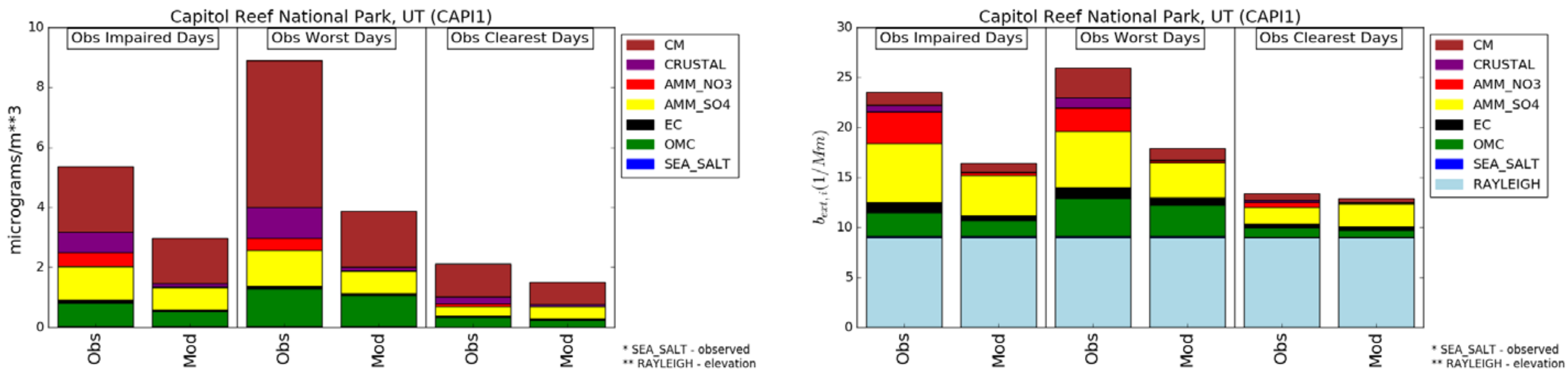
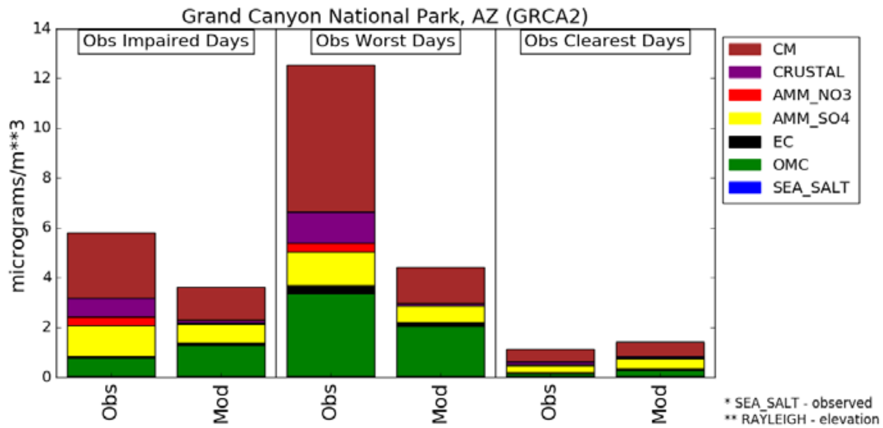


Figure 83: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Capitol Reef National Park (UT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.



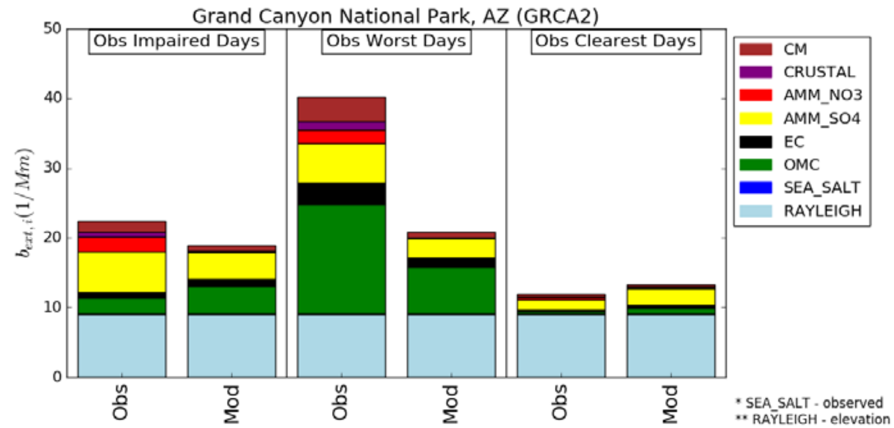
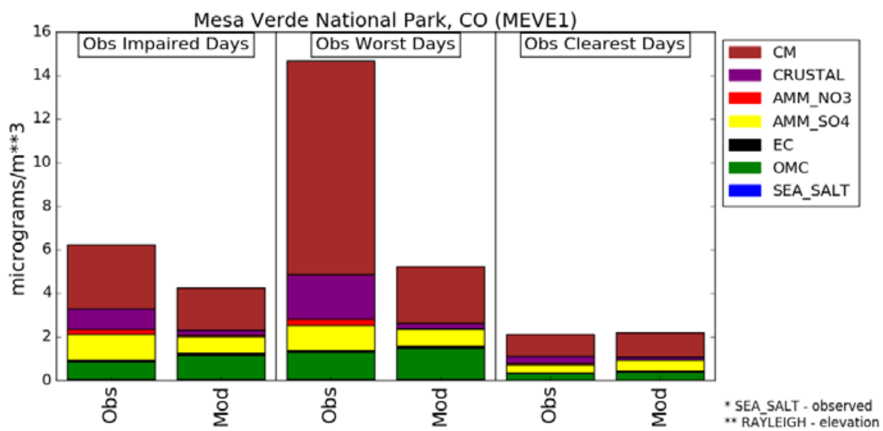


Figure 84: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Grand Canyon National Park (AZ) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.



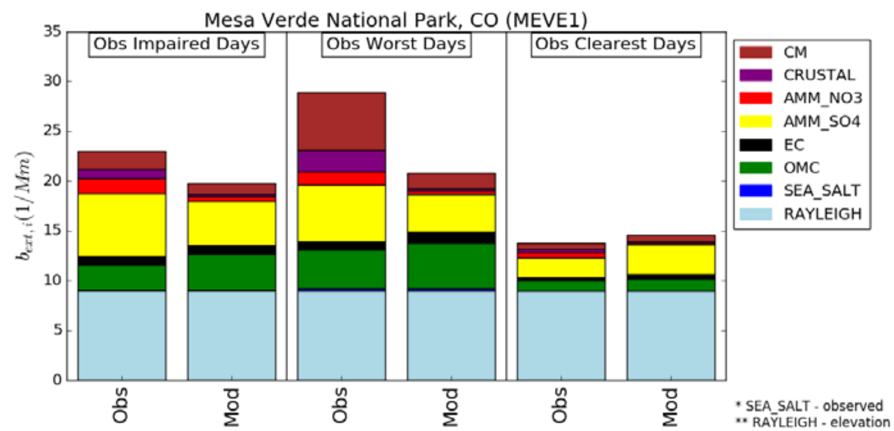


Figure 85: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Mesa Verde National Park (CO) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

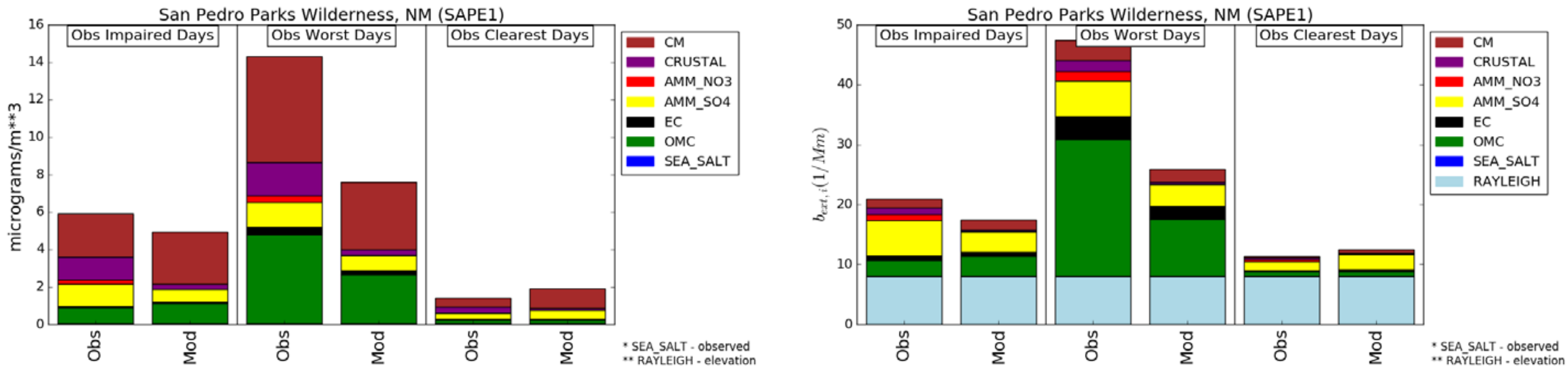


Figure 86: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the San Pedro Parks Wilderness (NM) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

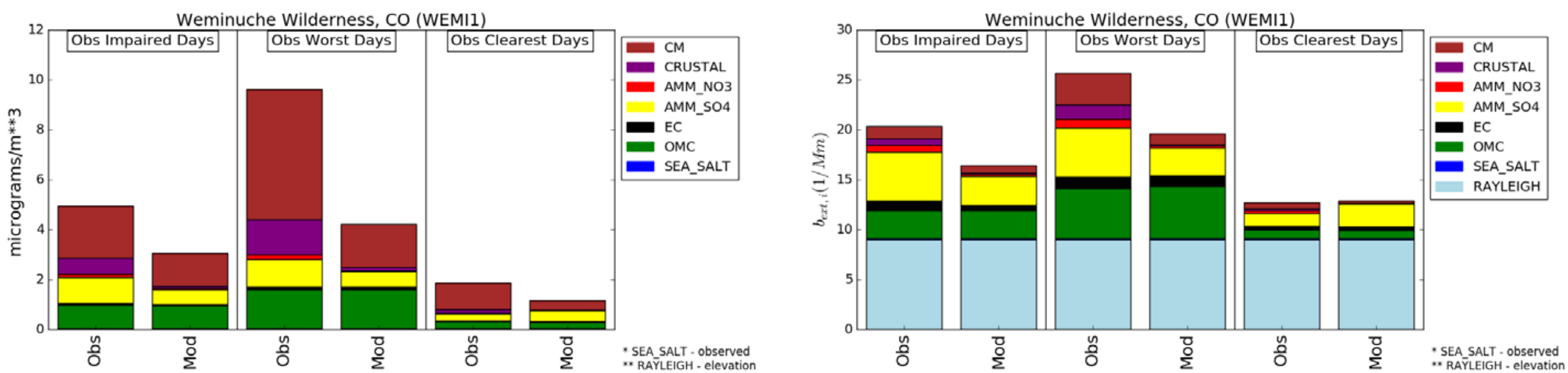
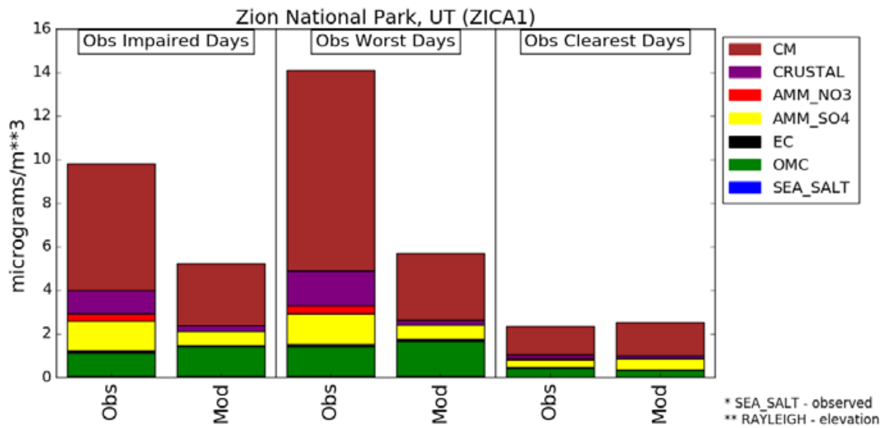


Figure 87: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Black Canyon of the Gunnison National Monument (CO), La Garita Wilderness (CO), and Weminuche Wilderness (CO) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.



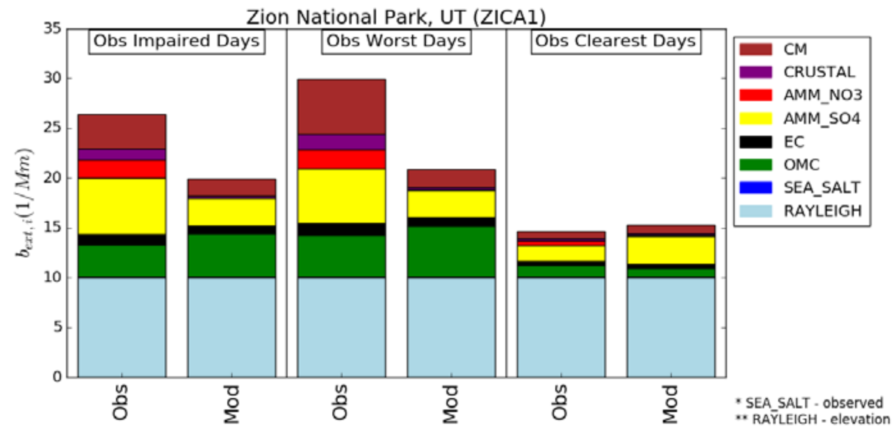


Figure 88: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Zion National Park (UT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Mogollon Plateau

- Mount Baldy Wilderness (AZ)(BALD1)
- Bosque del Apache (NM)(BOAP1)
- Gila Wilderness (NM)(GICL1)
- Mazatzal Wilderness (AZ) and Pine Mountain Wilderness (AZ)(IKBA1)
- Petrified Forest National Park (AZ)(PEFO1)
- Sierra Ancha Wilderness (AZ)(SIAN1)
- Sycamore Canyon Wilderness (AZ)(SYCA2)
- Superstition Wilderness (AZ)(TONT1)
- White Mountain Wilderness (NM)(WHIT1)

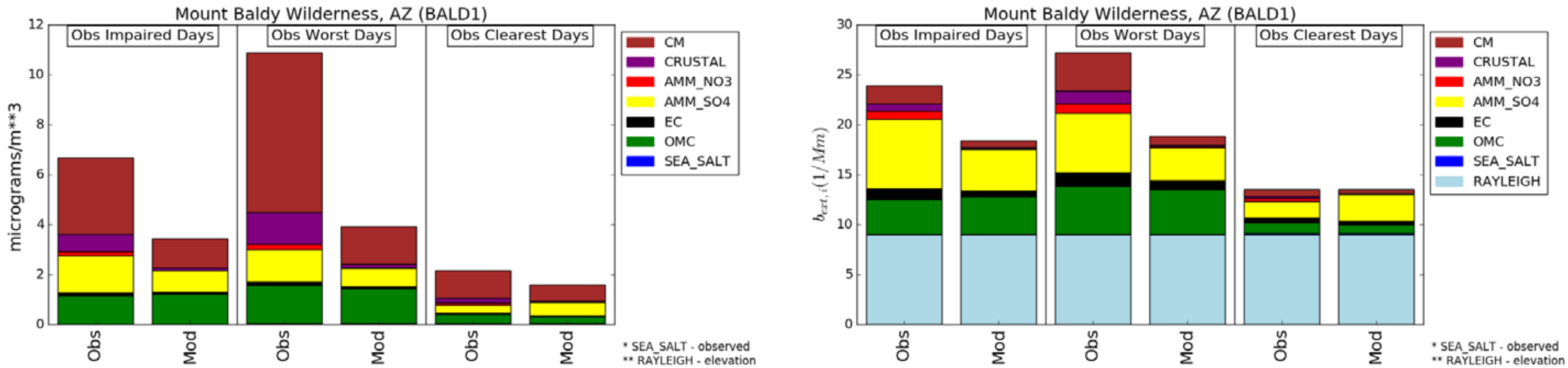


Figure 89: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Mount Baldy Wilderness (AZ) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

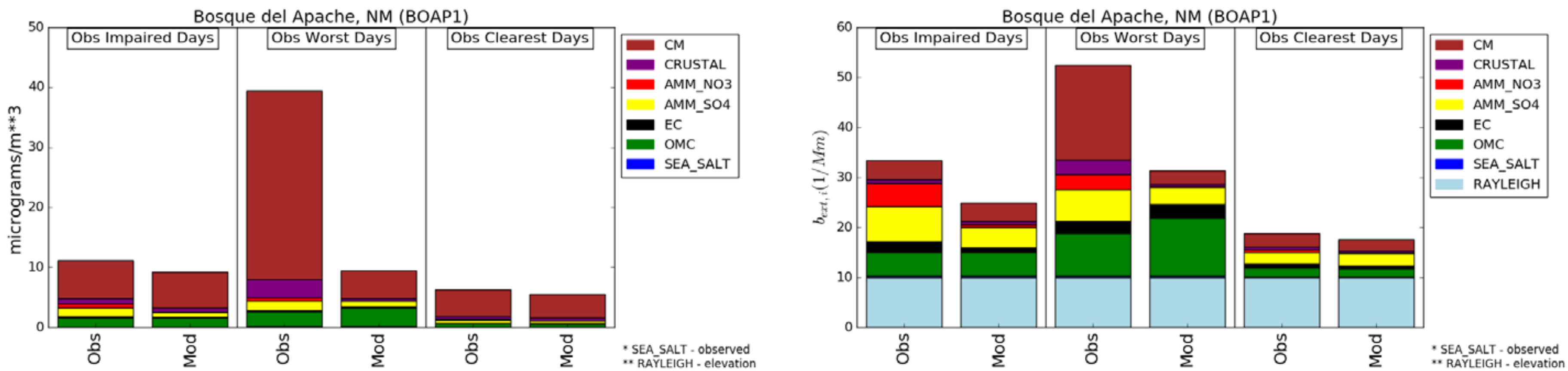


Figure 90: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Bosque del Apache (NM) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

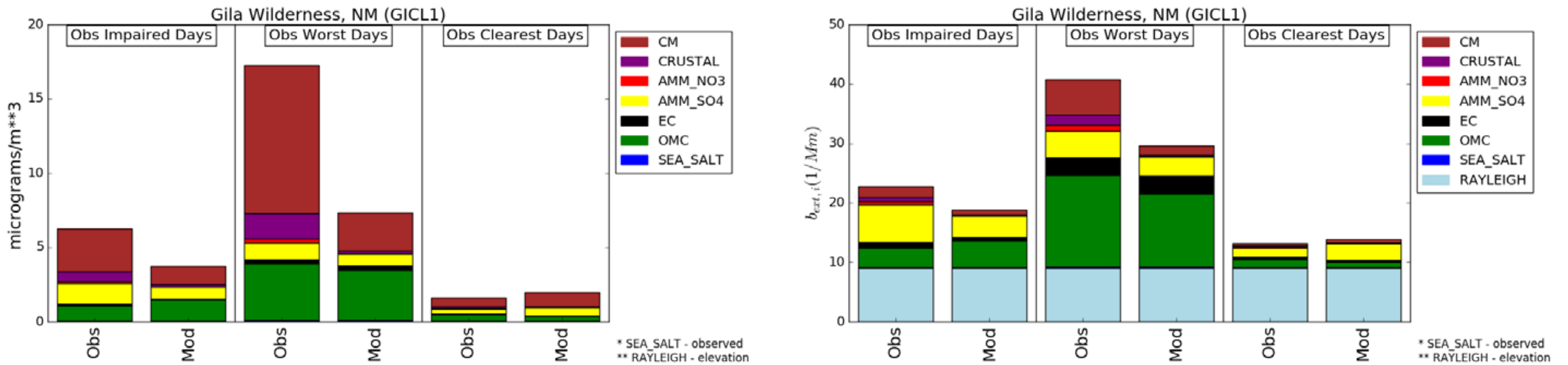


Figure 91: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Gila Wilderness (NM) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

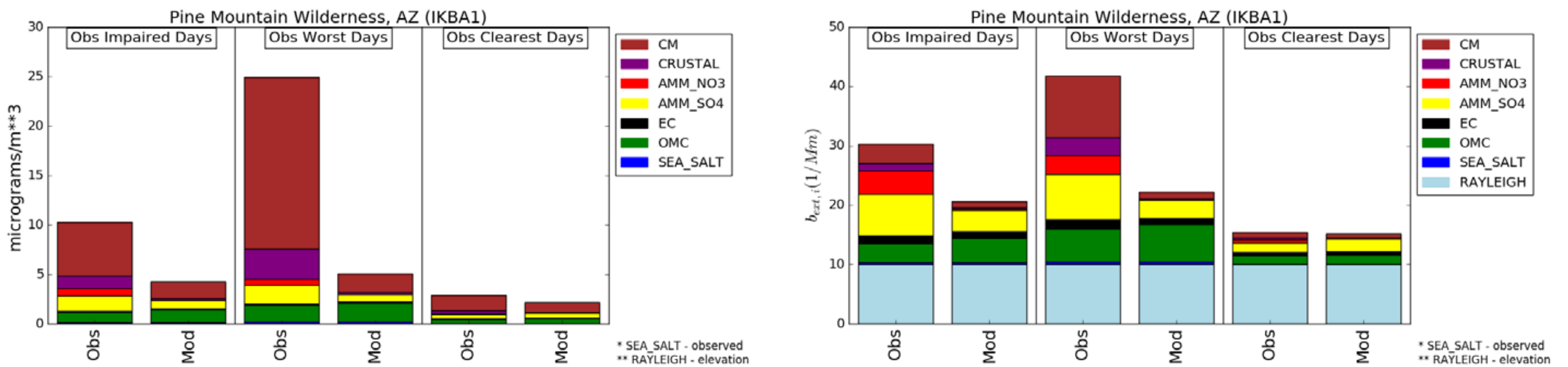


Figure 92: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Mazatzal Wilderness (AZ) and Pine Mountain Wilderness (AZ) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

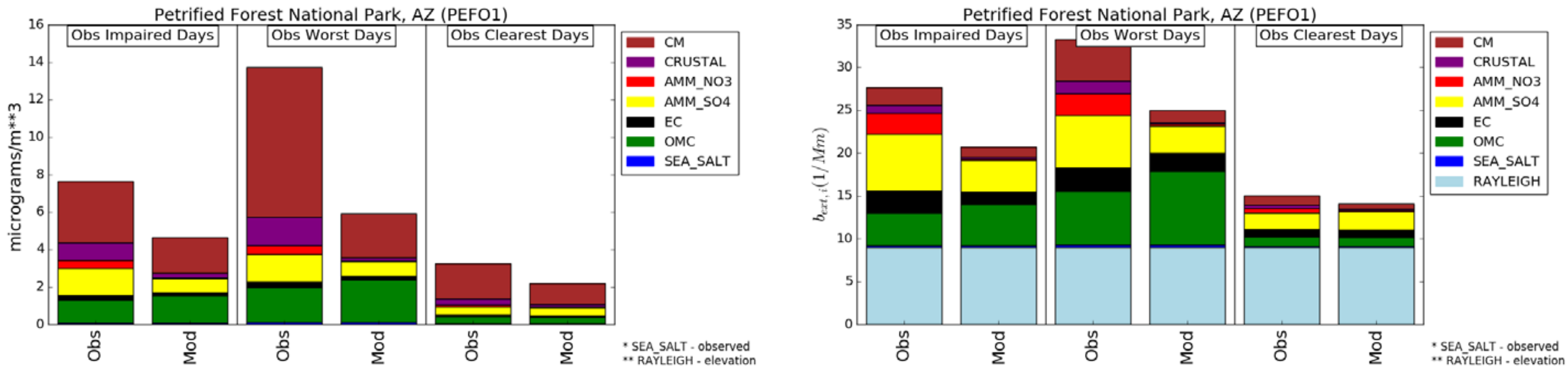


Figure 93: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Petrified Forest National Park (AZ) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

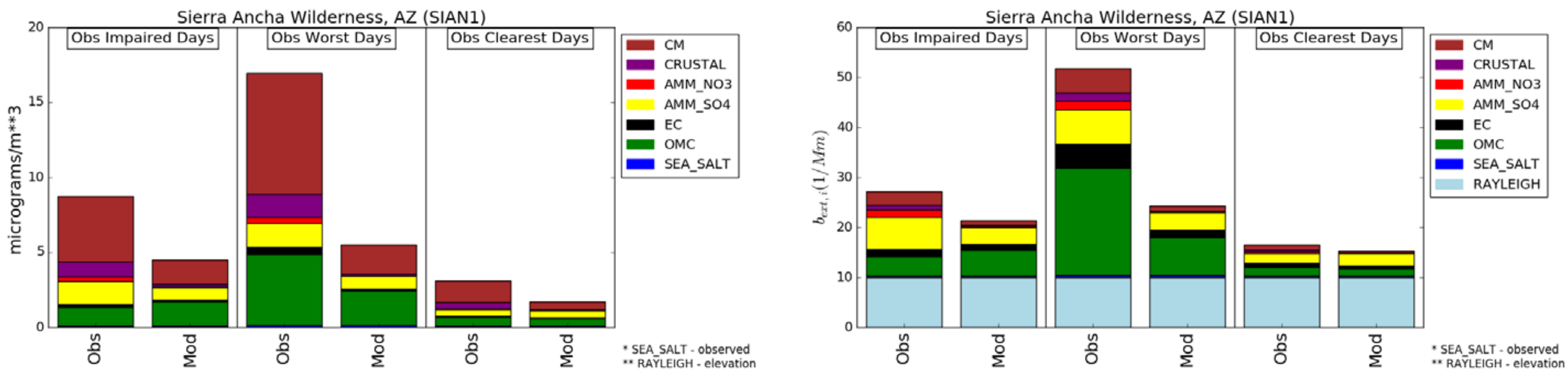


Figure 94: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Sierra Ancha Wilderness (AZ) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

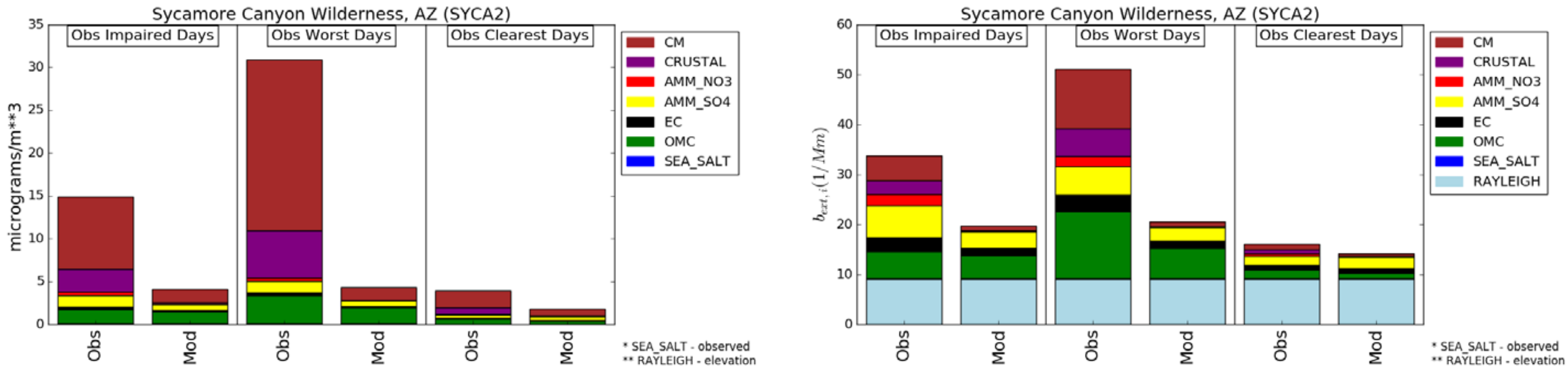


Figure 95: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Sycamore Canyon Wilderness (AZ) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

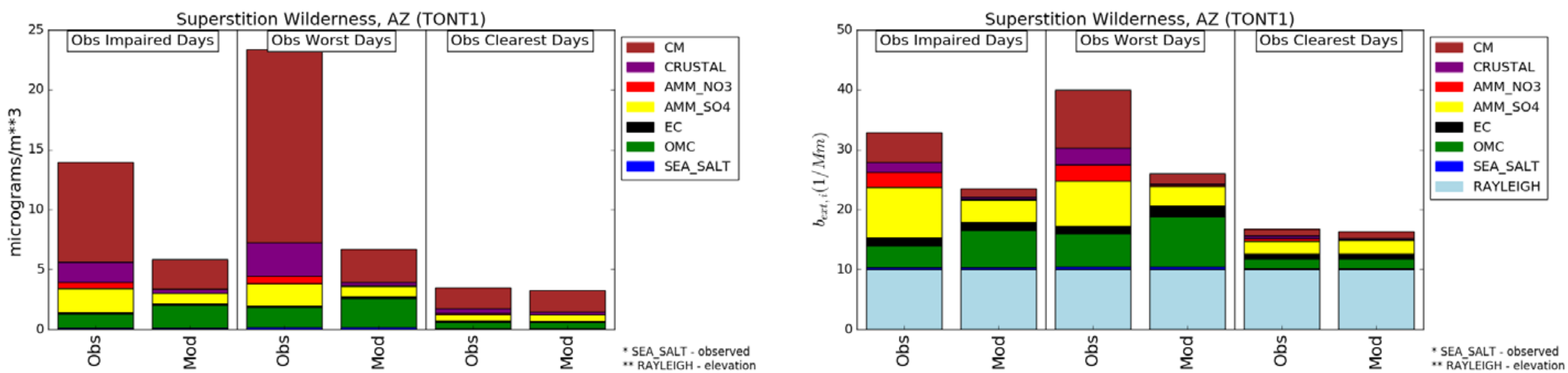


Figure 96: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Superstition Wilderness (AZ) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

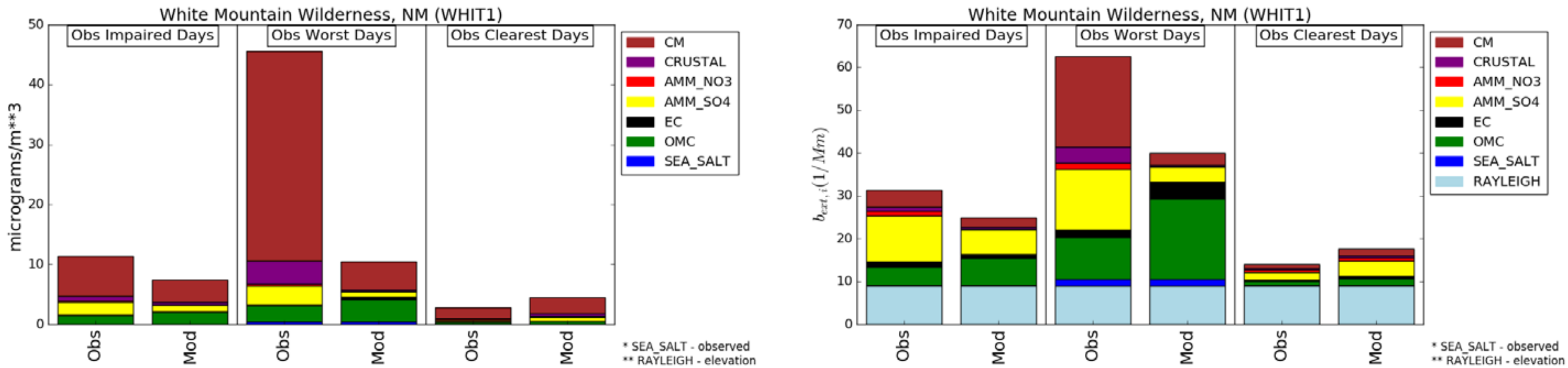


Figure 97: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the White Mountain Wilderness (NM) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Southern Arizona

- Chiricahua National Monument (AZ), Chiricahua Wilderness (AZ), and Galiuro Wilderness (AZ)(CHIR1)
- Saguaro National Monument (AZ)(SAGU1)

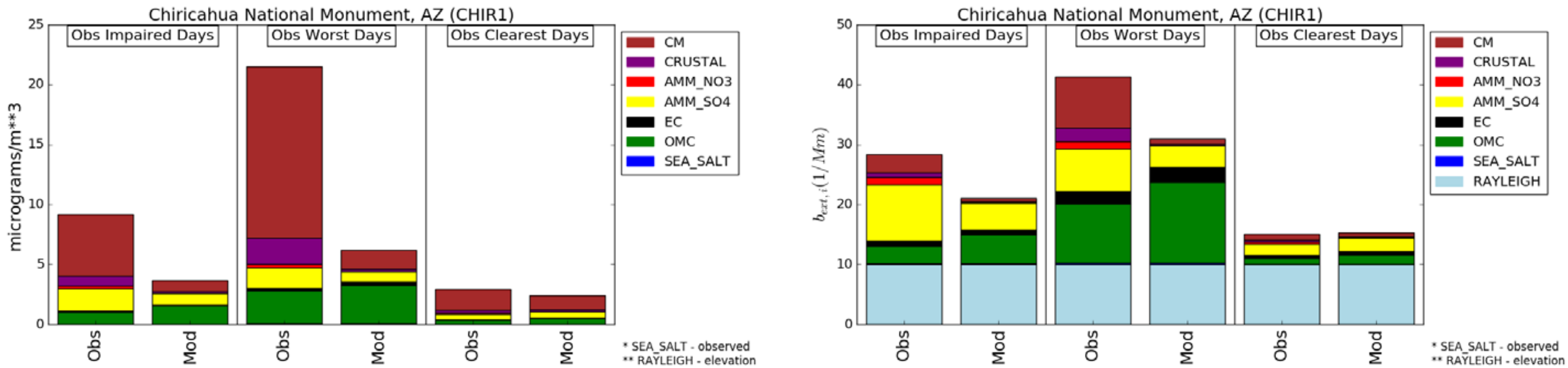


Figure 98: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Chiricahua National Monument (AZ), Chiricahua Wilderness (AZ), and Galiuro Wilderness (AZ) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

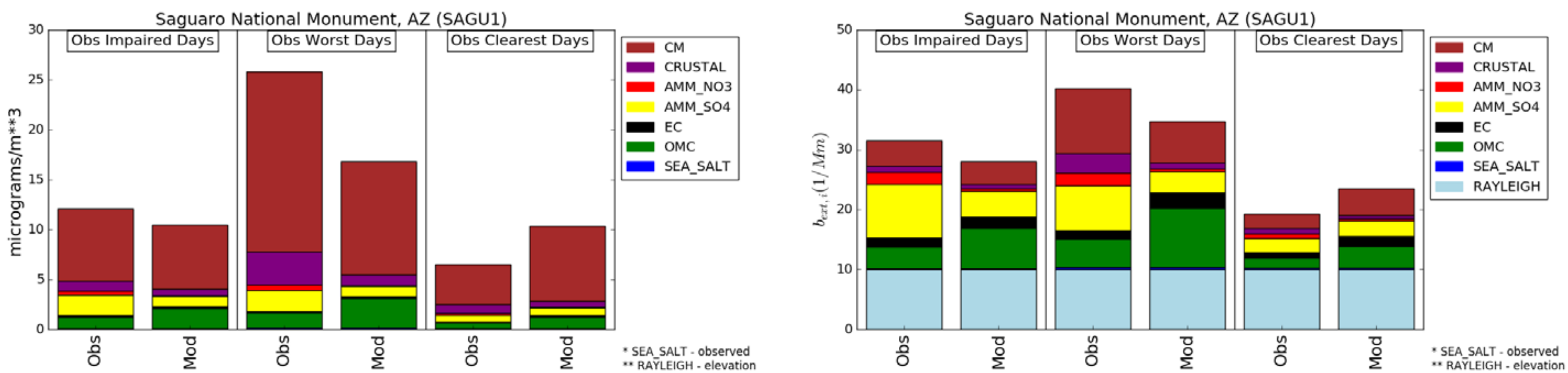


Figure 99: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Saguaro National Monument (AZ) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

West Texas

- Big Bend National Park (TX)(BIBE1)
- Carlsbad Caverns National Park (TX) and Guadalupe Mountains National Park (TX)(GUMO1)
- Salt Creek (NM)(SACR1)

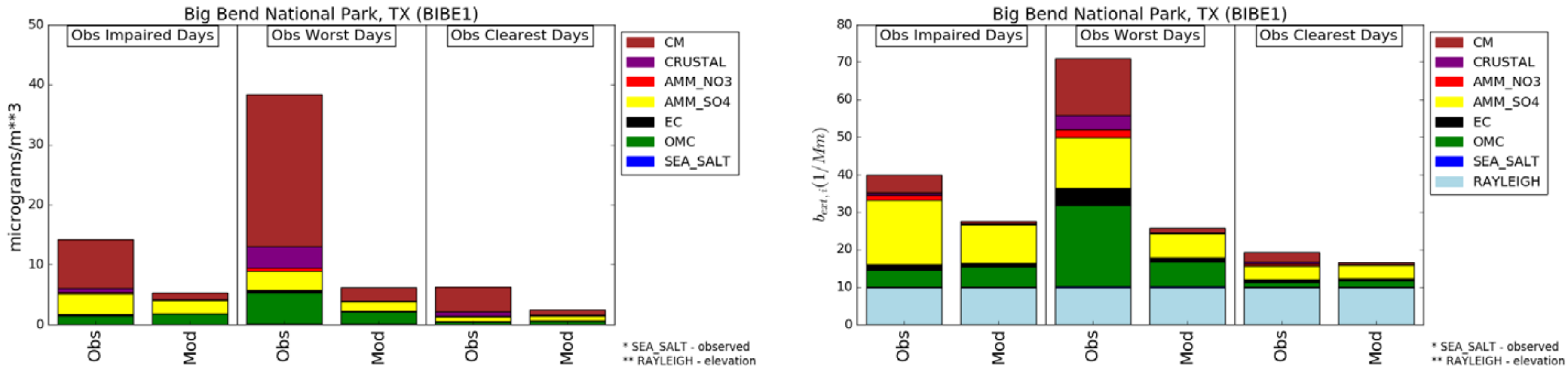


Figure 100: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Big Bend National Park (TX) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

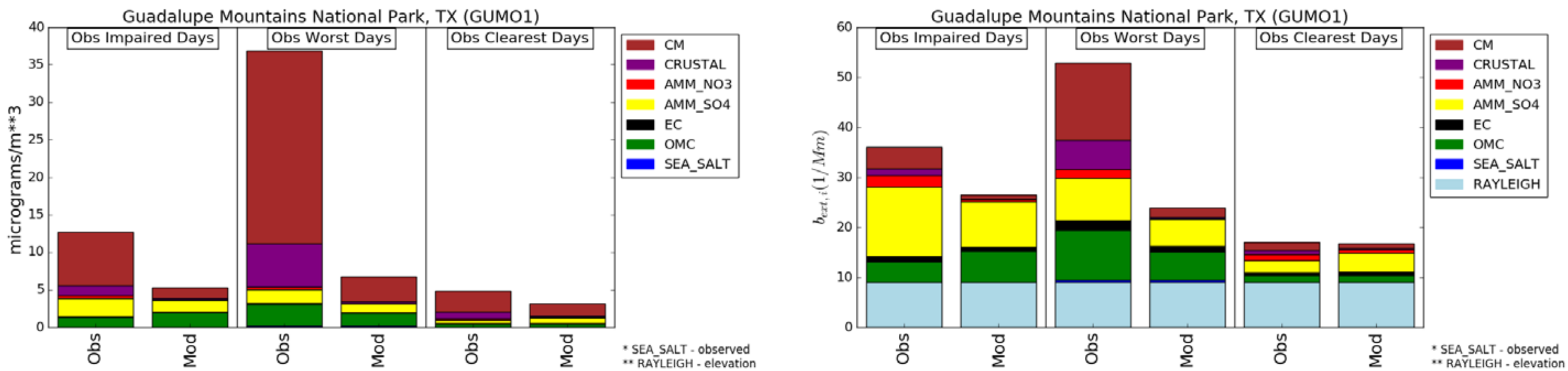
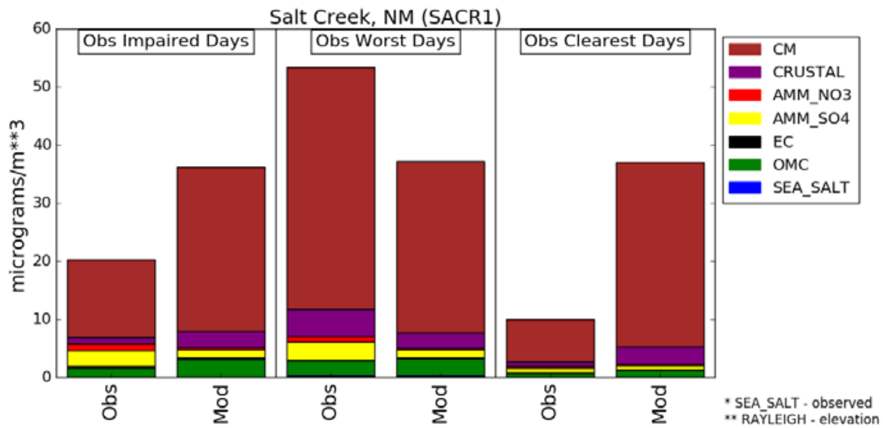


Figure 101: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Carlsbad Caverns National Park (TX) and Guadalupe Mountains National Park (TX) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.



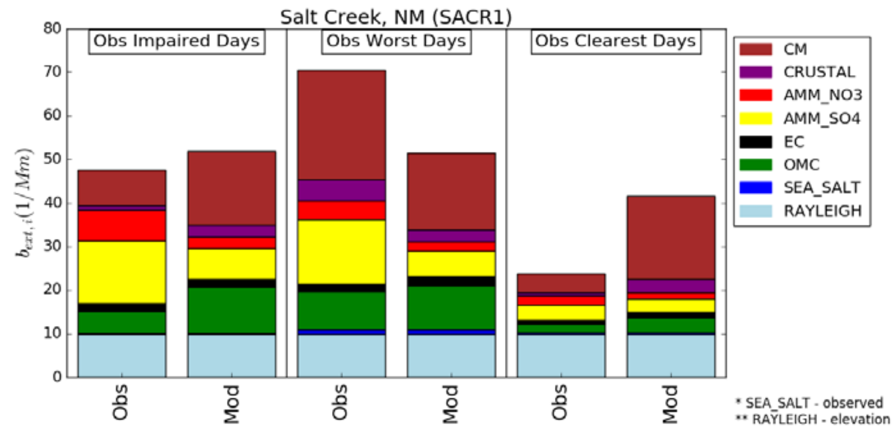


Figure 102: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Salt Creek (NM) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Northern Great Plains

- Badlands National Park (SD)(BADL1)
- Lostwood (ND)(LOST1)
- Medicine Lake (MT)(MELA1)
- Theodore Roosevelt National Park (ND)(THRO1)
- UL Bend (MT)(ULBE1)
- Wind Cave National Park (SD)(WICA1)

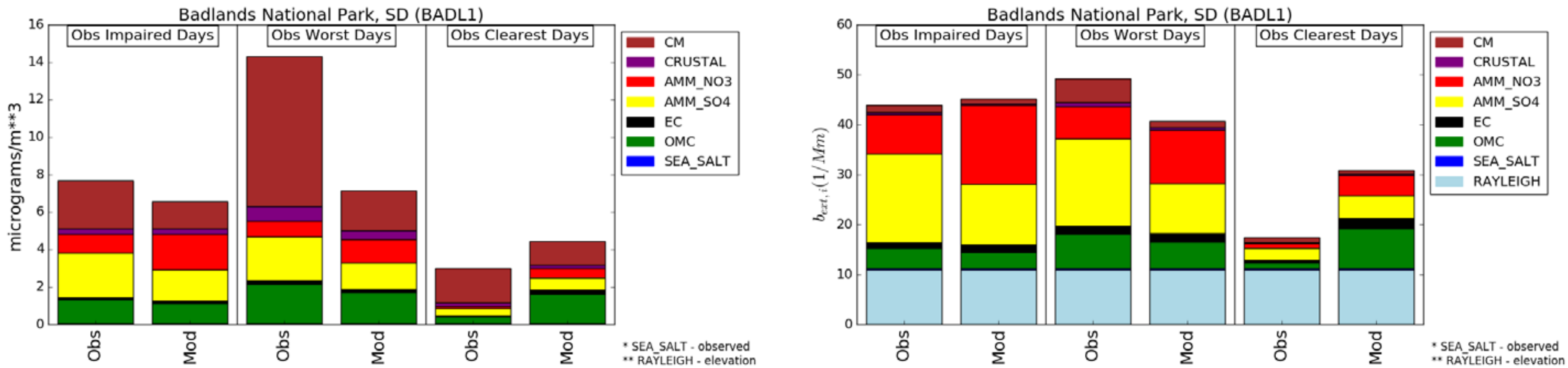


Figure 103: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Badlands National Park (SD) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

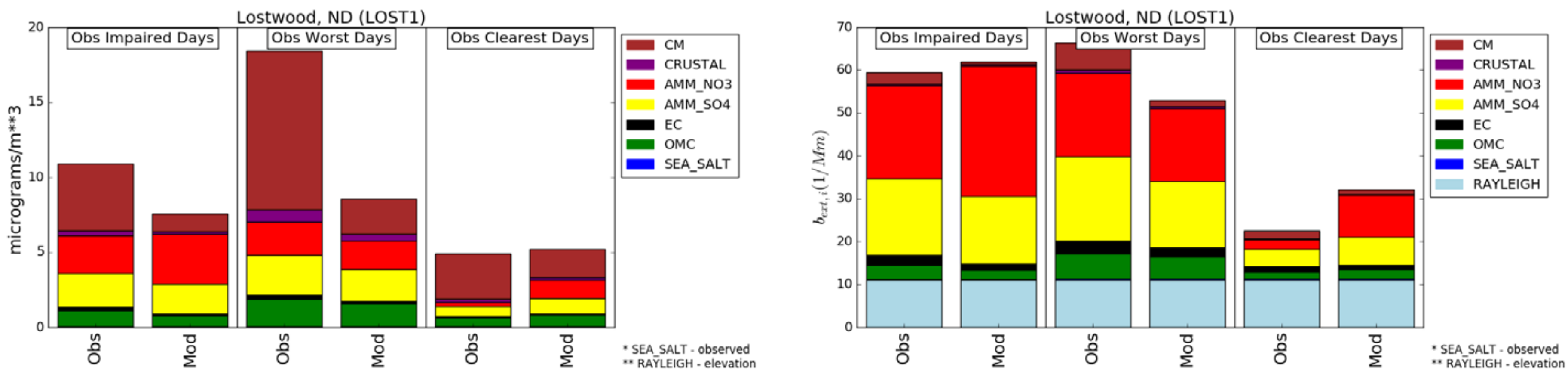
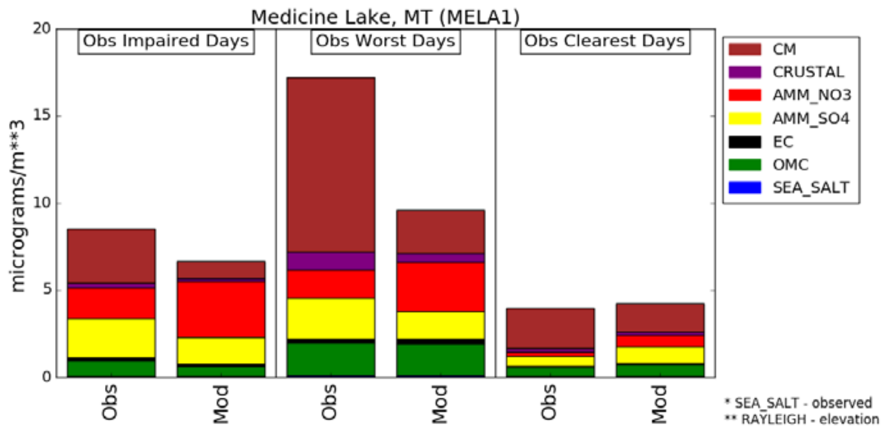


Figure 104: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Lostwood (ND) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.



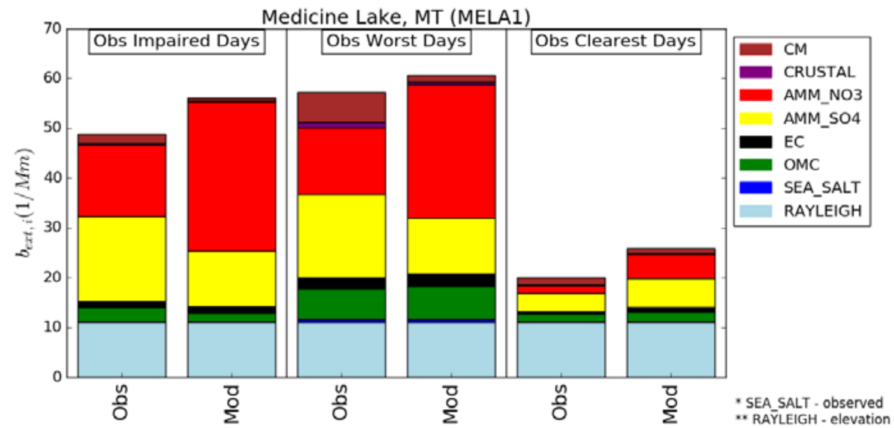
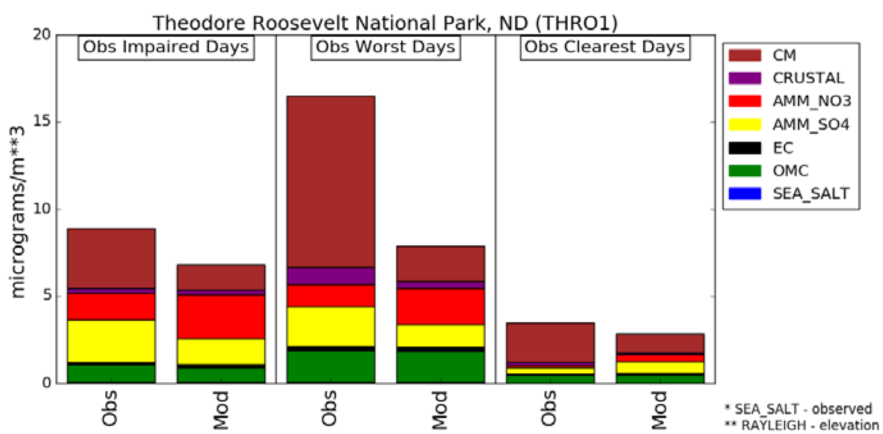


Figure 105: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Medicine Lake (MT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.



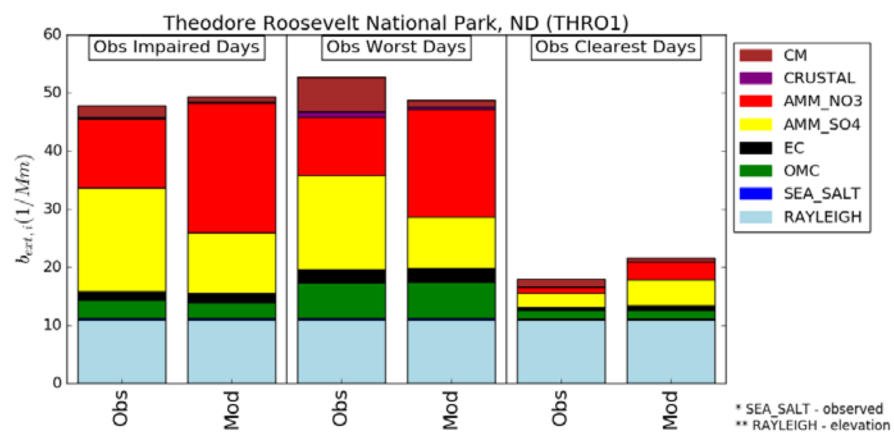


Figure 106: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Theodore Roosevelt National Park (ND) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

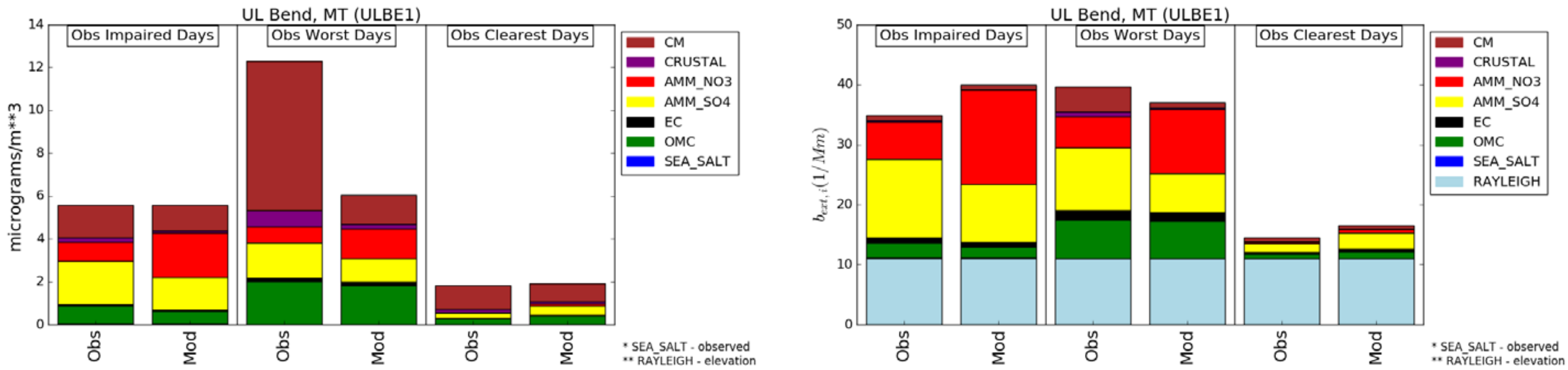


Figure 107: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the UL Bend (MT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

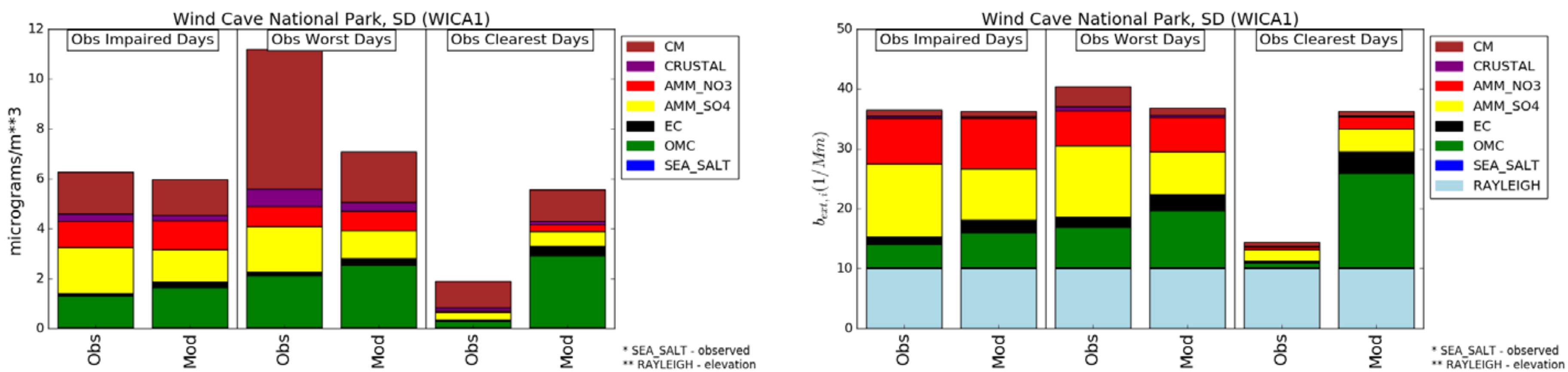


Figure 108: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Wind Cave National Park (SD) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Mid South

- Caney Creek Wilderness (AR)(CACR1)
- Hercules-Glades Wilderness (MO)(HEGL1)
- Upper Buffalo Wilderness (AR)(UPBU1)
- Wichita Mountains (OK)(WIMO1)

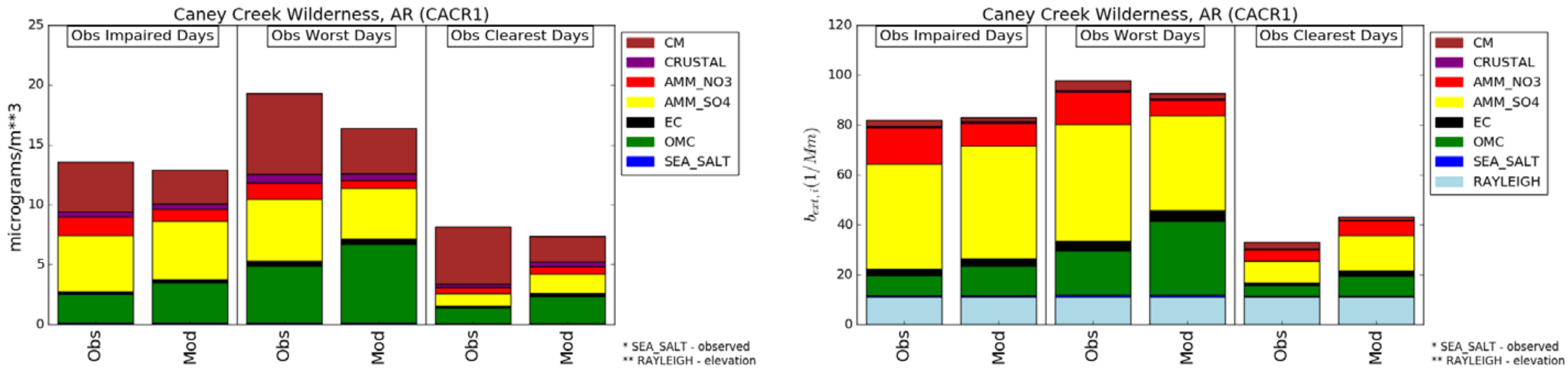


Figure 109: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Caney Creek Wilderness (AR) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

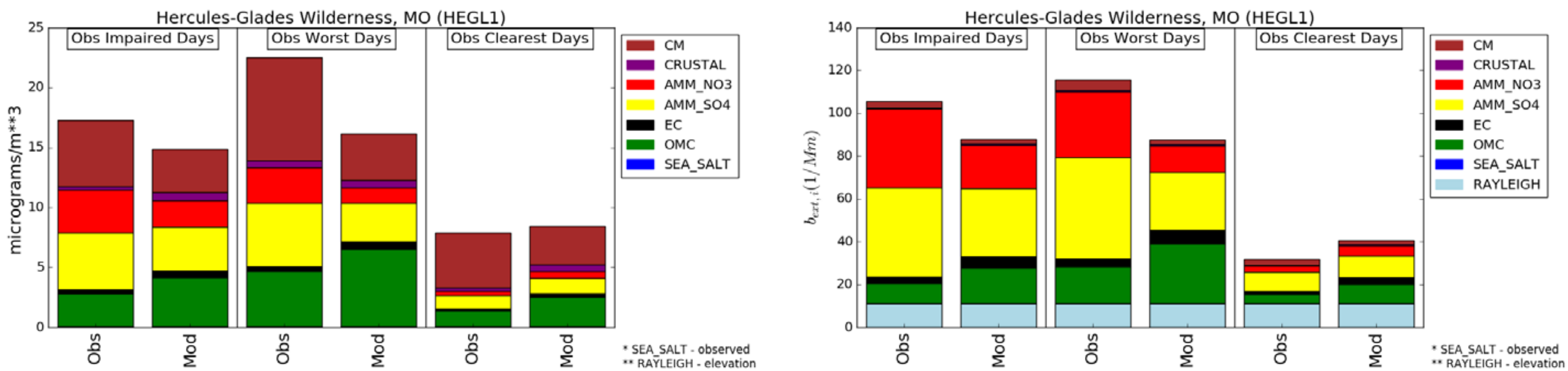


Figure 110: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Hercules-Glades Wilderness (MO) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

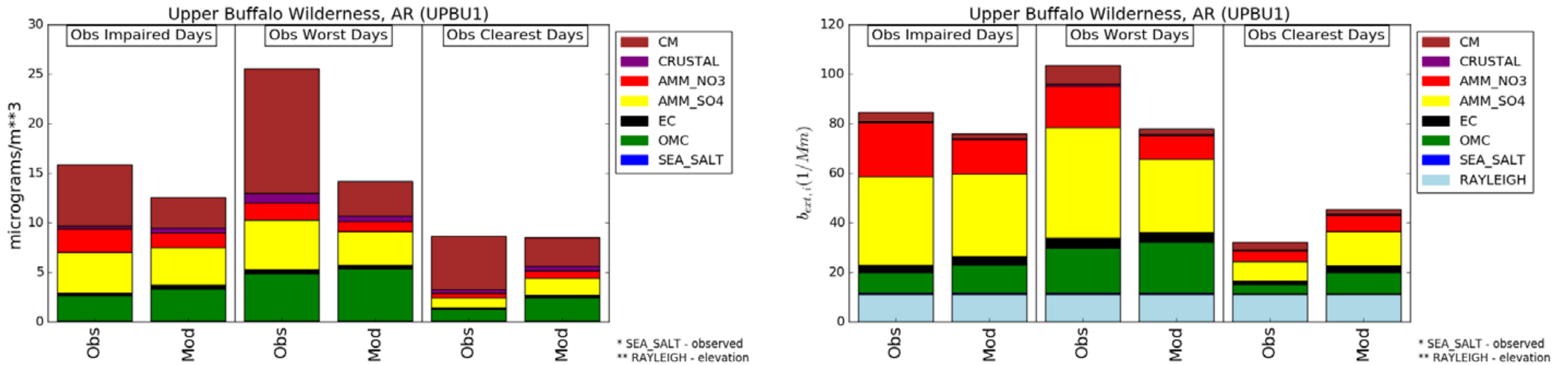


Figure 111: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Upper Buffalo Wilderness (AR) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

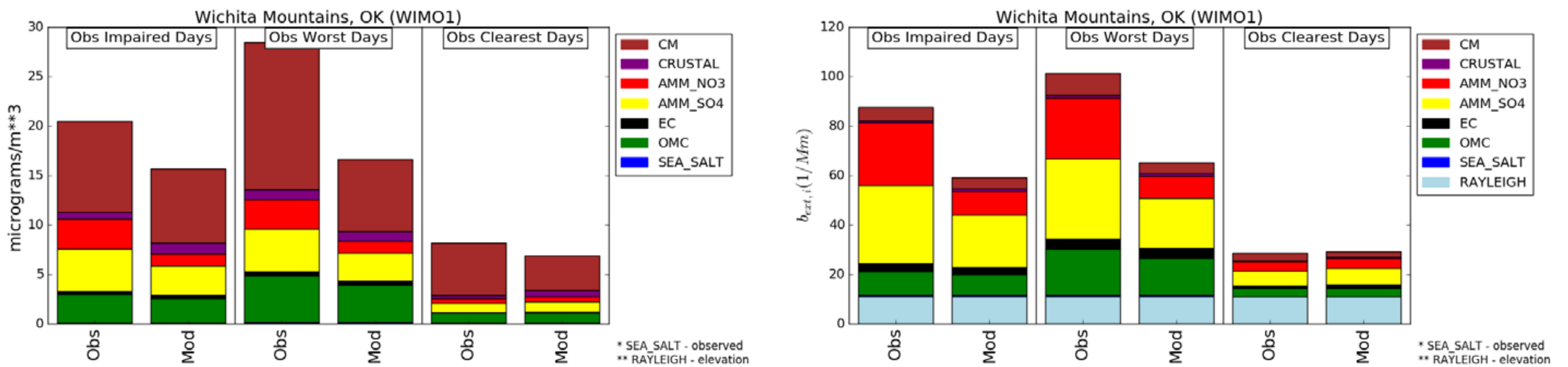


Figure 112: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Wichita Mountains (OK) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Boundary Waters

- Boundary Waters Canoe Area (MN)(BOWA1)
- Isle Royale National Park (MI)(ISLE1)
- Seney (MI)(SENE1)
- Voyageurs National Park (MN)(VOYA2)

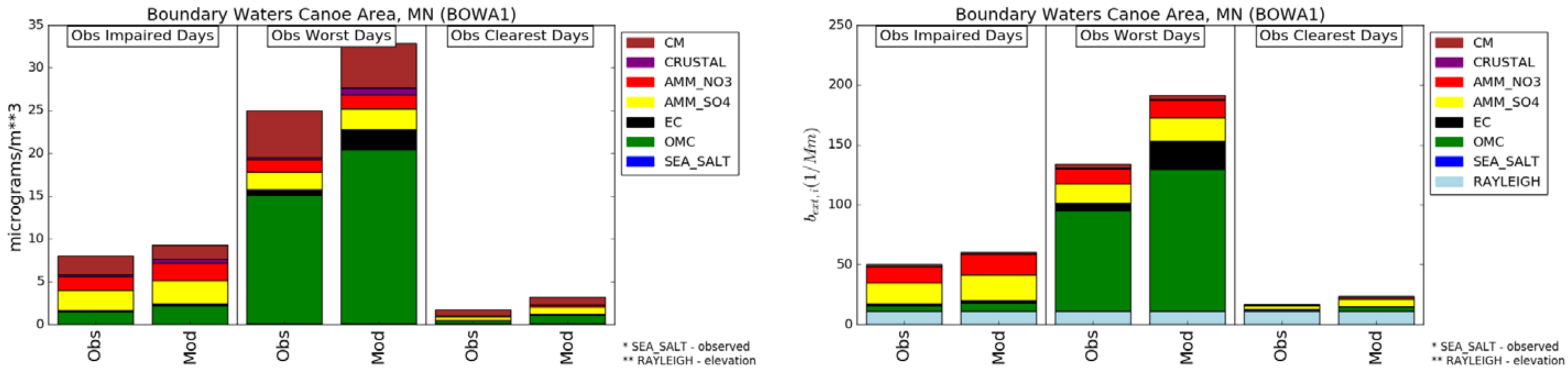


Figure 113: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Boundary Waters Canoe Area (MN) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

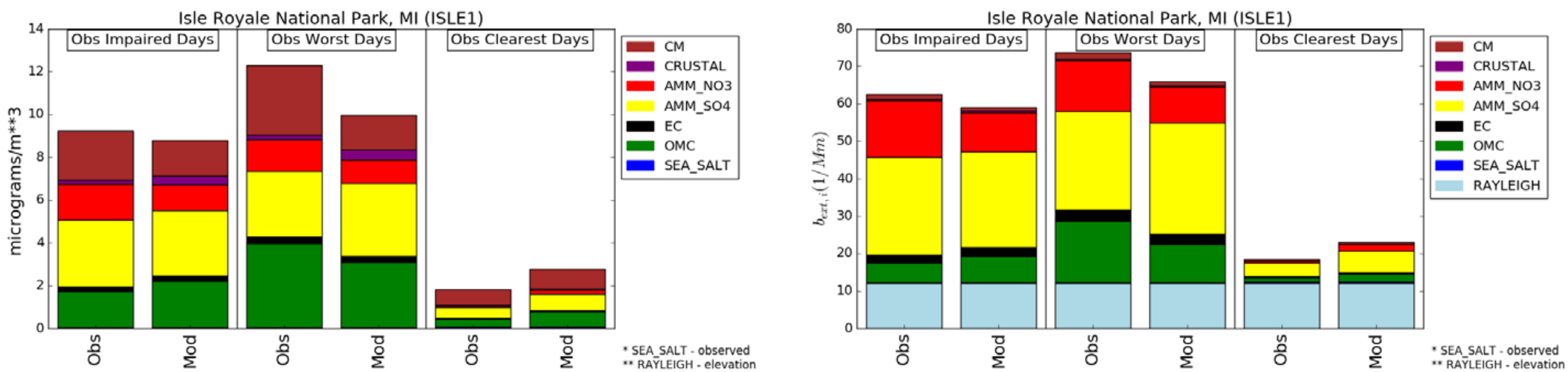


Figure 114: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Isle Royale National Park (MI) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

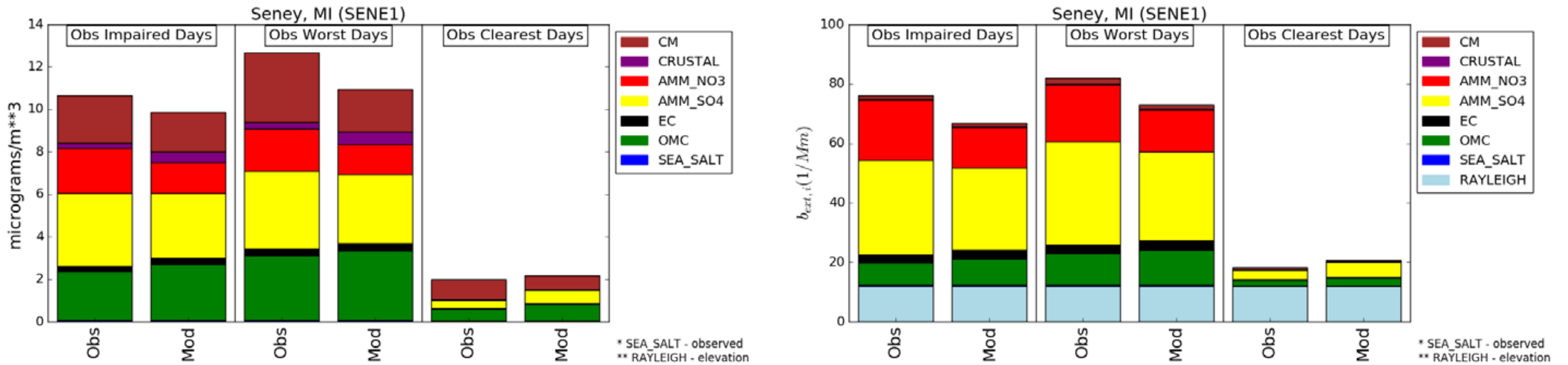


Figure 115: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Seney (MI) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

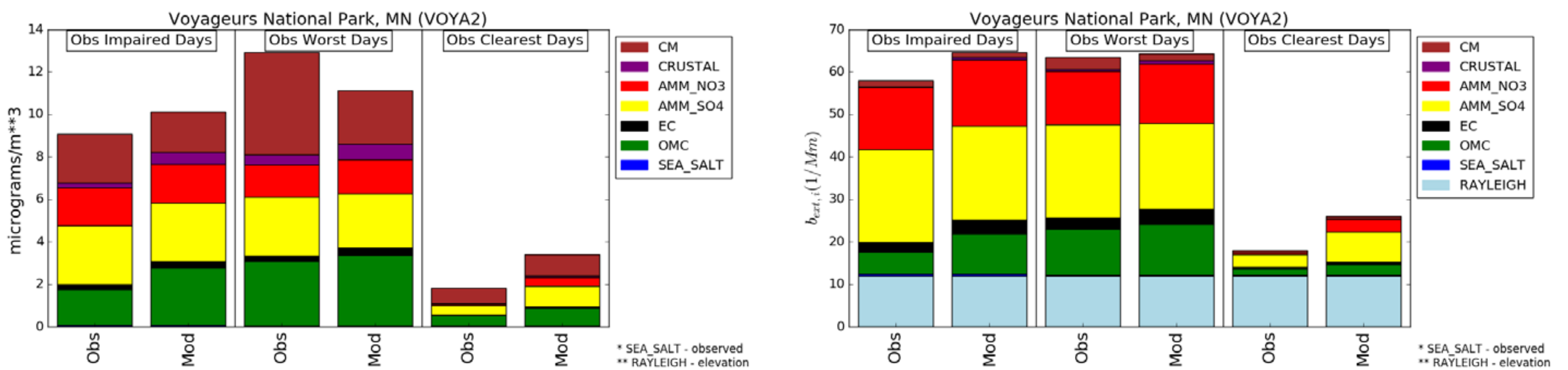


Figure 116: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Voyageurs National Park (MN) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Appalachia

- Cohutta Wilderness (GA)(COHU1)
- Dolly Sods Wilderness (WV) and Otter Creek Wilderness (WV)(DOSO1)
- Great Smoky Mountains National Park (TN) and Joyce-Kilmer-Slickrock Wilderness (TN)(GRSM1)
- James River Face Wilderness (VA)(JARI1)
- Linville Gorge Wilderness (NC)(LIGO1)
- Shenandoah National Park (VA)(SHEN1)
- Shining Rock Wilderness (NC)(SHRO1)
- Sipsey Wilderness (AL)(SIPS1)

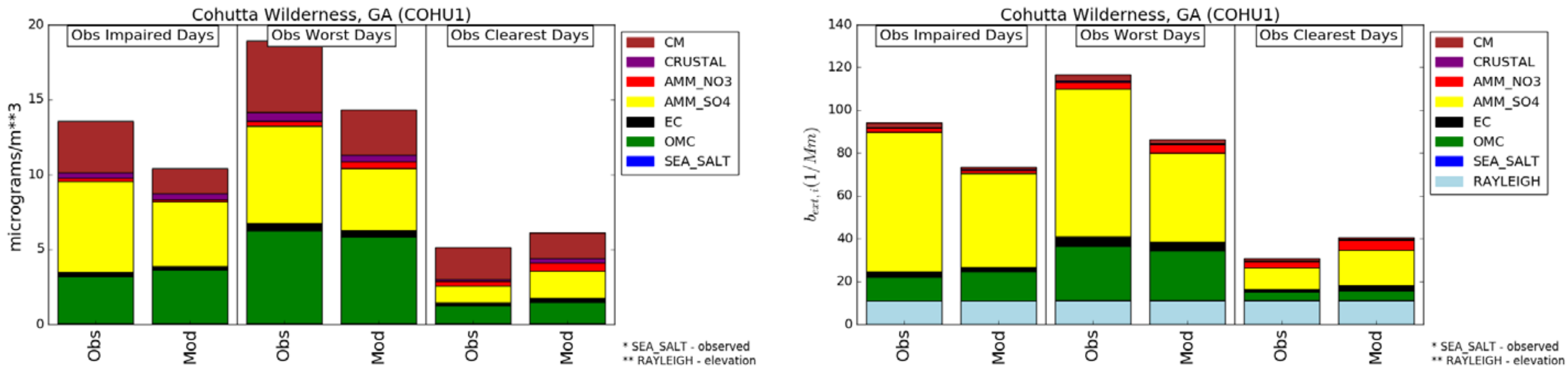


Figure 117: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Cohutta Wilderness (GA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

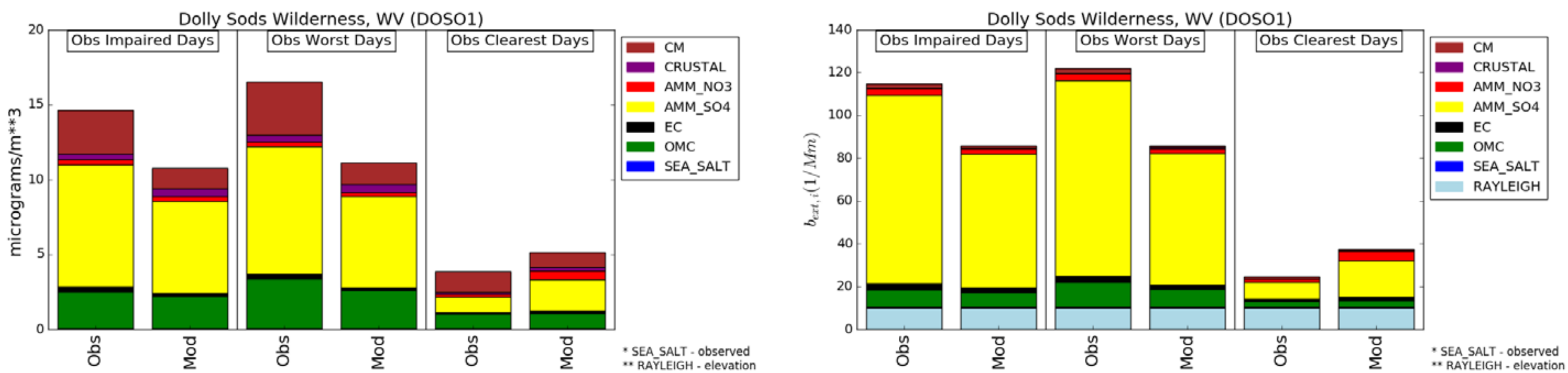


Figure 118: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Dolly Sods Wilderness (WV) and Otter Creek Wilderness (WV) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

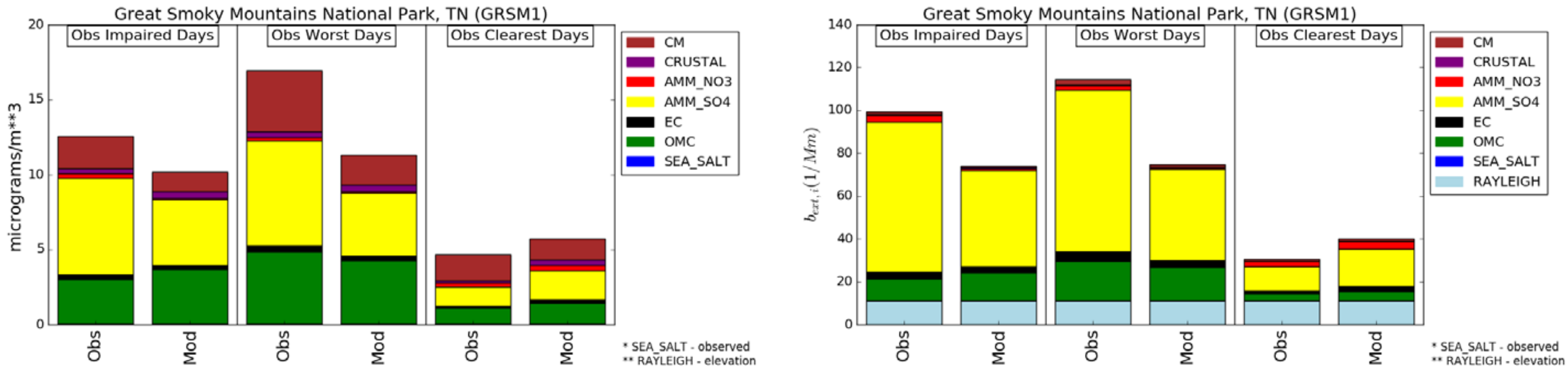


Figure 119: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Great Smoky Mountains National Park (TN) and Joyce-Kilmer-Slickrock Wilderness (TN) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

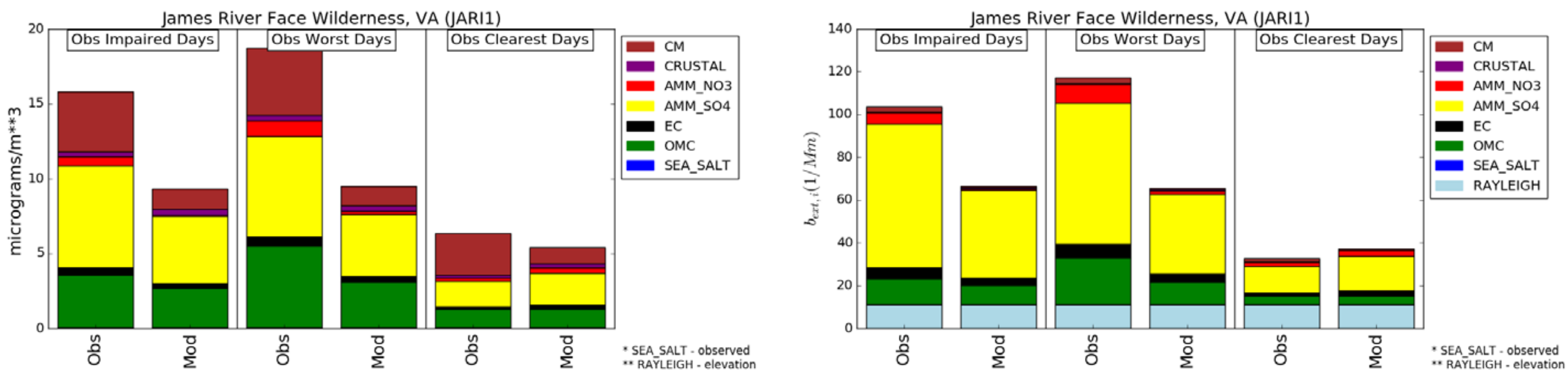


Figure 120: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the James River Face Wilderness (VA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

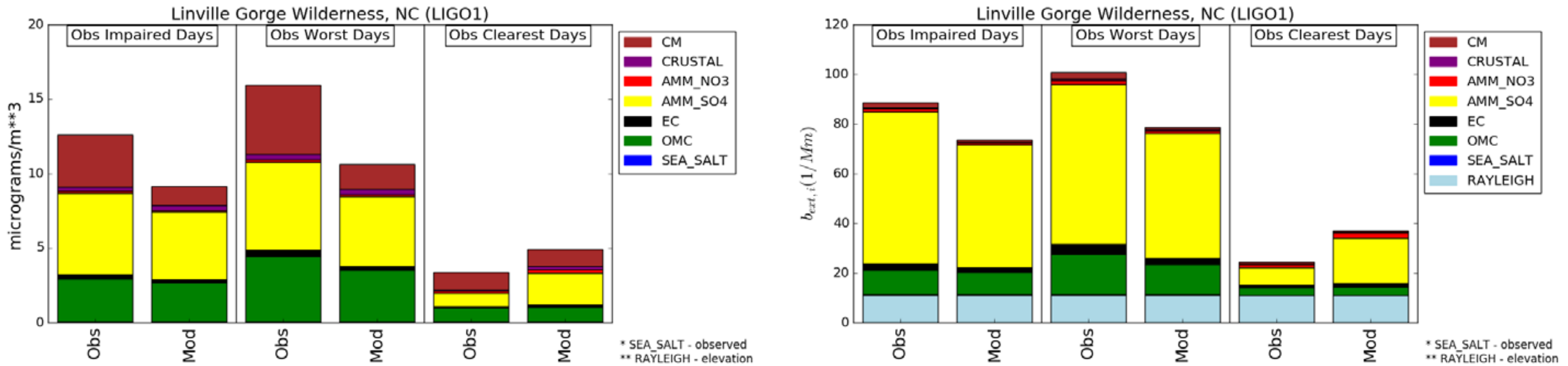


Figure 121: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Linville Gorge Wilderness (NC) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

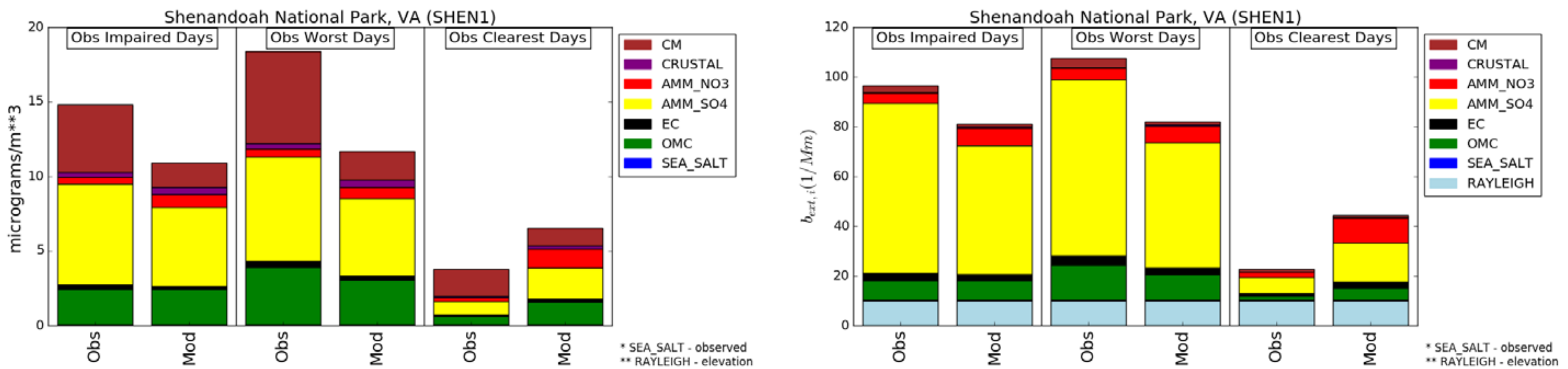


Figure 122: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Shenandoah National Park (VA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

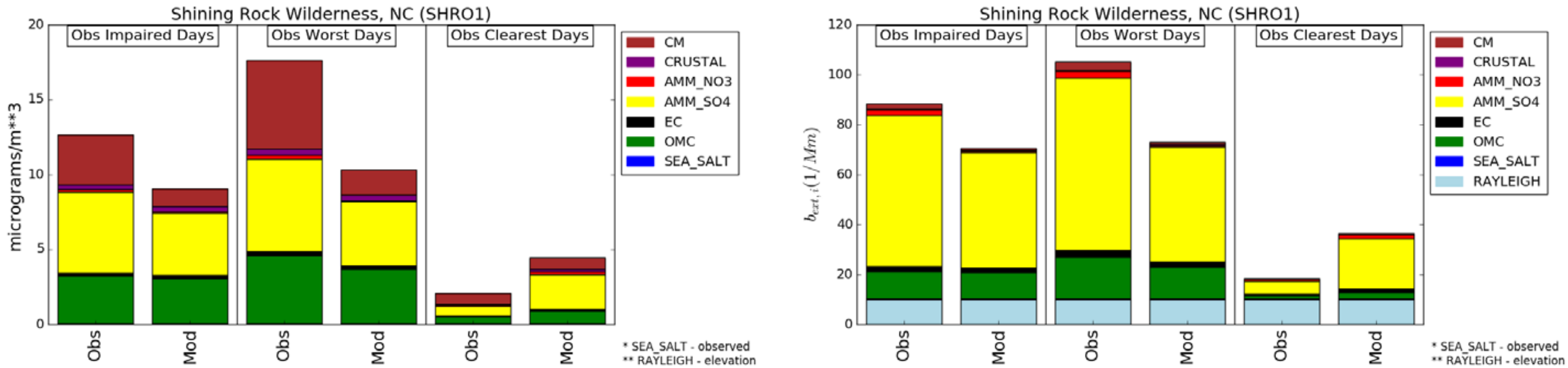


Figure 123: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Shining Rock Wilderness (NC) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

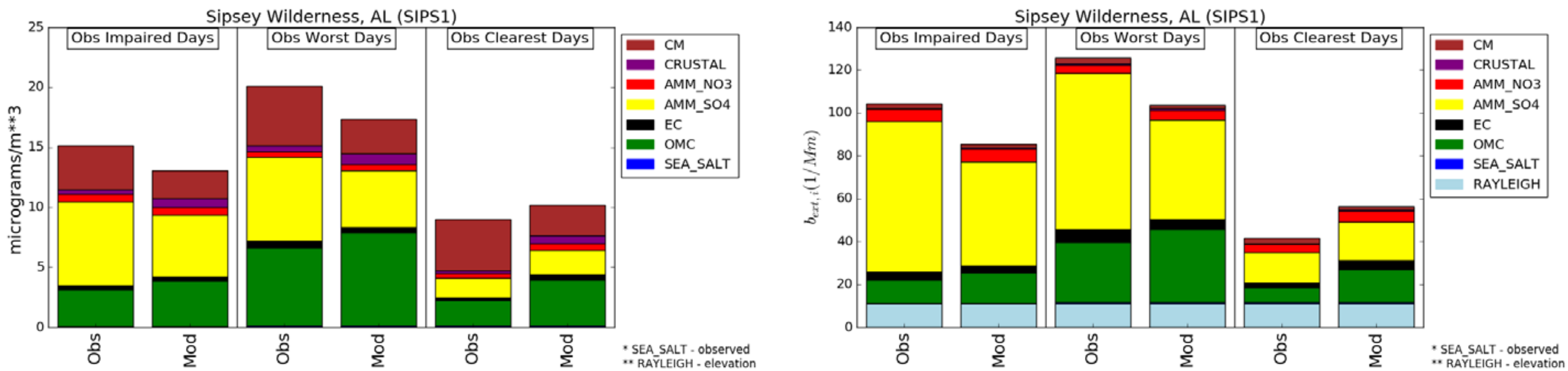


Figure 124: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Sipsey Wilderness (AL) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Ohio River Valley

- Mammoth Cave National Park (KY)(MACA1)
- Mingo (MO)(MING1)

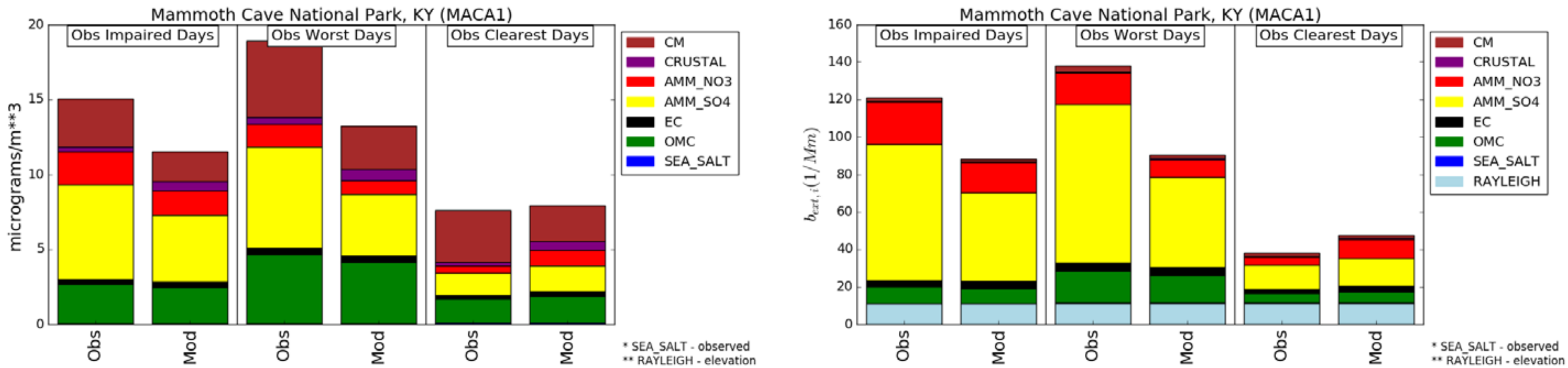


Figure 125: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Mammoth Cave National Park (KY) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

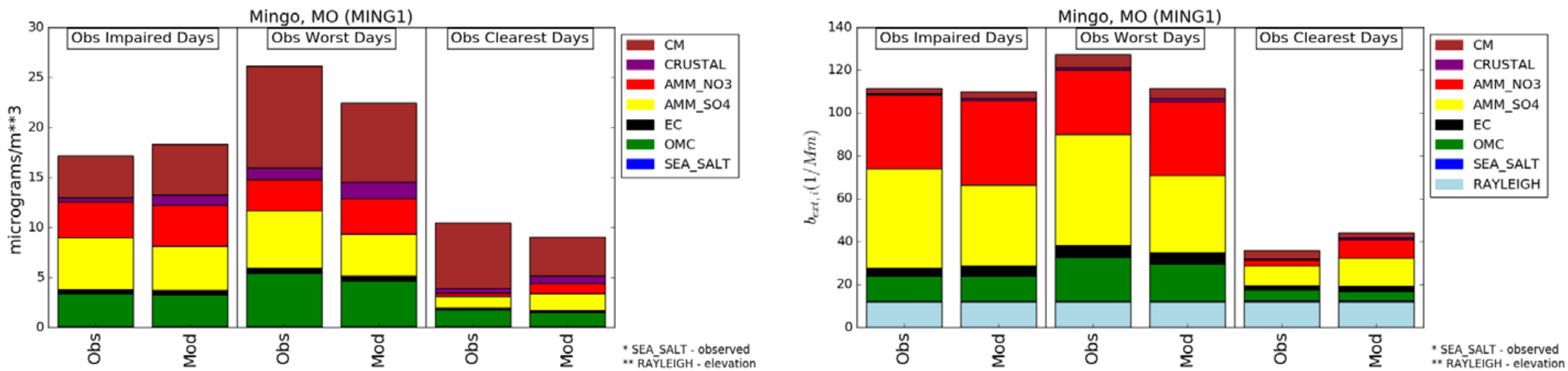


Figure 126: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Mingo (MO) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Southeast

- Breton (LA)(BRIS1)
- Chassahowitzka (FL)(CHAS1)
- Everglades National Park (FL)(EVER1)
- Okefenokee (GA) and Wolf Island (GA)(OKEF1)
- Cape Romain (SC)(ROMA1)
- St. Marks (FL)(SAMA1)

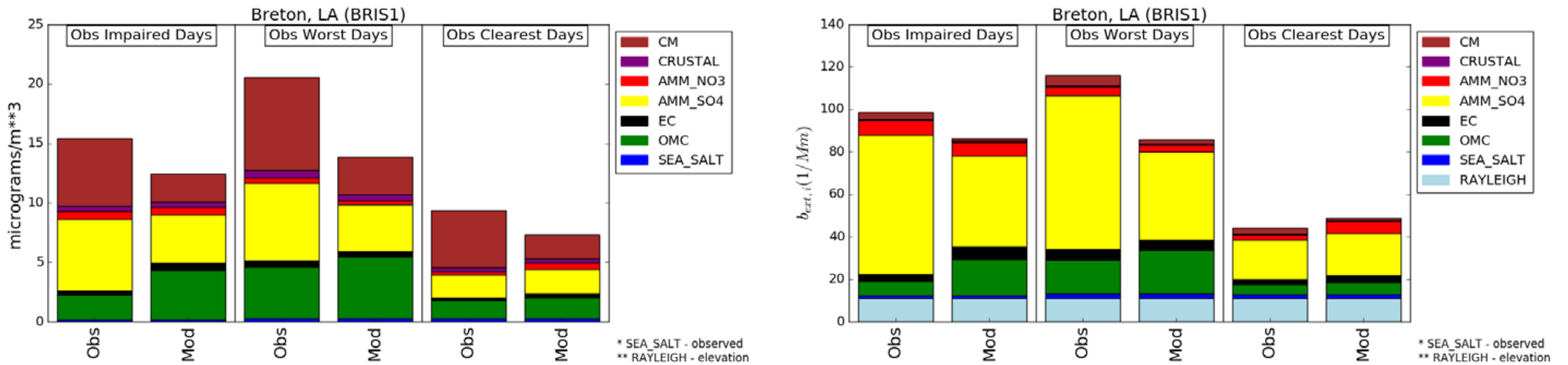


Figure 127: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Breton (LA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

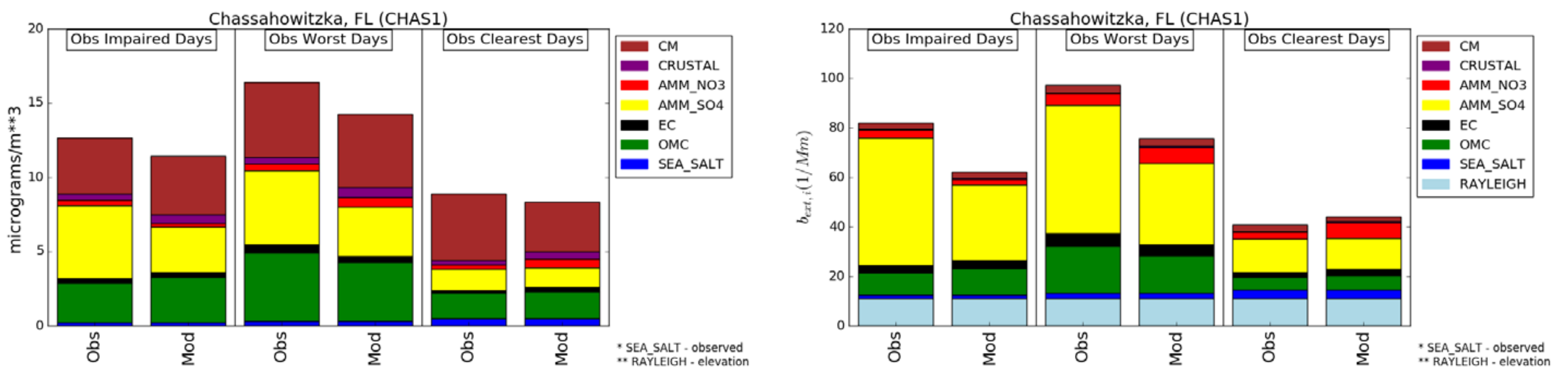


Figure 128: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Chassahowitzka (FL) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

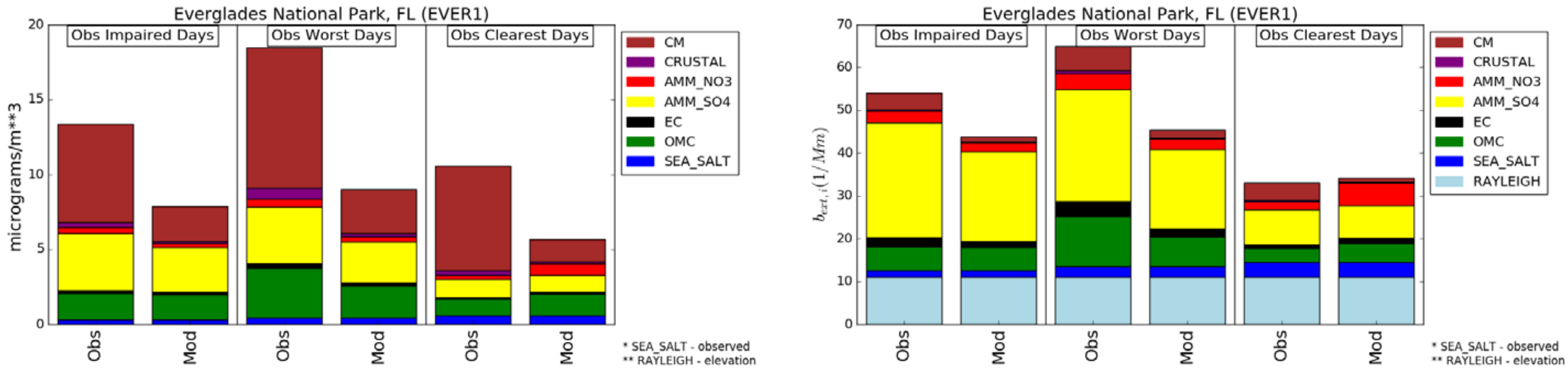


Figure 129: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Everglades National Park (FL) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

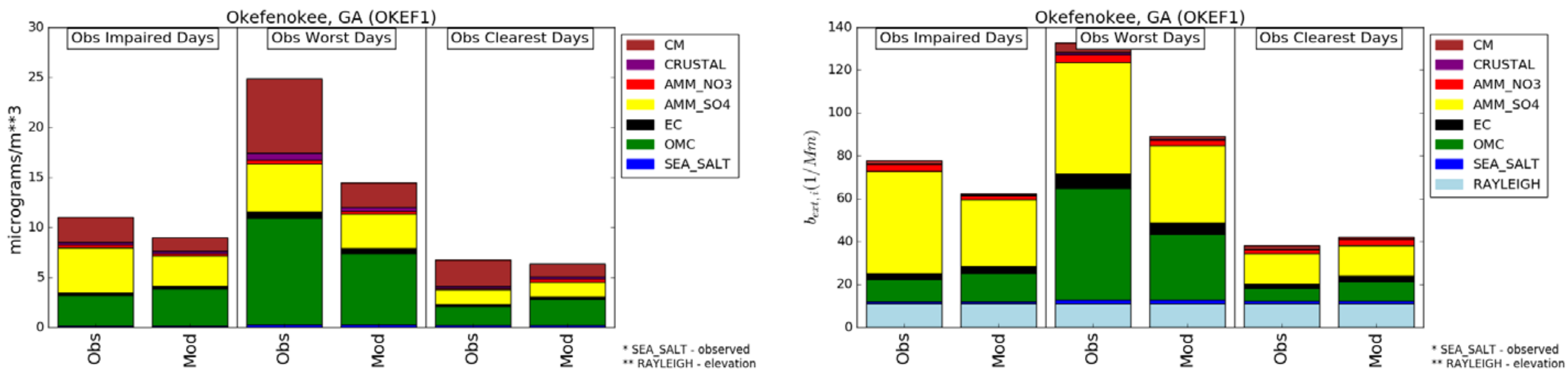


Figure 130: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Okefenokee (GA) and Wolf Island (GA) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

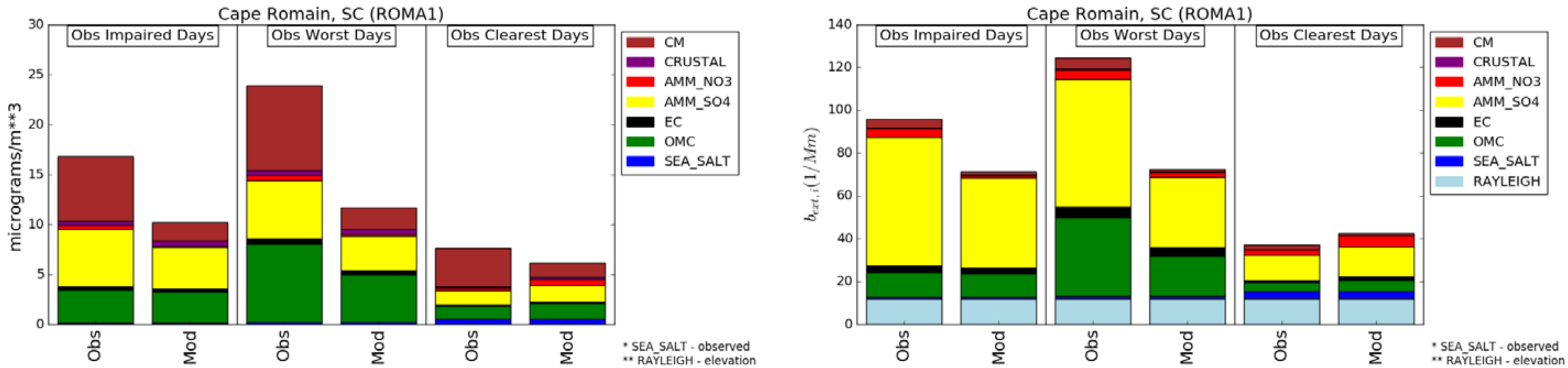


Figure 131: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Cape Romain (SC) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

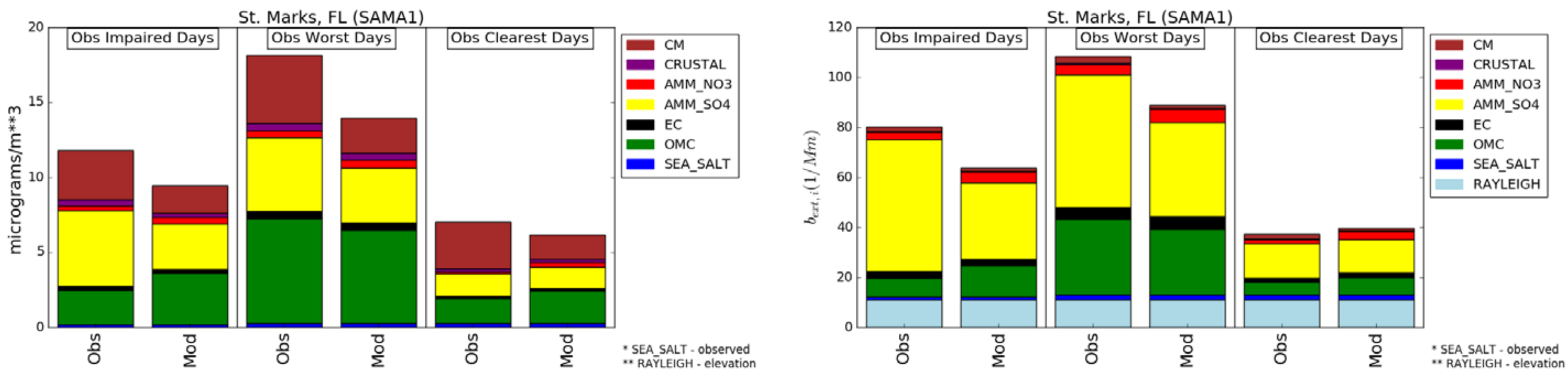


Figure 132: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the St. Marks (FL) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

East Coast

- Brigantine (NJ)(BRIG1)
- Swanquarter (NC)(SWAN1)

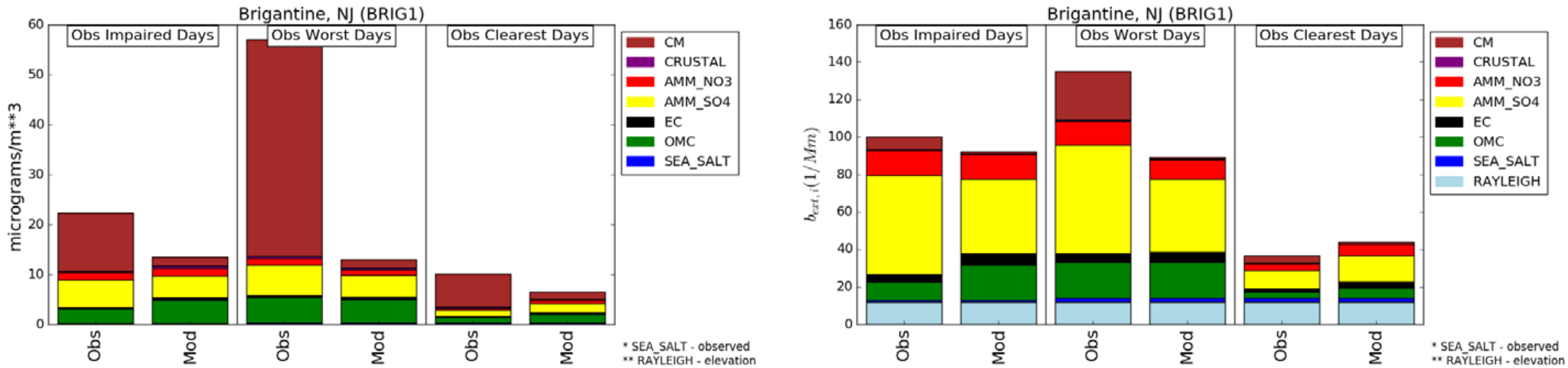


Figure 133: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Brigantine (NJ) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

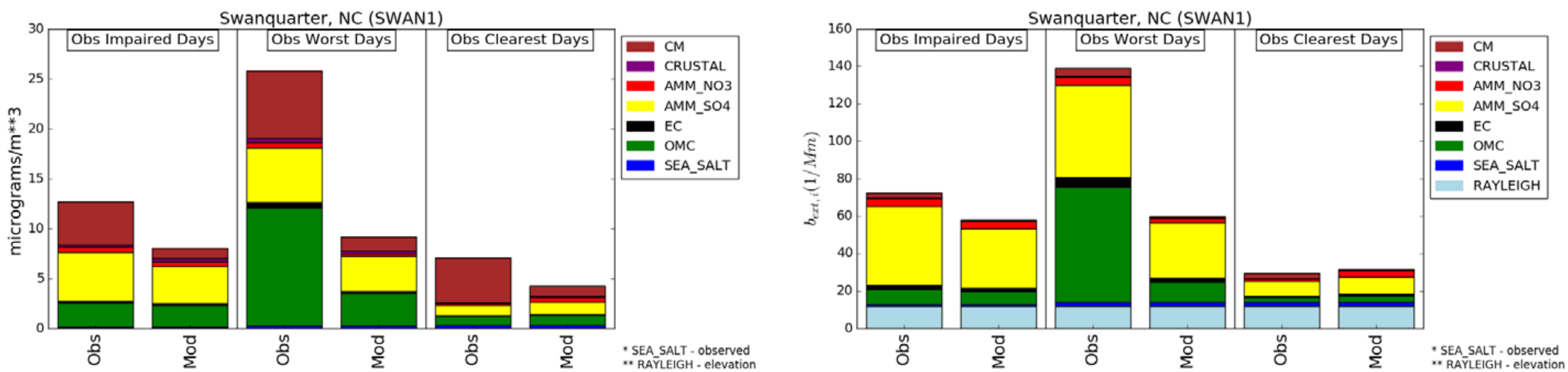


Figure 134: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Swanquarter (NC) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Northeast

- Acadia National Park (ME)(ACAD1)
- Great Gulf Wilderness (NH) and Presidential Range-Dry River Wilderness (NH)(GRGU1)
- Lye Brook Wilderness (VT)(LYEB1)
- Moosehorn (ME) and Roosevelt Campobello International Park (ME)(MOOS1)

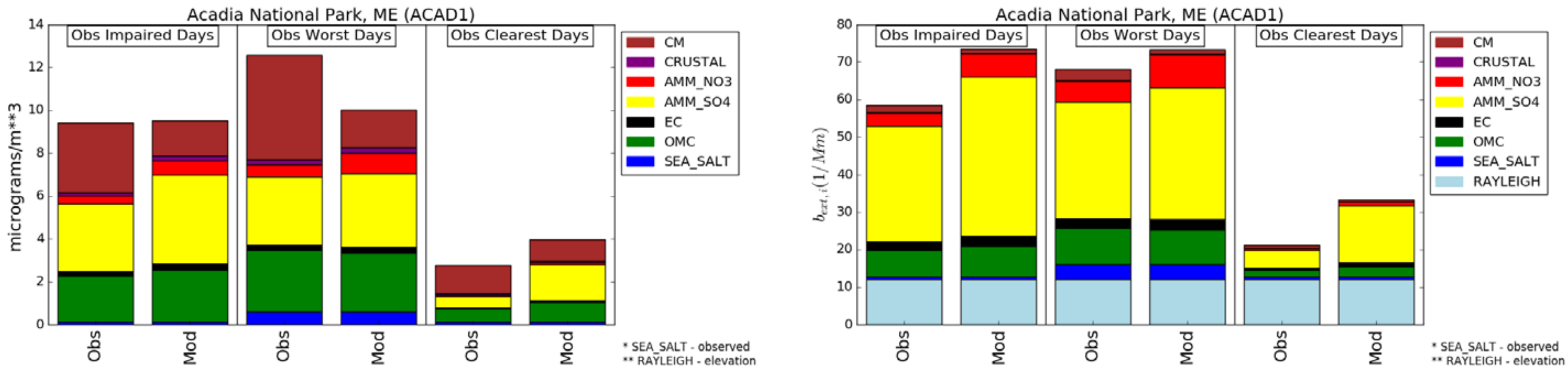


Figure 135: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Acadia National Park (ME) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

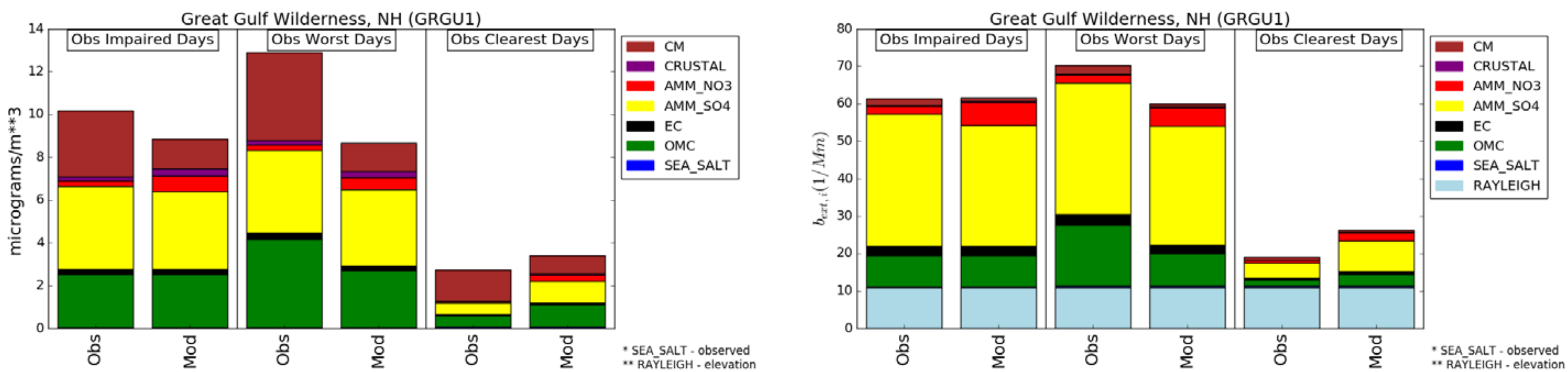


Figure 136: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Great Gulf Wilderness (NH) and Presidential Range-Dry River Wilderness (NH) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

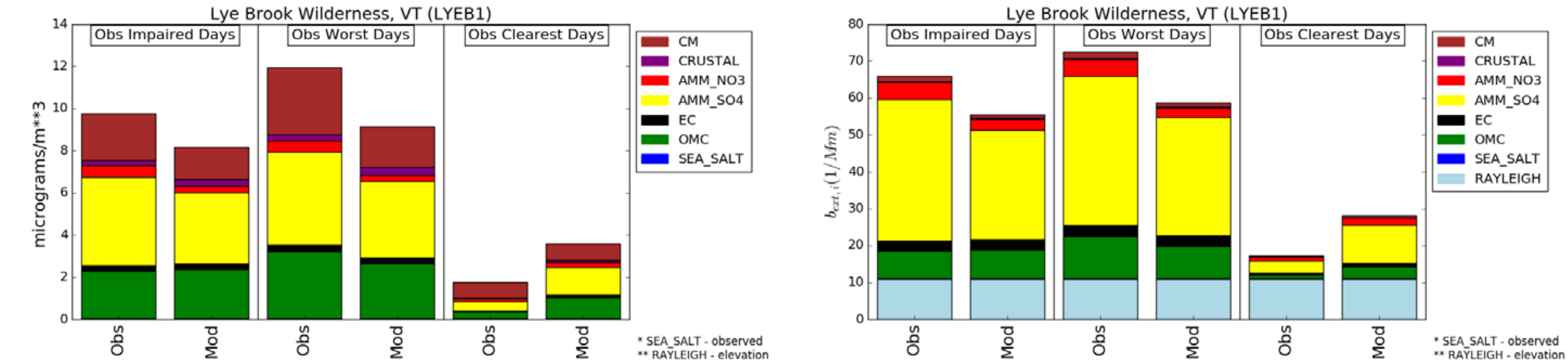


Figure 137: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Lye Brook Wilderness (VT) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

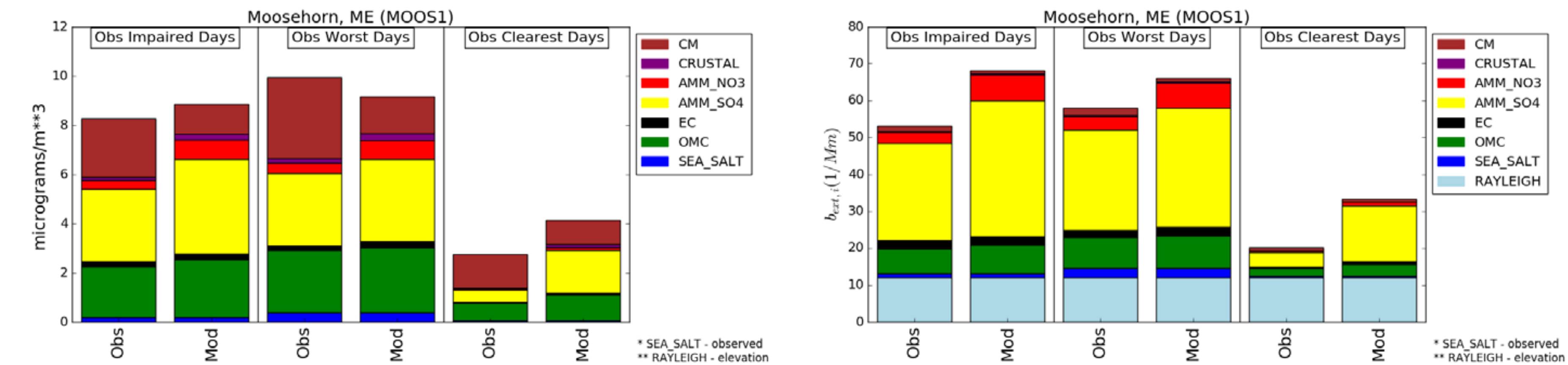


Figure 138: Observed (Obs) and predicted (Mod) concentrations (left) and extinctions (right) at the Moosehorn (ME) and Roosevelt Campobello International Park (ME) on the observed 20% most impaired, observed 20% worst, and observed 20% clearest days.

Appendix B

IMPROVE Site Summary Plots

IMPROVE Site Summary Plots

The following plots provide a summary of relevant observational and modeling data at each IMPROVE station. To help orient the reader, each figure is labeled with the main Class I area represented by the IMPROVE site and has an inset map with a red dot to indicate the geographic location of the IMPROVE station.

- The 2009-2013 observed annual average light extinction values (1/Mm) on the 20% most impaired days are shown as (up to 5) black dots with the 5-year average as a horizontal blue line over the same time period.

- For the 2011 year, the average observed magnitude and composition of extinction (on the 20% most impaired days) is indicated by the left-most stacked bar. The 2011 observation is broken down into Rayleigh (light blue), sea salt (blue), organic carbon matter (green), elemental carbon (black), ammonium sulfate (yellow), ammonium nitrate (red), fine crustal material (purple) and coarse mass (brown). Rayleigh scattering is site-specific, depending on the site elevation (higher elevation has lower Rayleigh scattering). It varies between 8 and 12 Mm^{-1} for all areas and does not vary by day or year.

- Also for 2011 year, the second stacked bar shows the CAMx modeled PM light extinction magnitude and composition on the 20% most impaired days. The observed sea salt scattering has been copied over to the modeling results (we are not using modeled sea salt) and the site-specific Raleigh scattering is also used directly and does not change between the base and future.

- A species-specific relative response factor was calculated using the raw 2011 simulated PM species concentrations and the raw 2028 simulated PM species concentrations and used to project observations. The effective net relative change in extinction between 2011 and 2028 is visualized by the blue dashed line connecting the 5-year average (solid horizontal blue line) with the top of the 2028 stacked bar (in some cases, the blue dashed line does not exactly hit the top of the 2028 stacked bar because the plots are shown in extinction, but the actual 2028 projections are calculated in deciviews, which is a log function). See the modeling technical support document (TSD) for more details on the calculations.

- The shades of grey in the 2028 stacked bar represent source apportionment emissions summary categories to represent United States Anthropogenic, “Mixed”, International Anthropogenic, and Natural sources. The “Mixed” category is most often dominated by modeled boundary conditions, which can be a combination of sources including natural, recirculated U.S. pollution, off-shore activity, and trans-hemispheric anthropogenic. See Table B-1 below for the definition of the “emissions summary categories” and the modeling TSD for more details.

Table B-1 Source apportionment emissions summary categories

Emissions Summary Category	Emissions Sectors (PSAT tags)	Notes
US Anthropogenic	On-road mobile, Non-road mobile, EGUs, NonEGU point, Oil and Gas, Nonpoint (area), Commercial marine (onshore), Prescribed fires, Agricultural fires, Rail, Residential Wood combustion (RWC)	Most certain contributors to US anthropogenic visibility.
International	Anthropogenic Canada and Mexico	Contribution from Canadian and Mexican emissions within the 12km CONUS domain
Natural	Biogenic, Wildfires (domainwide), Sea salt	Most certain contributors to natural visibility
"Mixed"	Boundary conditions, Fugitive dust, Offshore (commercial marine and oil platforms), Secondary organics	Each of these sectors are particularly uncertain regarding their representation in the model, including their relative contribution of natural vs. international vs. US anthropogenic sources. Need further discussion and assessment to improve our understanding of the contributions.

- The "2028 US anthropogenic percentage" is a fraction of the total projected non-Rayleigh extinction. The U.S. anthropogenic sources are then normalized by this fraction and further identified in the pie chart, where unique categories total to ≥75% and the remaining are indicated as "US Anthro Other." Thus, the sector's percentage in the pie chart represents that sector's percentage of total U.S. anthropogenic extinction.

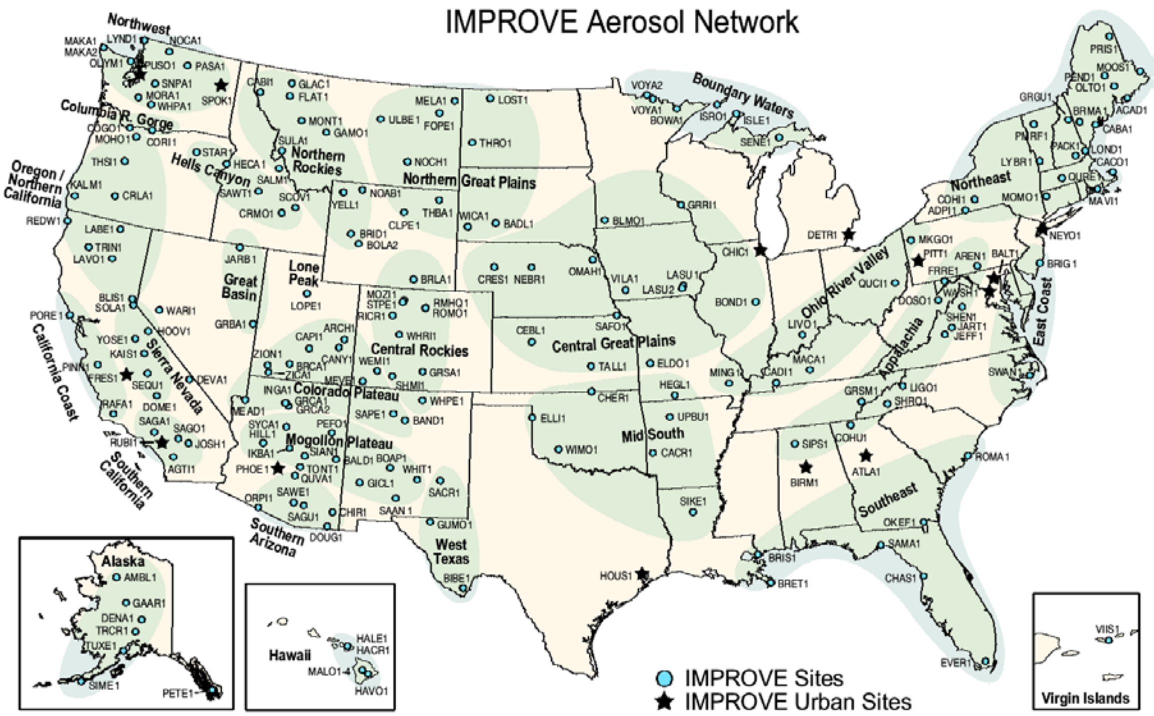
- The "Range" (the top and bottom of the whisker on the 2028 stacked bar) for 2028 extinction is an attempt to put bounds on projections that result from model skill and assumptions. We use two alternative projections to bound the projected future: (1) the boundary conditions are accurate and (2) the boundary conditions will be reduced by 50% between 2011 and 2028. See the modeling TSD for more details on the "range" calculations.

Table B-2 Sector category abbreviations in the summary plots

Summary plot US anthropogenic sector abbreviations	Full sector name
EGU	Electric generating units (EGU)
NonEGU_Pt	NonEGU point sources
Oil_Gas	Oil and gas (point and nonpoint)
Ag_Fires	Agricultural fires
Rail	Rail
RWC	Residential wood combustion
Non_point	Nonpoint (area) sources
On_road	On-road mobile
CMV	Commercial marine vessels (onshore)
Non_road	Non-road mobile
Prescribed_Fires	Prescribed fires

Figure B-1 Location of Federal Class I areas

Figure B-2 Map of IMPROVE network regions used in the summary plots



Source: 2011 IMPROVE Report http://vista.cira.colostate.edu/Improve/spatial-and-seasonal-patterns-and-temporal-variability-of-haze-and-its-constituents-in-the-united-states-report-v-june-2011

Northwest

- Mount Rainier National Park (WA)(MORA1)
- Glacier Peak Wilderness (WA) and North Cascades National Park (WA)(NOCA1)
- Olympic National Park (WA)(OLYM1)
- Pasayten Wilderness (WA)(PASA1)
- Alpine Lake Wilderness (WA)(SNPA1)
- Goat Rocks Wilderness (WA) and Mount Adams Wilderness (WA)(WHPA1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, organic carbon
Model visibility performance summary (on 20% most impaired days)	Generally good performance, dominated by sulfate. Nitrate overpredicted at MORA and WHPA.
Uncertainty in sector contributions	High “mixed” sector contribution percentage (all sites > 60%).
2028 US anthropogenic percent contribution	7-18%
Largest US anthropogenic sector contributions	Residential wood and nonEGU point

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high “mixed” (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

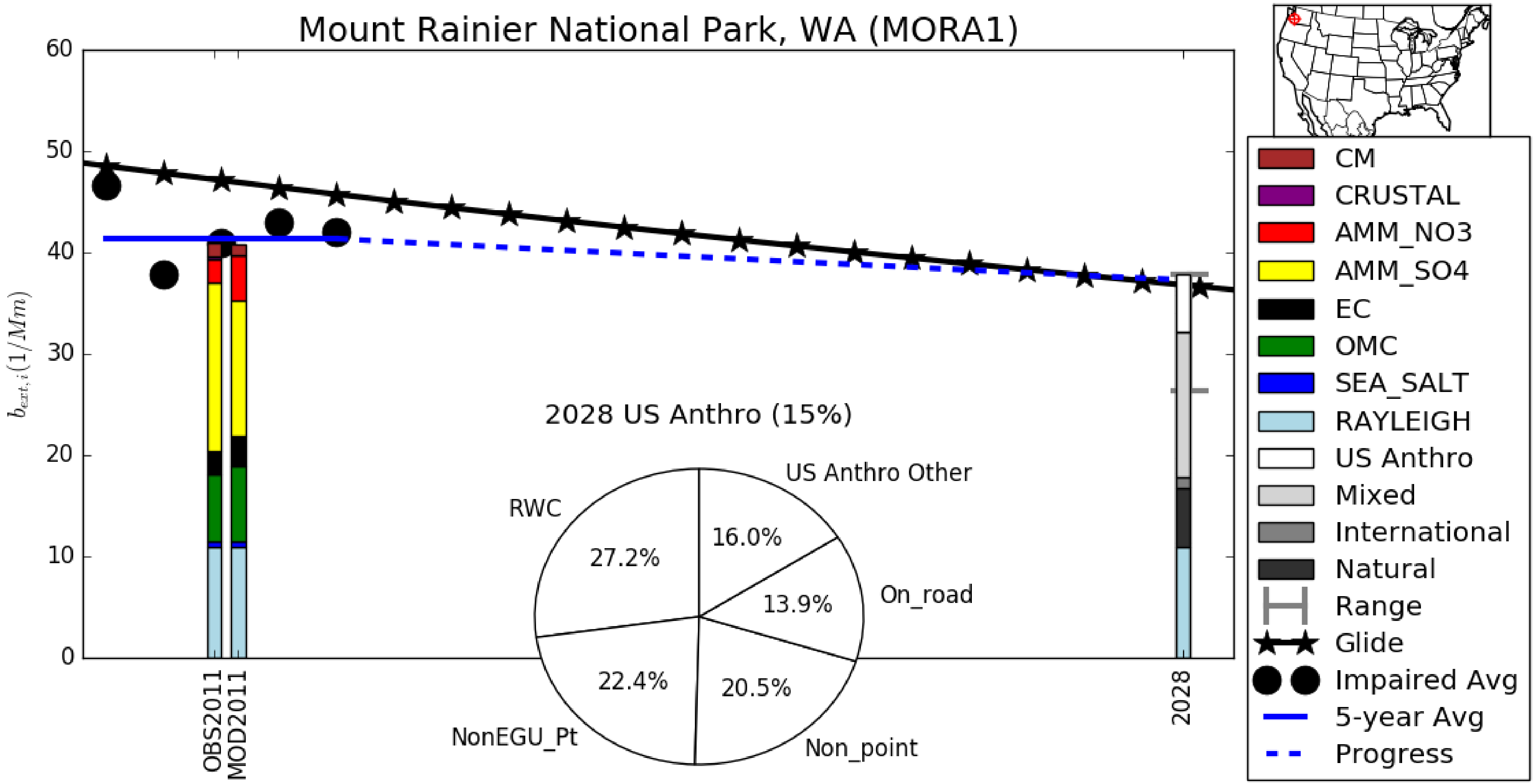


Figure B-3: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Mount Rainier National Park (WA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

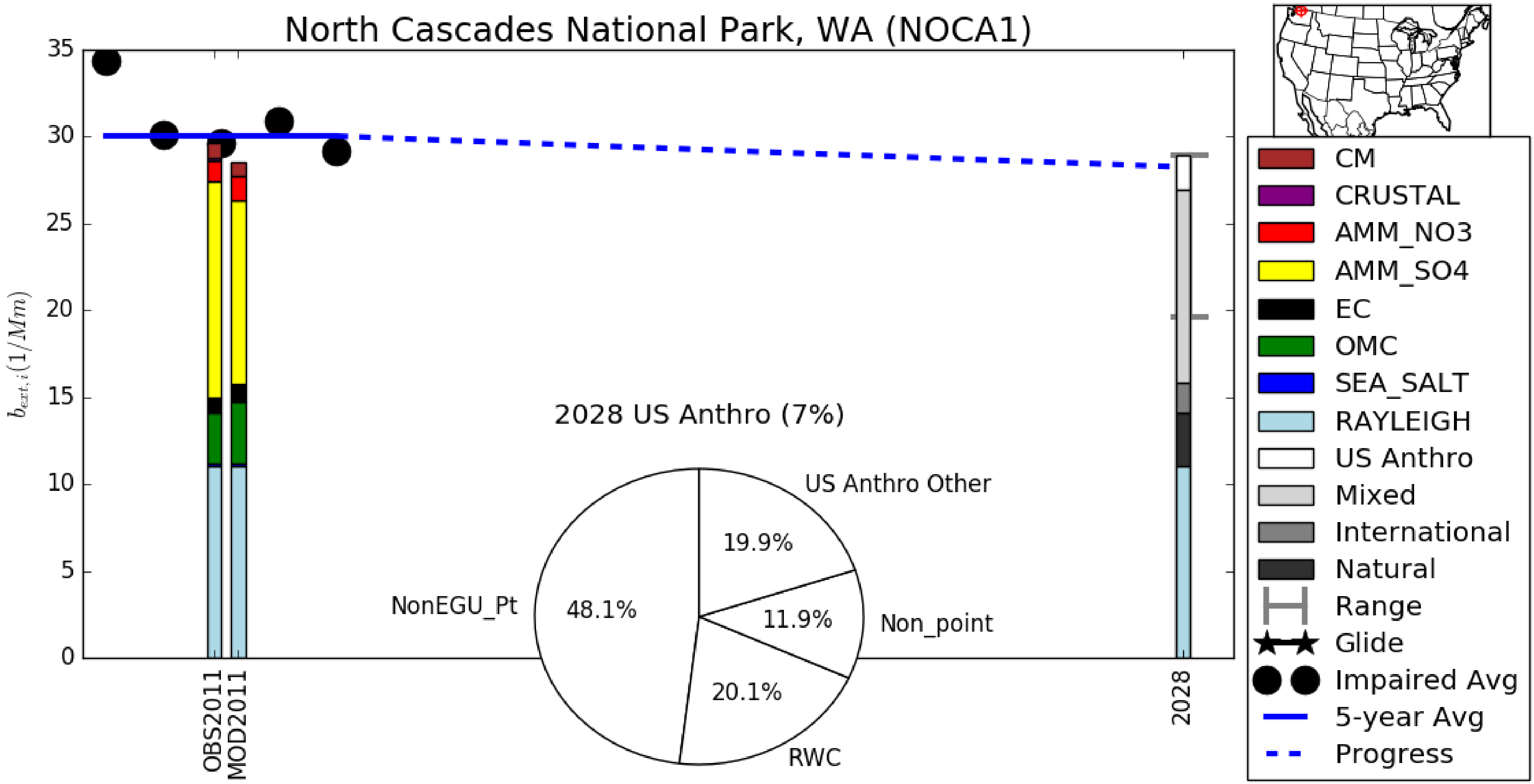


Figure B-4: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Glacier Peak Wilderness (WA) and North Cascades National Park (WA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

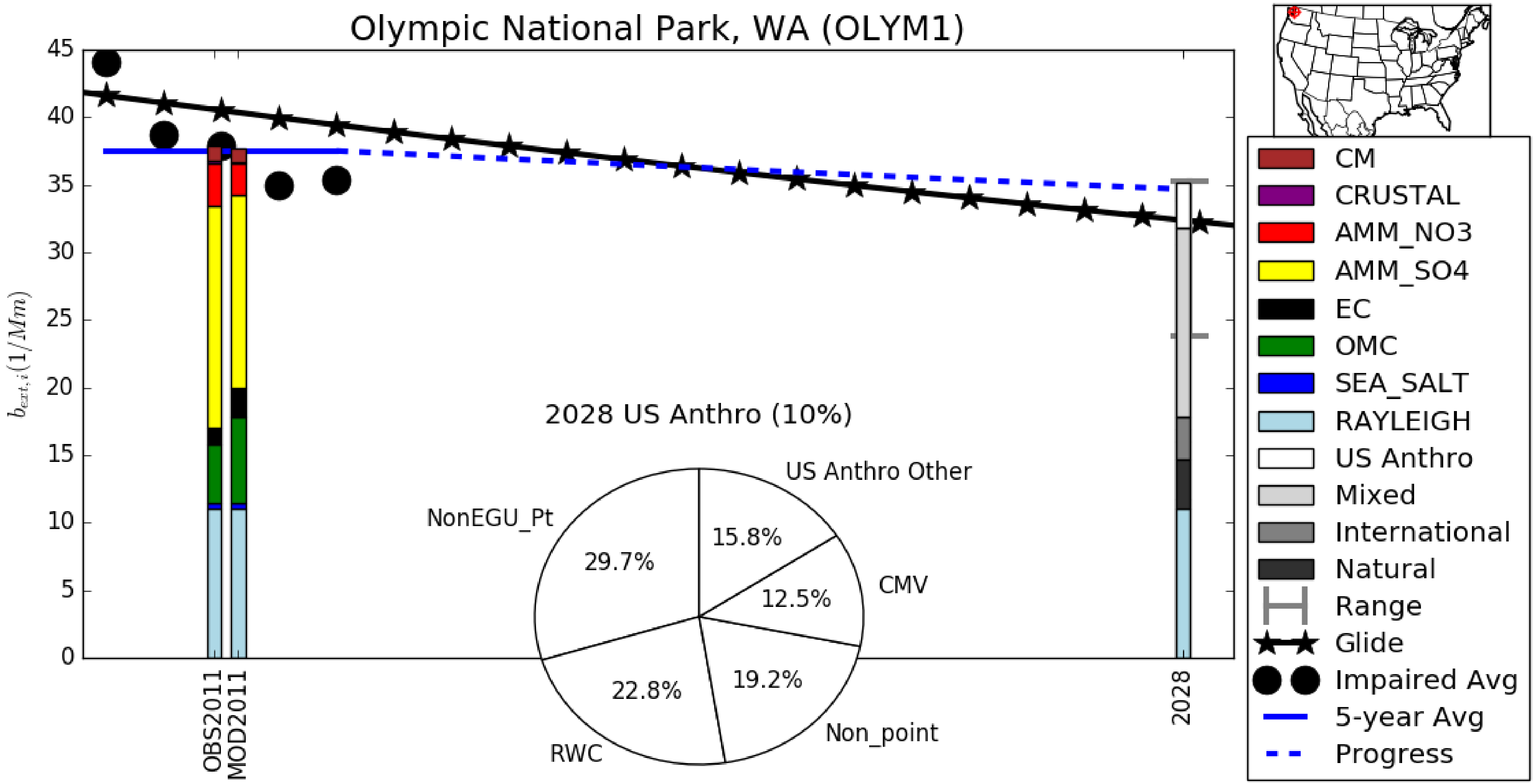


Figure B-5: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Olympic National Park (WA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

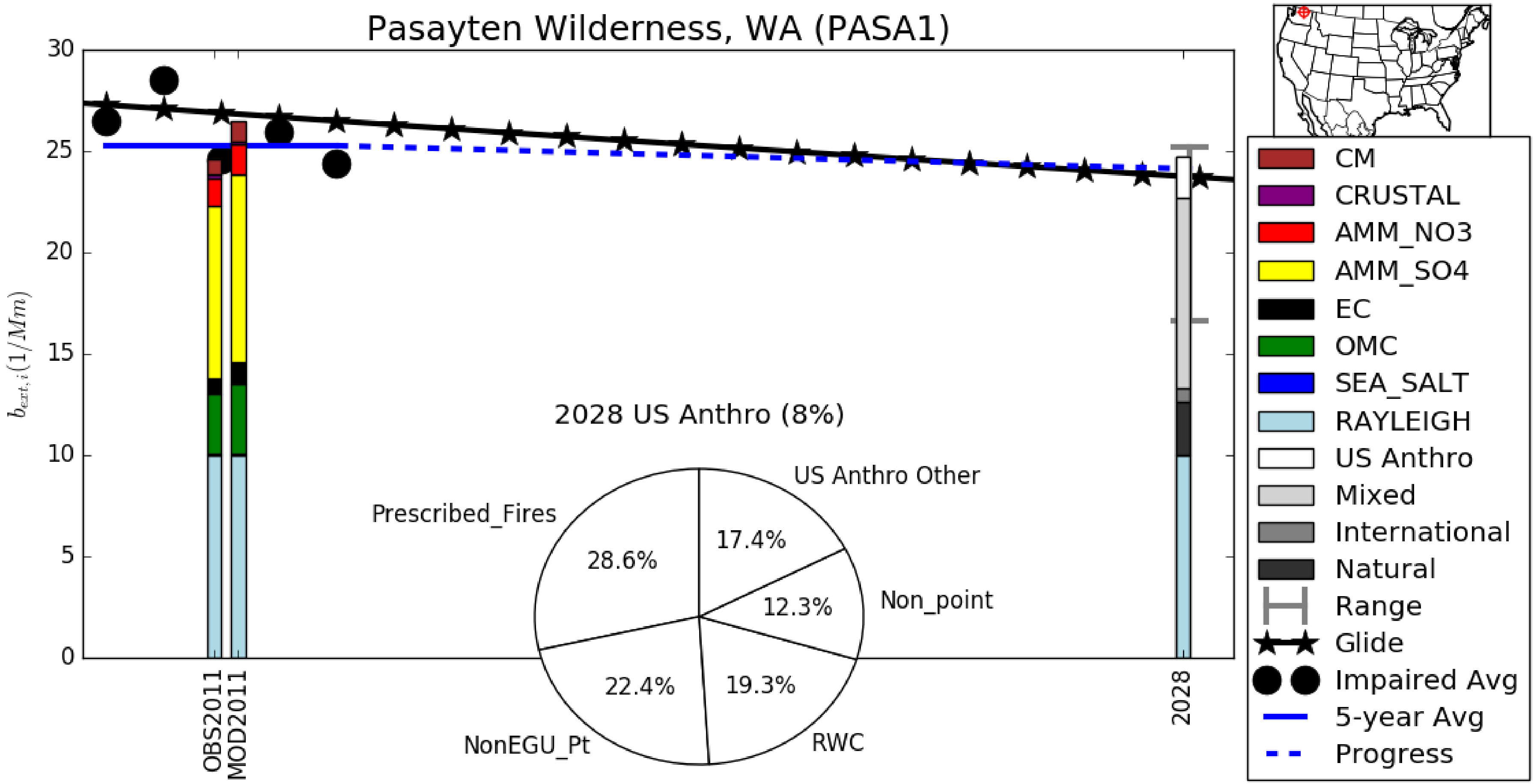


Figure B-6: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Pasayten Wilderness (WA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

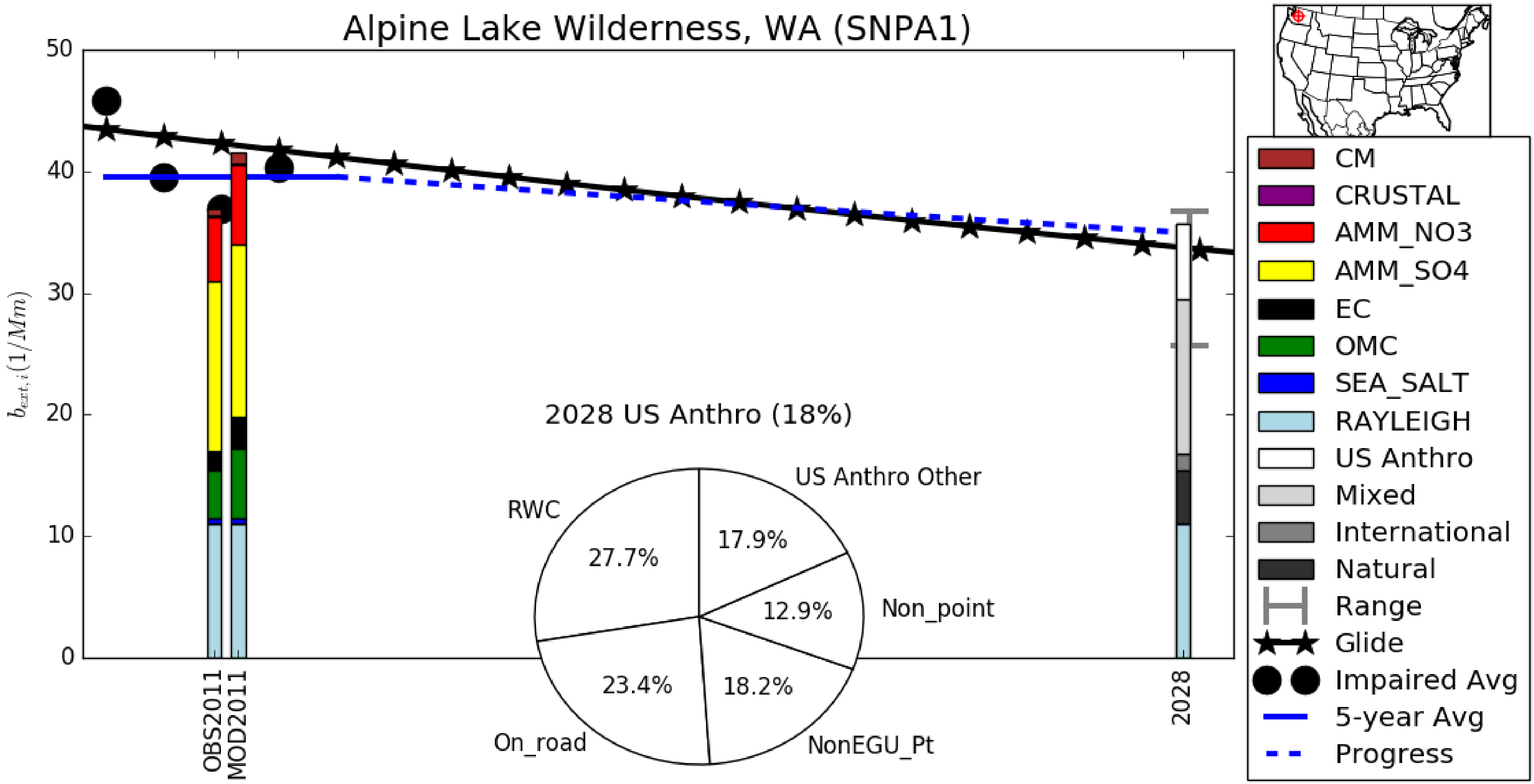


Figure B-7: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Alpine Lake Wilderness (WA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

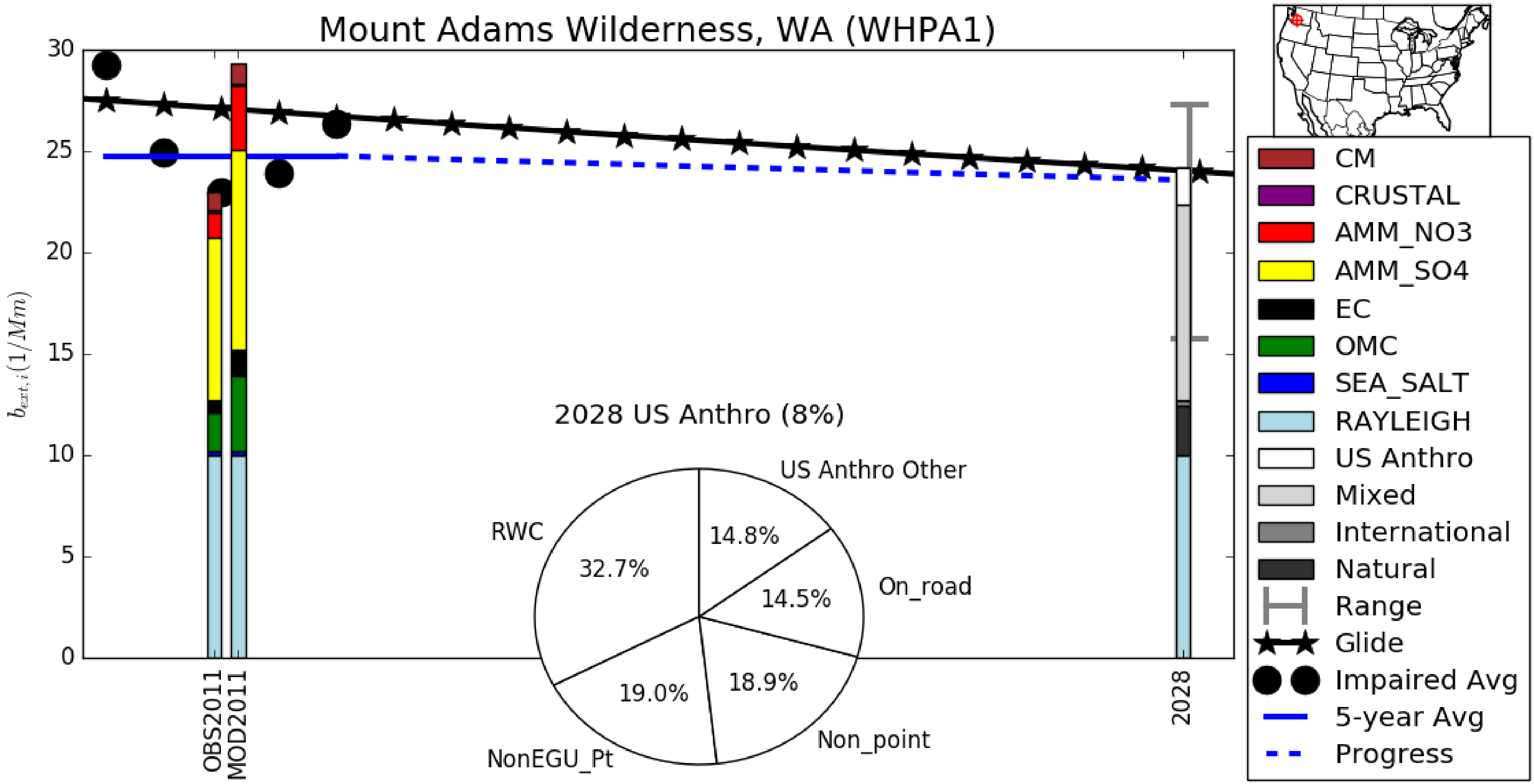


Figure B-8: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Goat Rocks Wilderness (WA) and Mount Adams Wilderness (WA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Oregon and Northern California

- Desolation Wilderness (CA) and Mokelumne Wilderness (CA)(BLIS1)
- Crater Lake National Park (OR), Diamond Peak Wilderness (OR), Gearhart Mountain Wilderness (OR), and Mountain Lakes Wilderness (OR)(CRLA1)
- Kalmiopsis Wilderness (OR)(KALM1)
- Lava Beds National Monument (CA) and South Warner Wilderness (CA)(LABE1)
- Caribou Wilderness (CA), Lassen Volcanic National Park (CA), and Thousand Lakes Wilderness (CA)(LAVO1)
- Mount Hood Wilderness (OR)(MOHO1)
- Redwood National Park (CA)(REDW1)
- Mount Jefferson Wilderness (OR), Mount Washington Wilderness (OR), and Three Sisters Wilderness (OR)(THSI1)
- Marble Mountain Wilderness (CA) and Yolla Bolly Middle Eel Wilderness (CA)(TRIN1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, organic carbon High sea salt at REDW1
Model visibility performance summary (on 20% most impaired days)	Generally good performance, with small biases.
Uncertainty in sector contributions	High "mixed" sector contribution percentage (all sites > 59%).
2028 US anthropogenic percent contribution	5-15%
Largest US anthropogenic sector contributions	Nonpoint, nonEGU point, and Residential wood

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

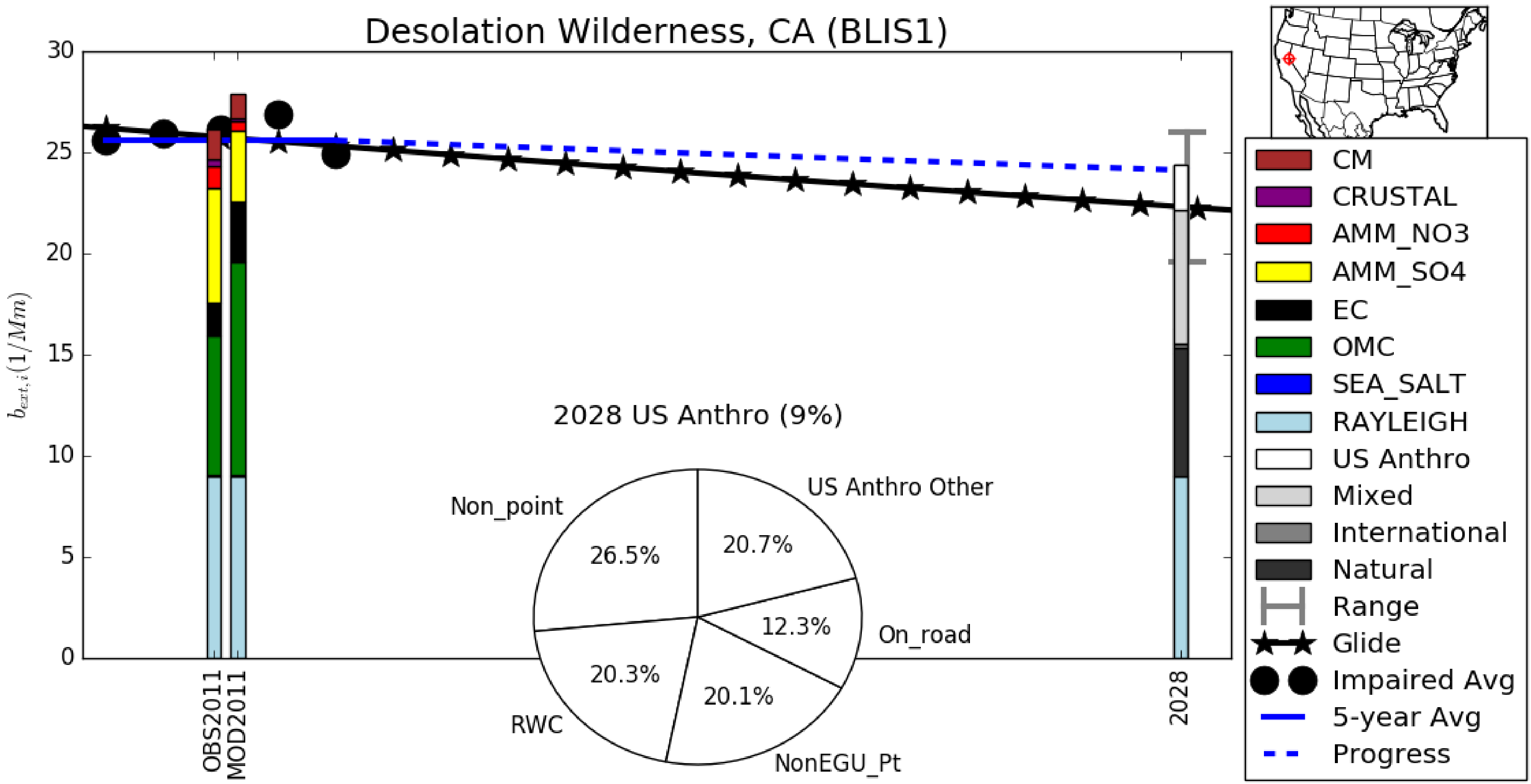


Figure B-9: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Desolation Wilderness (CA) and Mokelumne Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

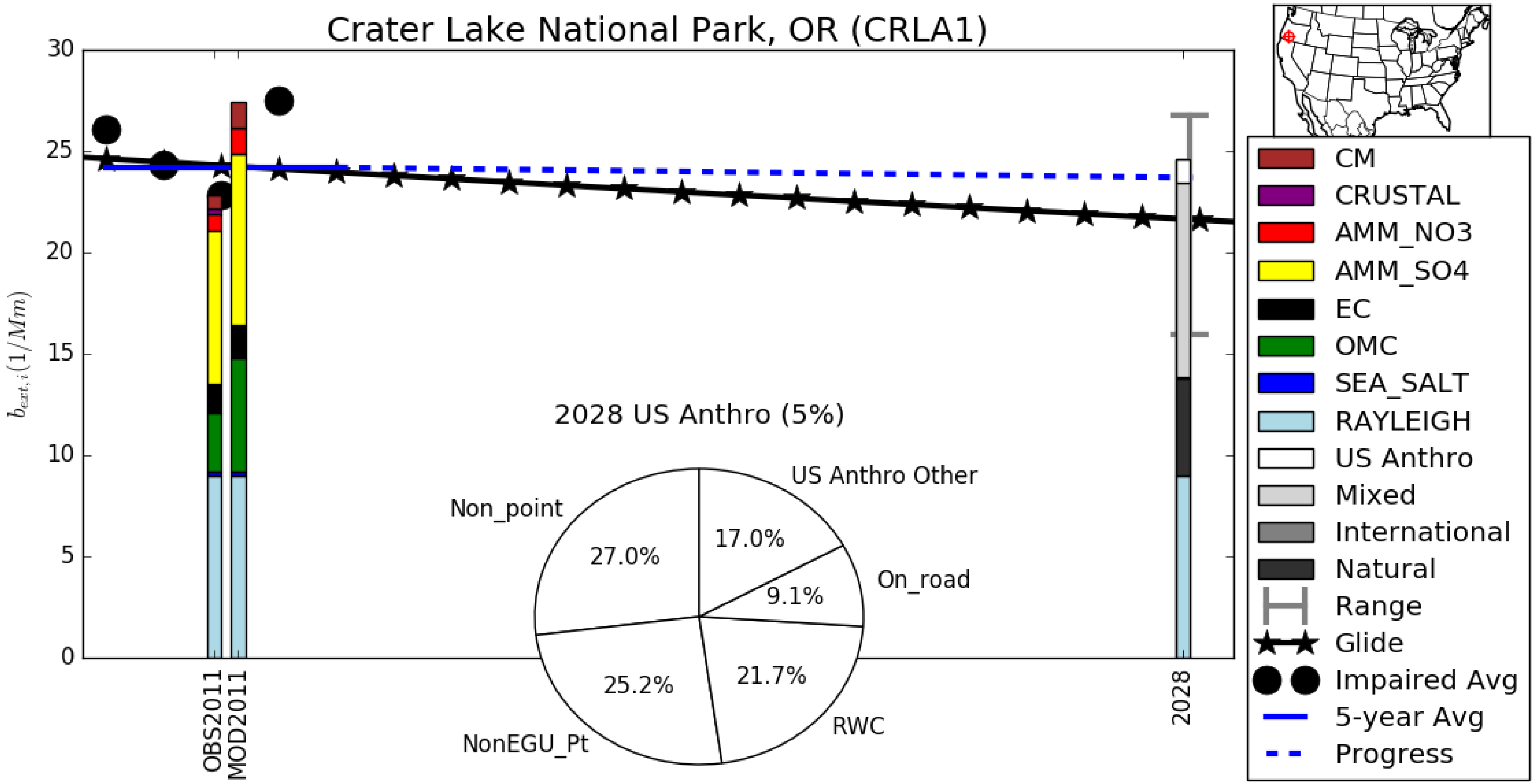


Figure B-10: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Crater Lake National Park (OR), Diamond Peak Wilderness (OR), Gearhart Mountain Wilderness (OR), and Mountain Lakes Wilderness (OR).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

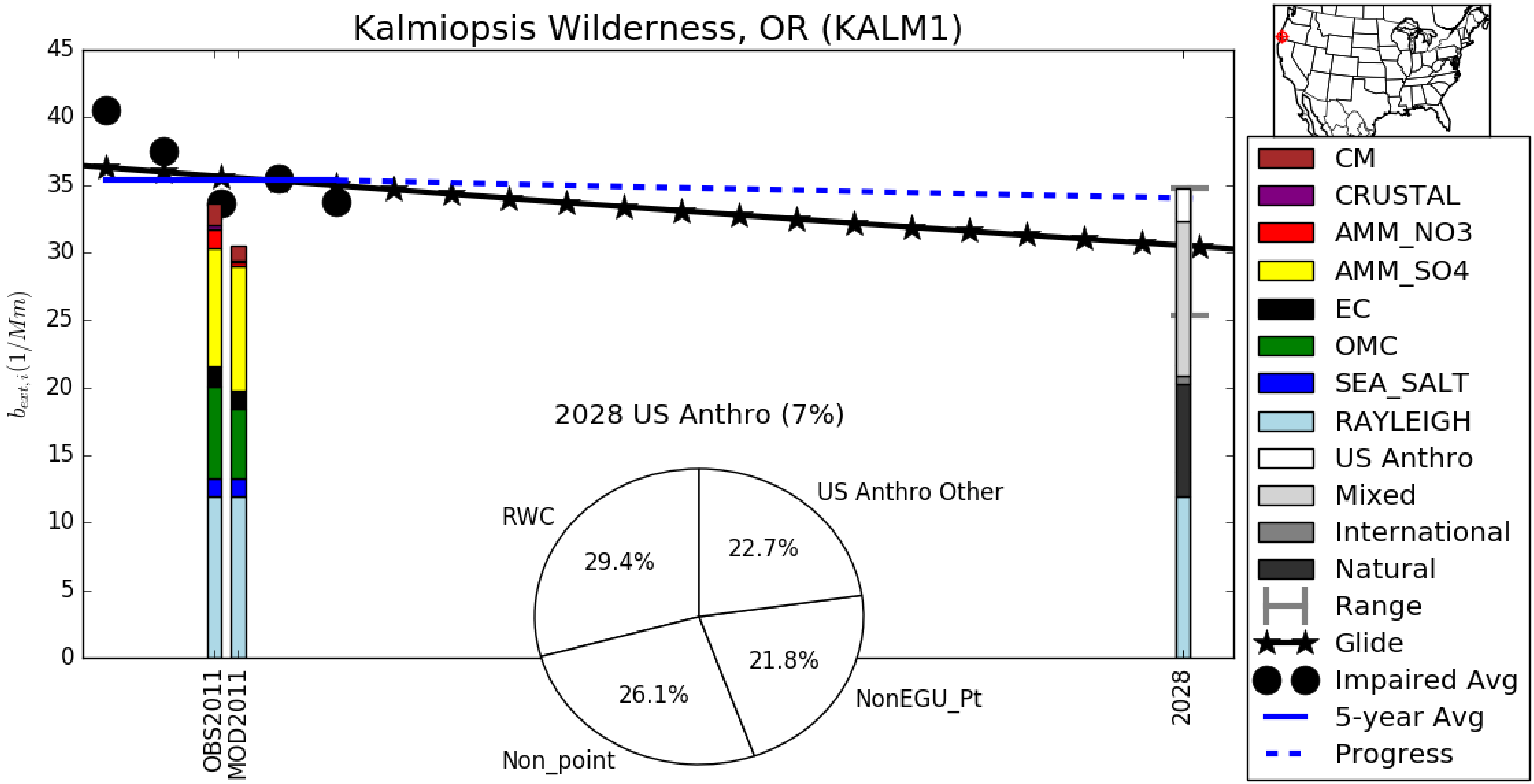


Figure B-11: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Kalmiopsis Wilderness (OR).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

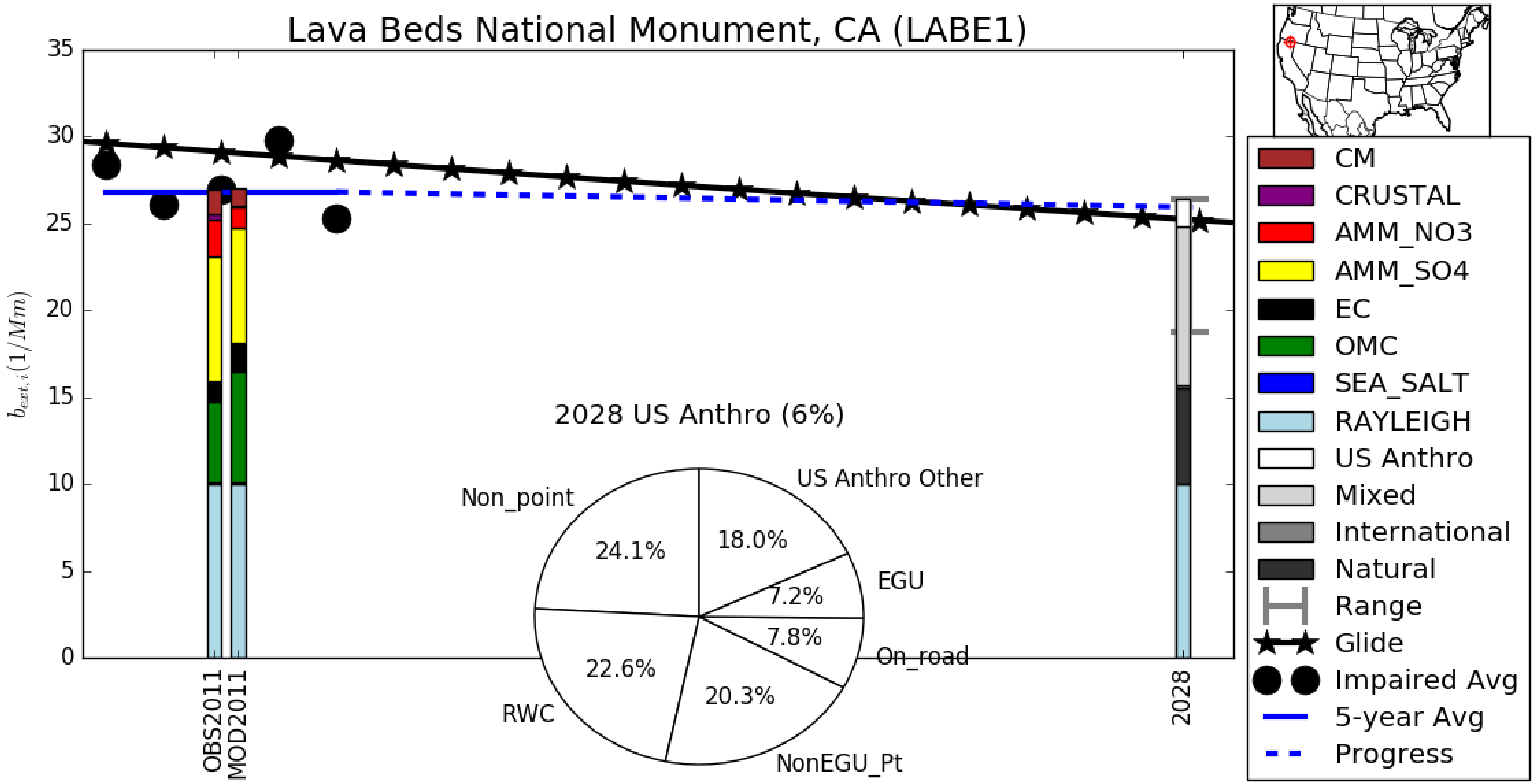


Figure B-12: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Lava Beds National Monument (CA) and South Warner Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

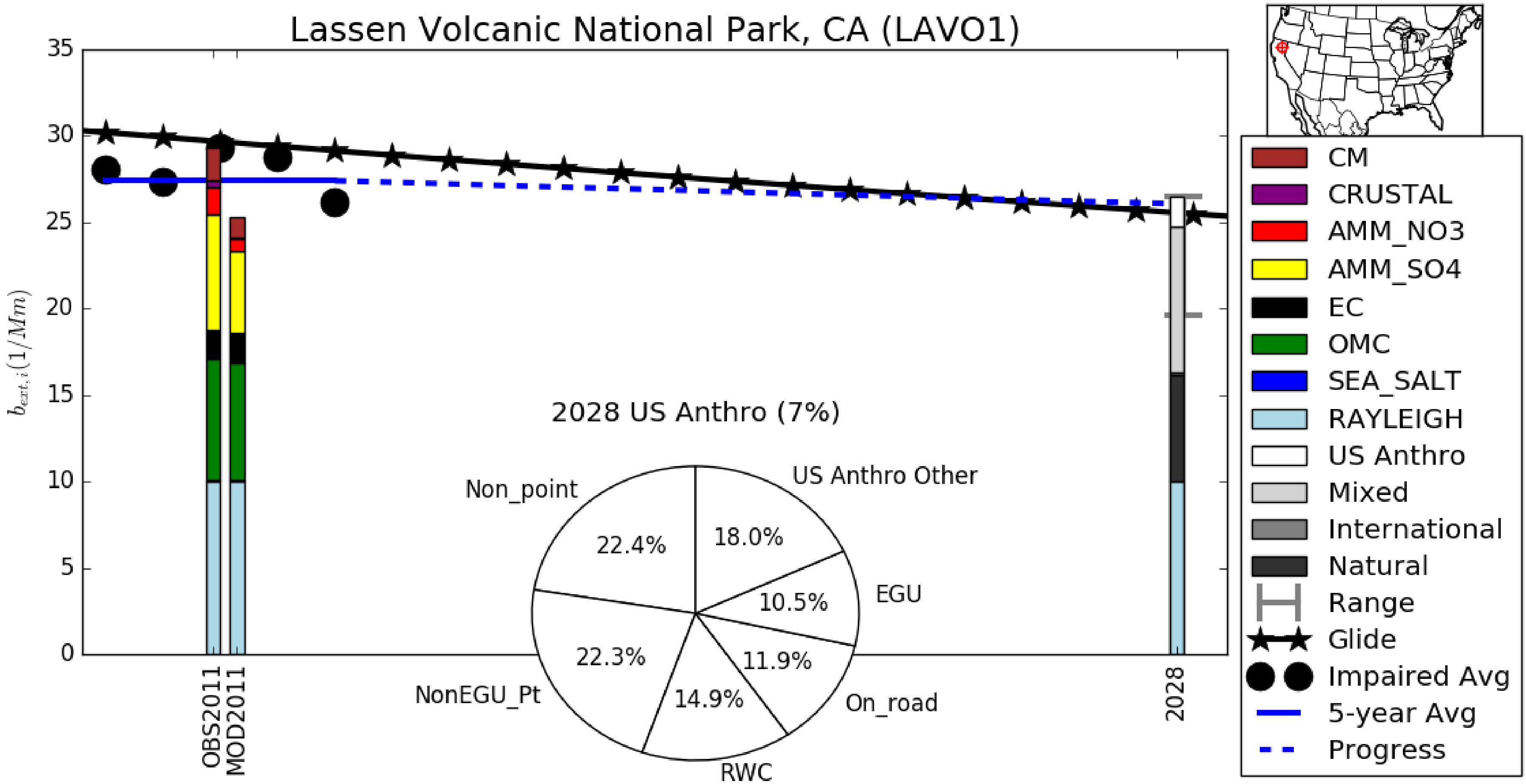


Figure B-13: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Caribou Wilderness (CA), Lassen Volcanic National Park (CA), and Thousand Lakes Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

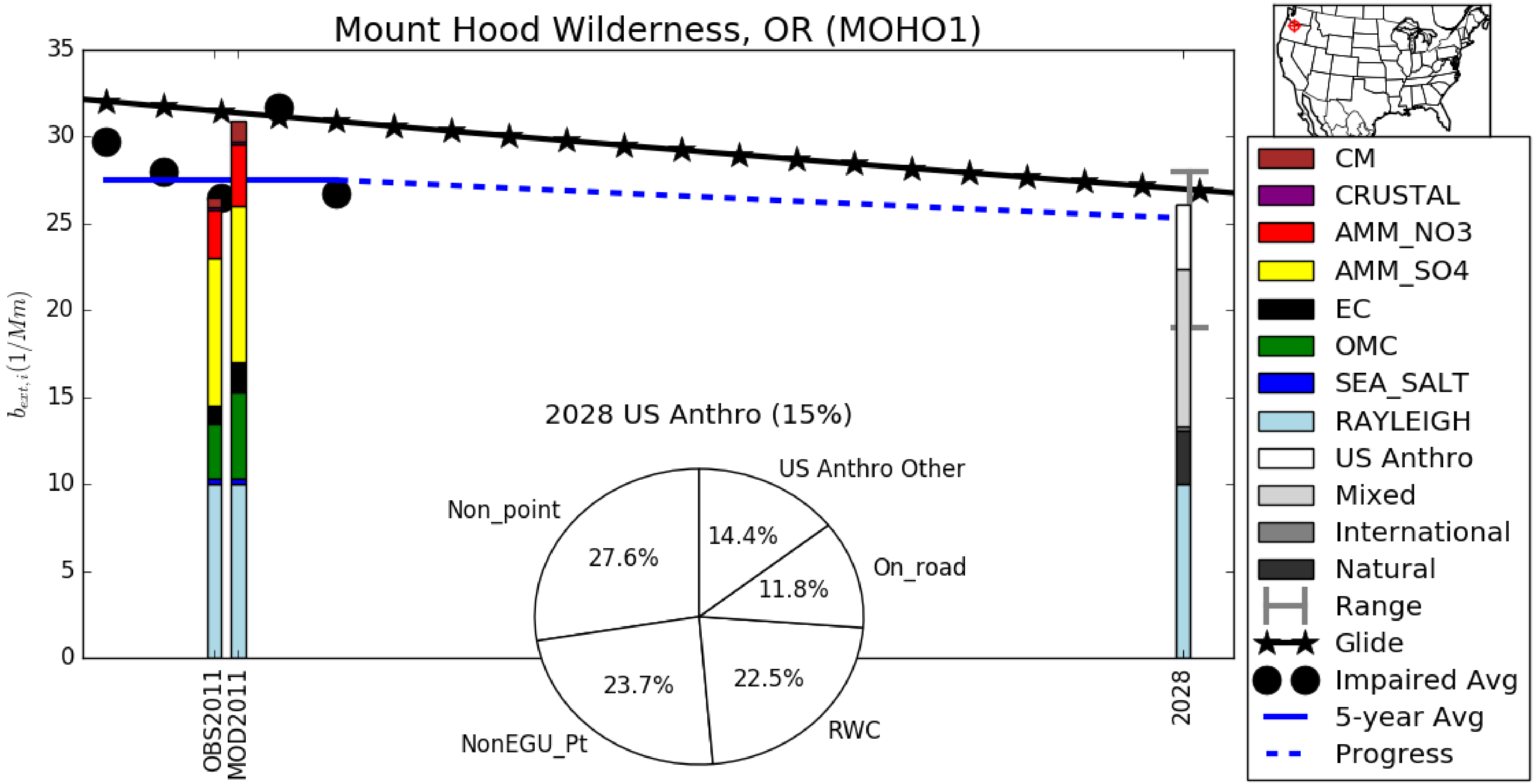


Figure B-14: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Mount Hood Wilderness (OR).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

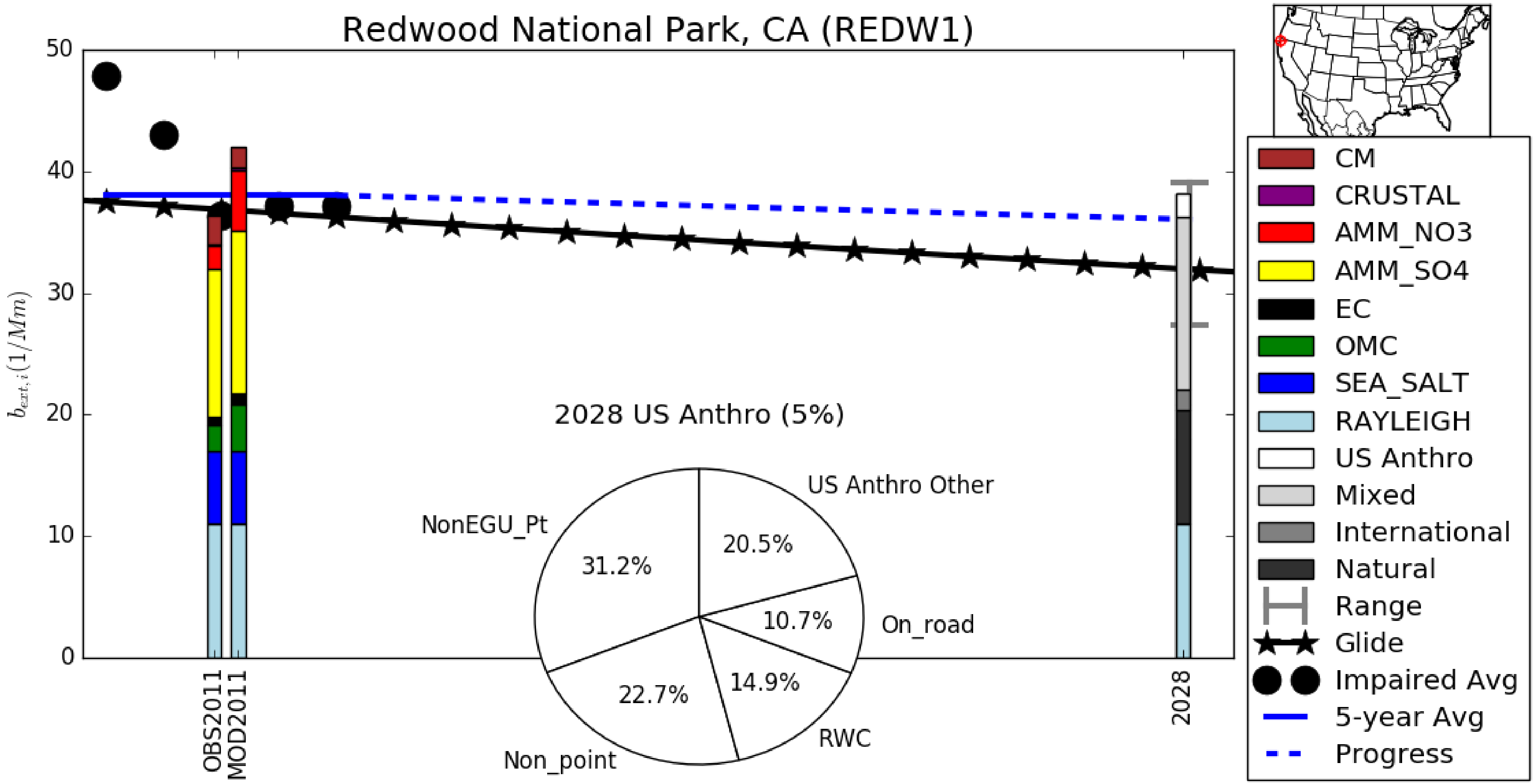


Figure B-15: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Redwood National Park (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

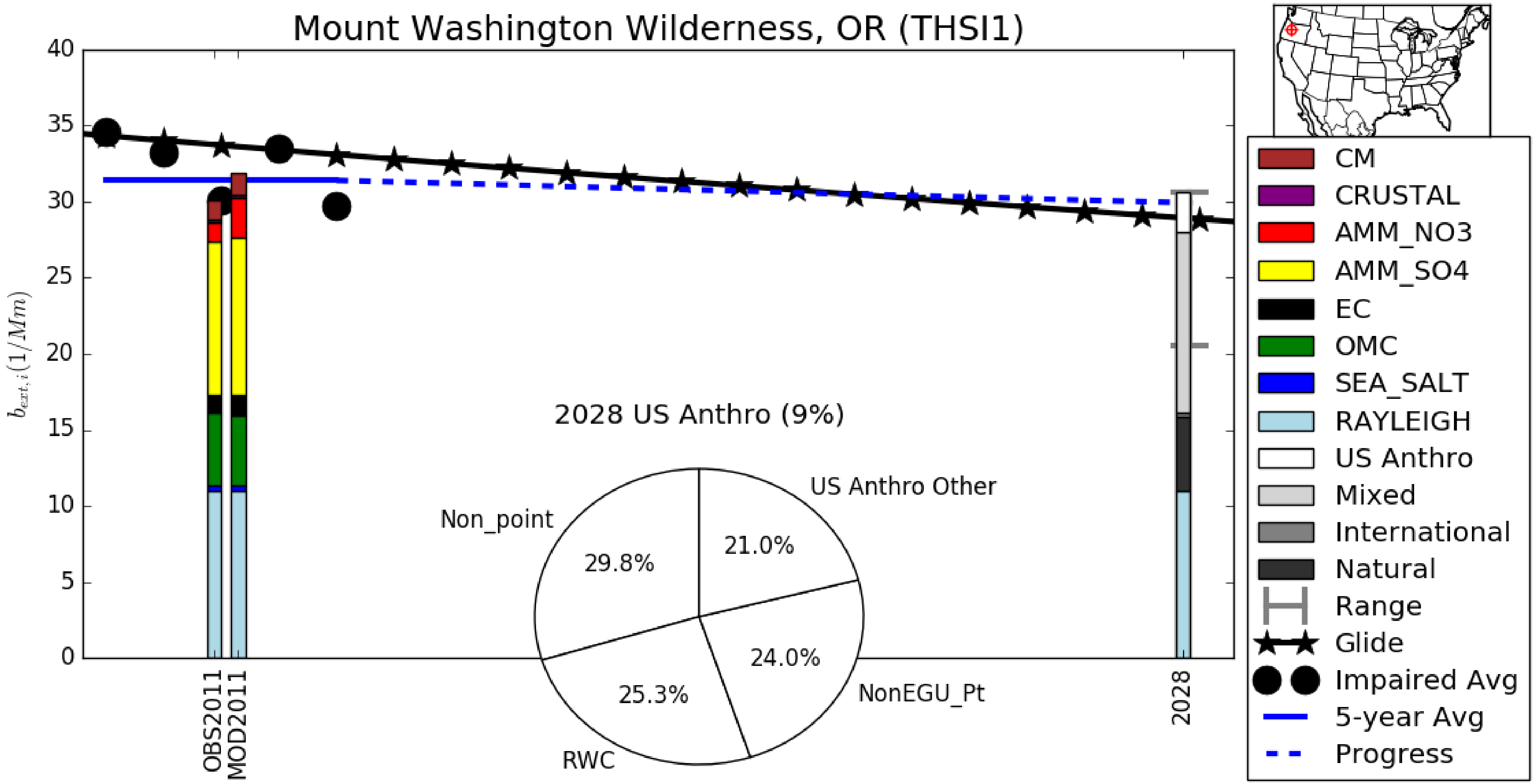


Figure B-16: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Mount Jefferson Wilderness (OR), Mount Washington Wilderness (OR), and Three Sisters Wilderness (OR).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

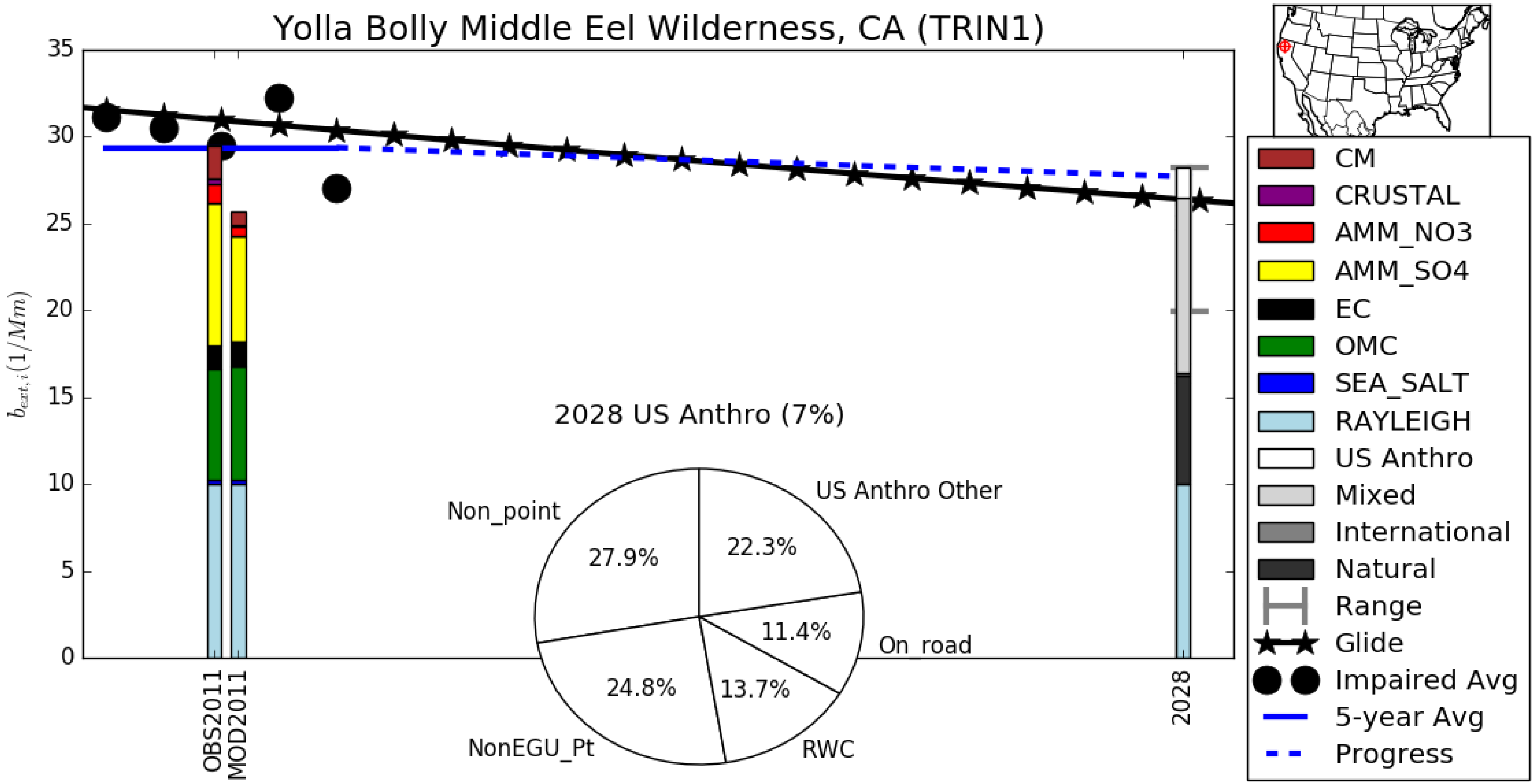


Figure B-17: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Marble Mountain Wilderness (CA) and Yolla Bolly Middle Eel Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

California Coast

- Pinnacles National Monument (CA) and Ventana Wilderness (CA)(PINN1)
- Point Reyes NS (CA)(PORE1)
- San Rafael Wilderness (CA)(RAFA1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, nitrate, relatively high sea salt
Model visibility performance summary (on 20% most impaired days)	Sulfate underpredicted at PINN1 and RAFA1, nitrate underpredicted at PORE1 and RAFA1, coarse mass underpredicted at RAFA
Uncertainty in sector contributions	High “mixed” sector contribution percentage (49%-67%).
2028 US anthropogenic percent contribution	14-28%
Largest US anthropogenic sector contributions	Nonpoint, nonEGU point, On-road, and Residential wood

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high “mixed” (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

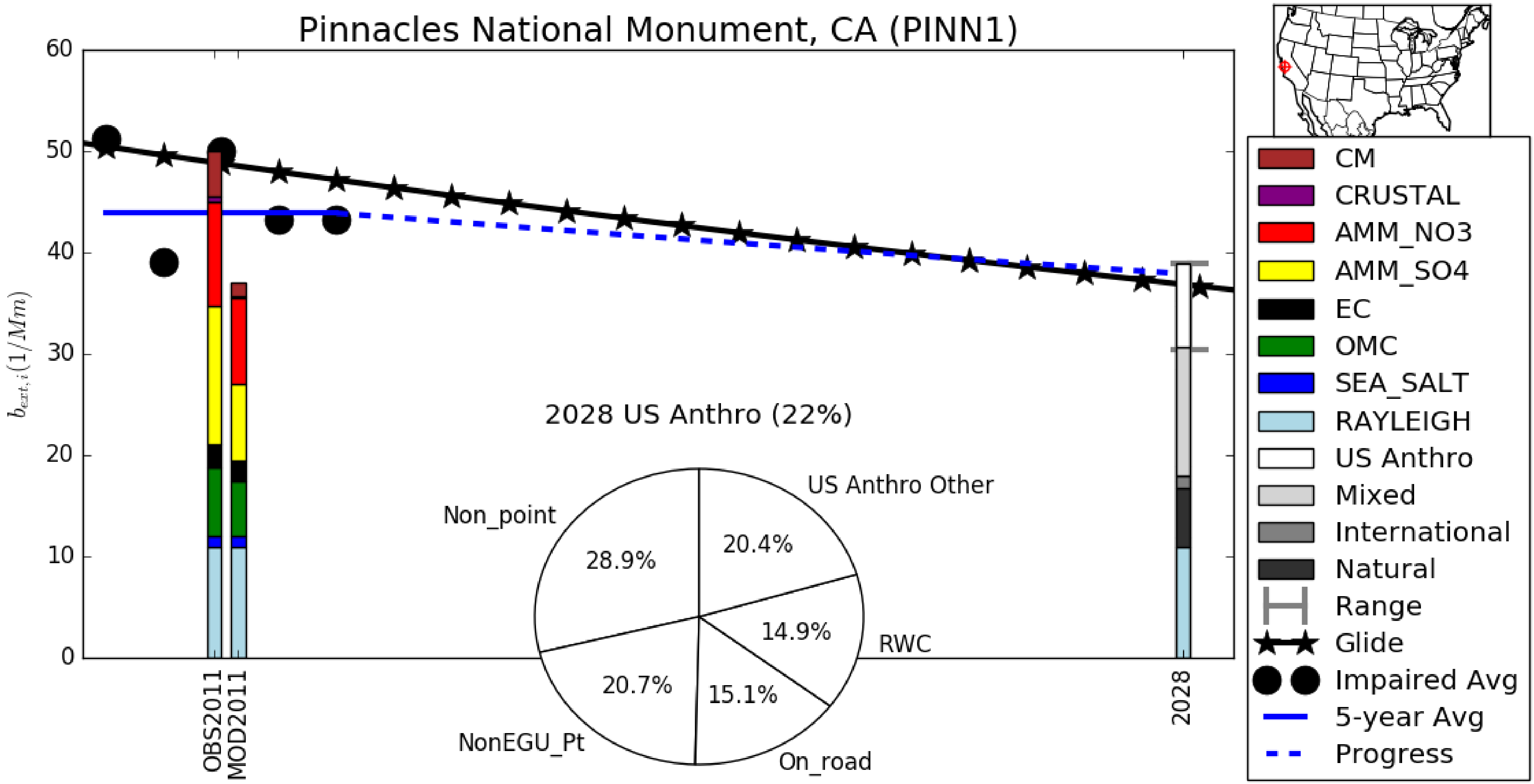


Figure B-18: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Pinnacles National Monument (CA) and Ventana Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

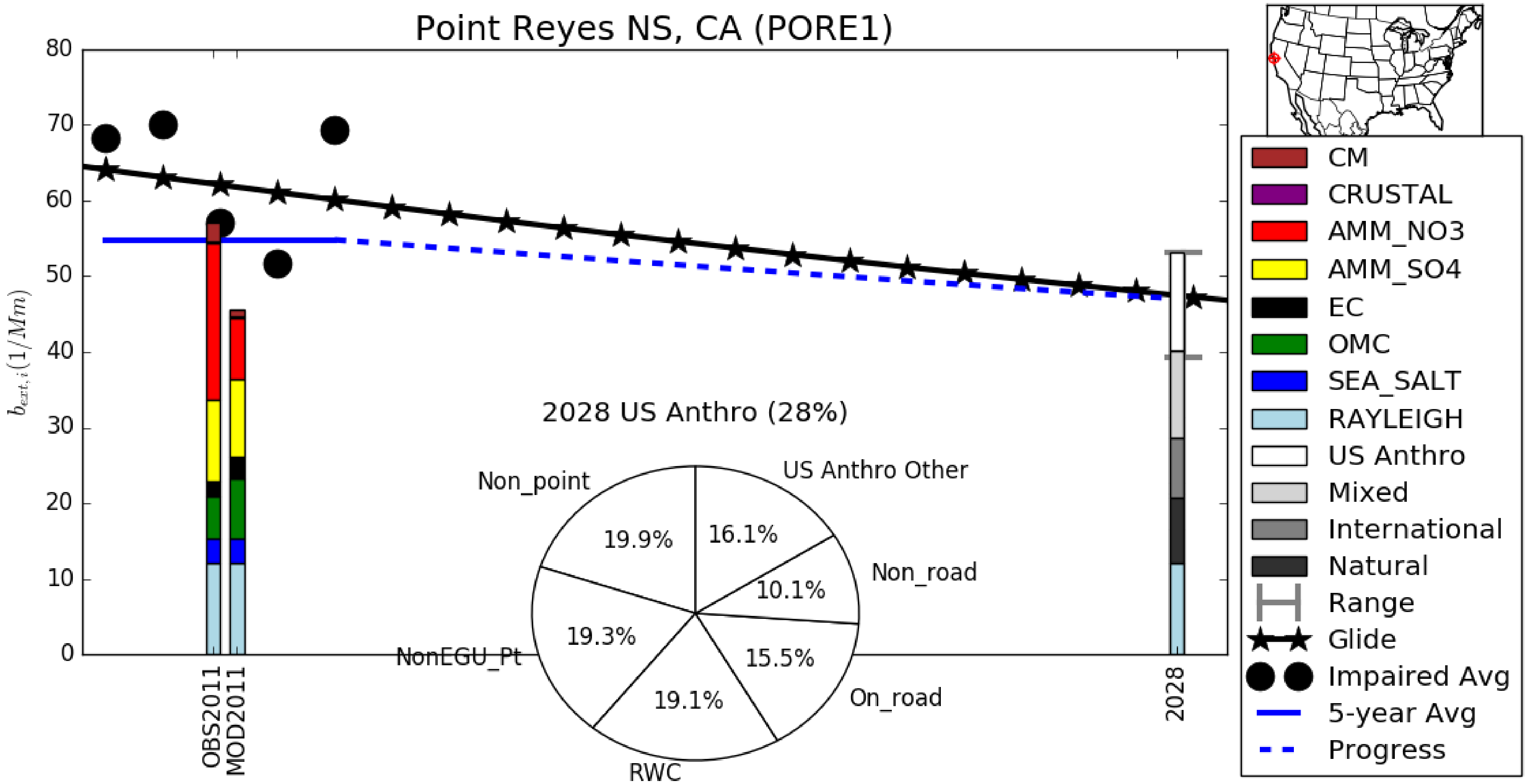


Figure B-19: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Point Reyes NS (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

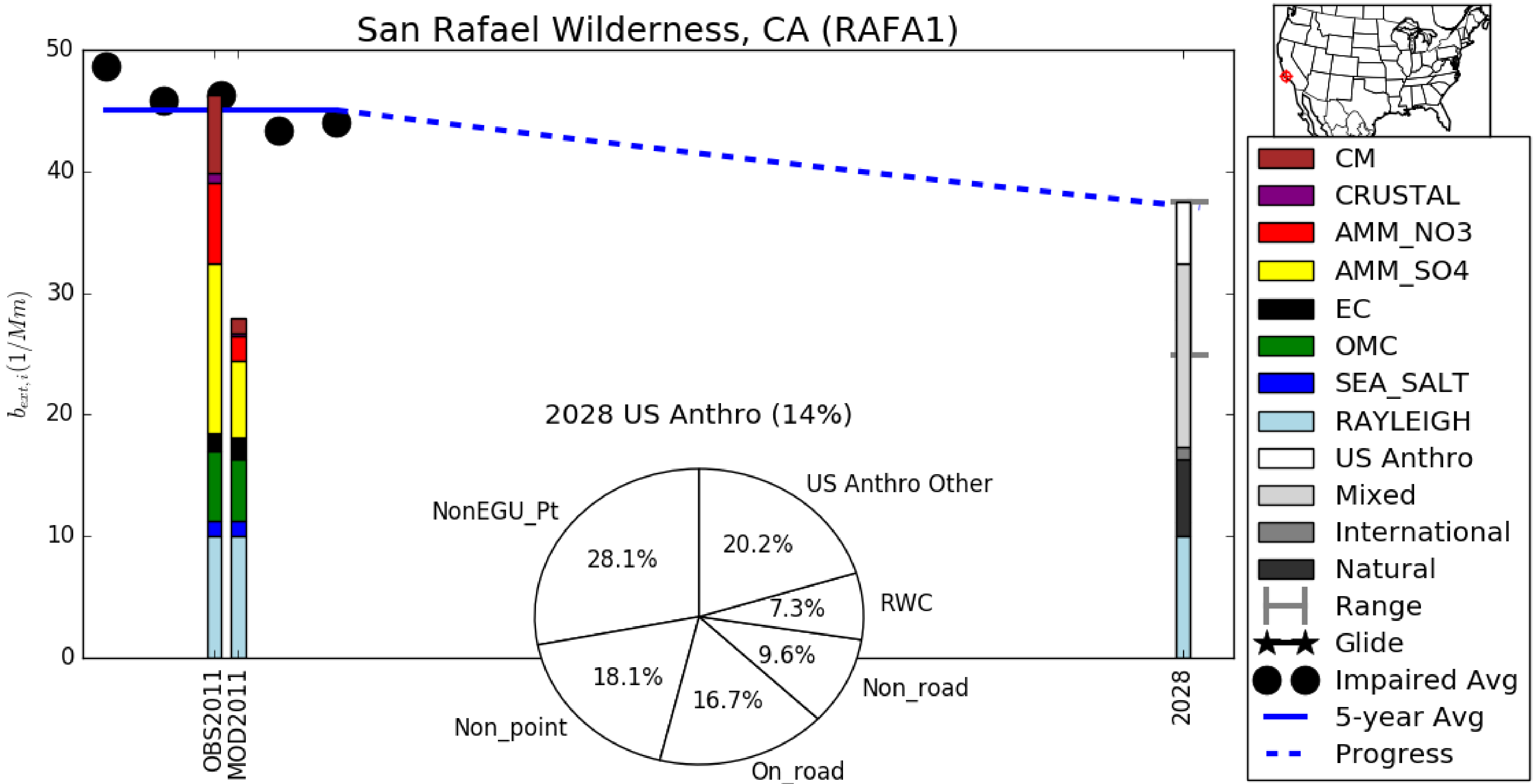


Figure B-20: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at San Rafael Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

Sierra Nevada

- Dome Land Wilderness (CA)(DOME1)
- Hoover Wilderness (CA)(HOOV1)
- Ansel Adams Wilderness (Minarets) (CA), John Muir Wilderness (CA), and Kaiser Wilderness (CA)(KAIS1)
- Kings Canyon National Park (CA) and Sequoia National Park (CA)(SEQU1)

Emigrant Wilderness (CA) and Yosemite National Park (CA)(YOSE1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, nitrate
Model visibility performance summary (on 20% most impaired days)	Very large sulfate and nitrate underpredictions, except at HOOV1 SEQU1 is the worst performing site in the country (especially large underprediction of nitrate)
Uncertainty in sector contributions	High "mixed" sector contribution percentage (49%-67%).
2028 US anthropogenic percent contribution	10-26%
Largest US anthropogenic sector contributions	Nonpoint, nonEGU point, On-road, and Residential wood

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

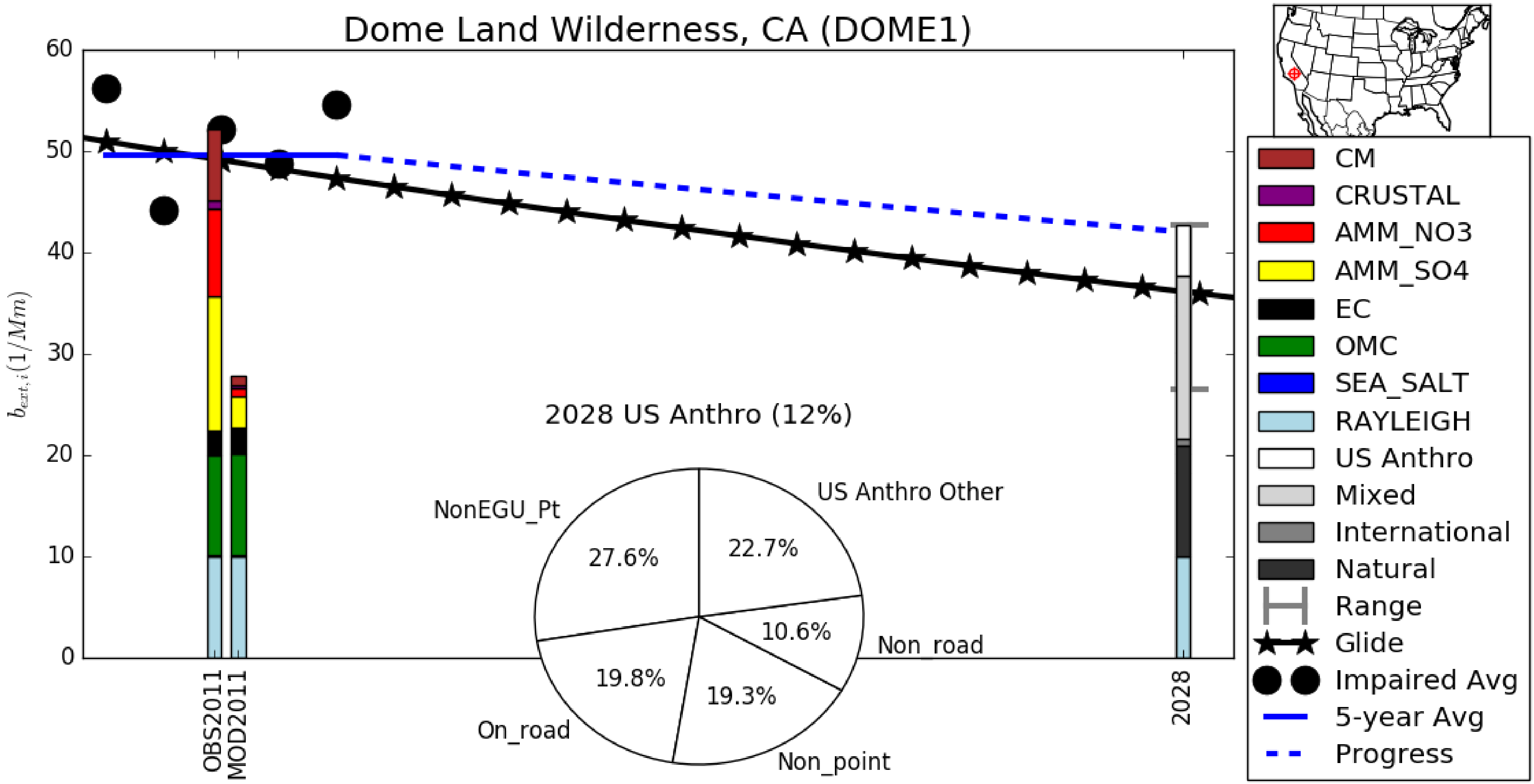


Figure B-21: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Dome Land Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

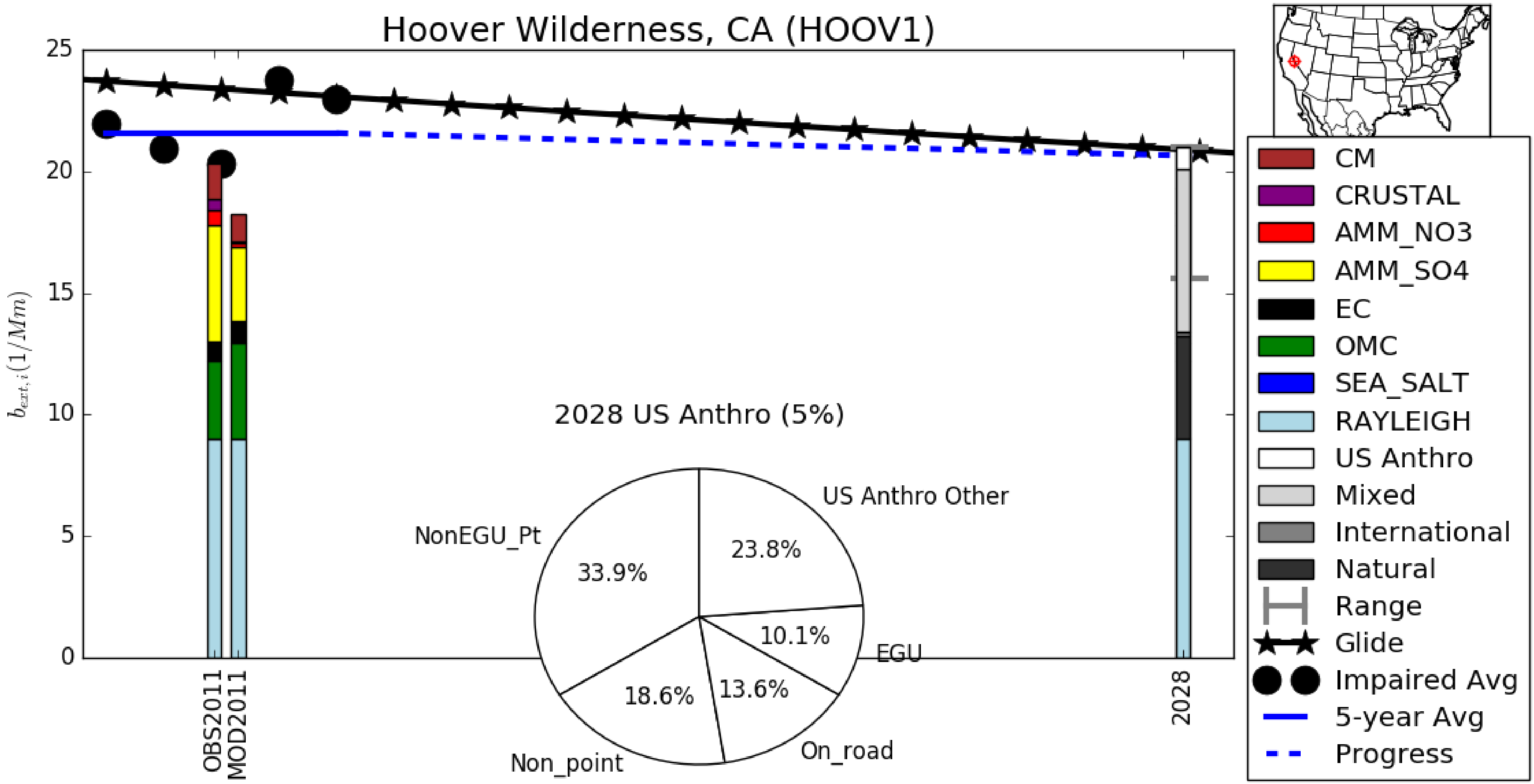


Figure B-22: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Hoover Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

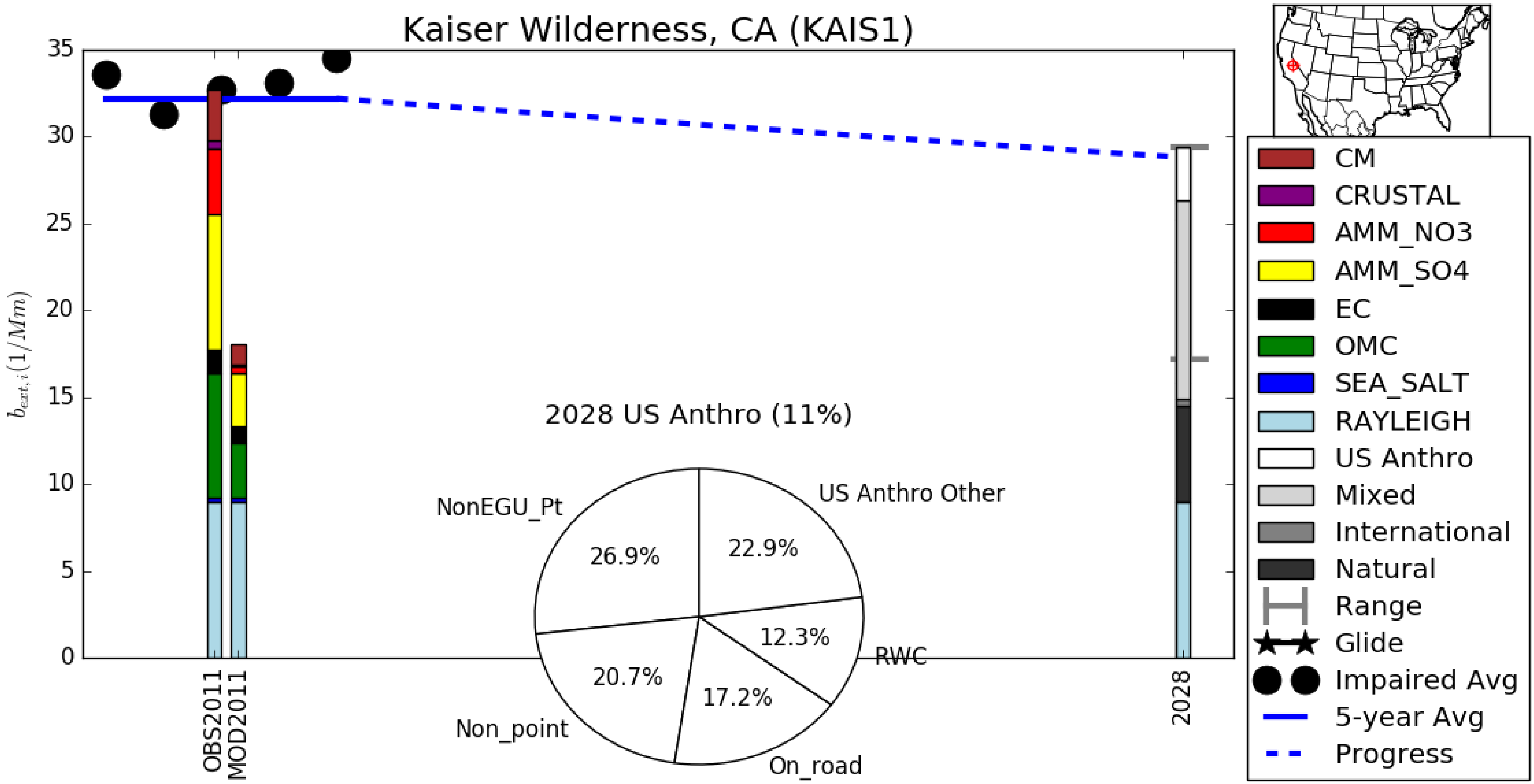


Figure B-23: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Ansel Adams Wilderness (Minarets) (CA), John Muir Wilderness (CA), and Kaiser Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

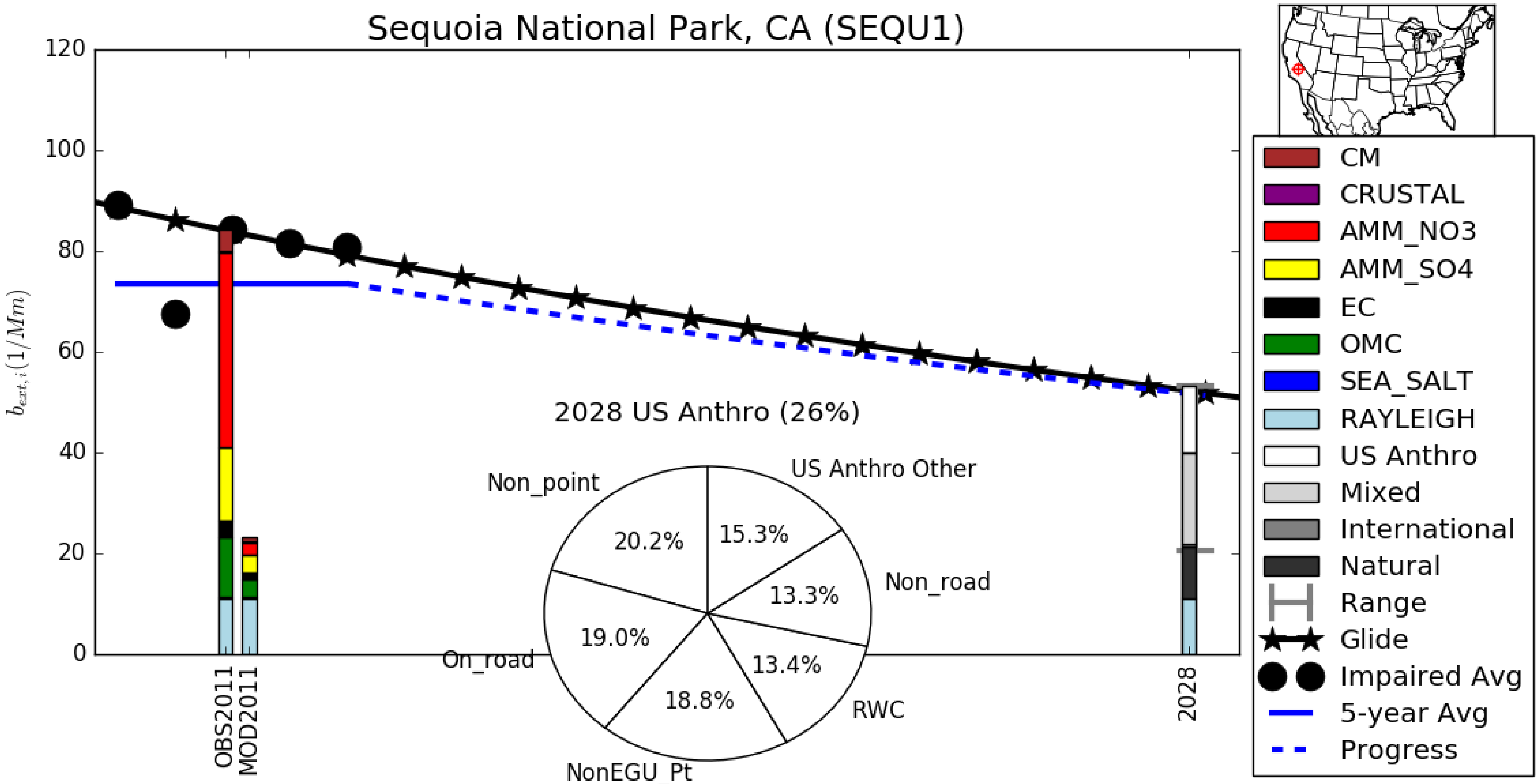


Figure B-24: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Kings Canyon National Park (CA) and Sequoia National Park (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

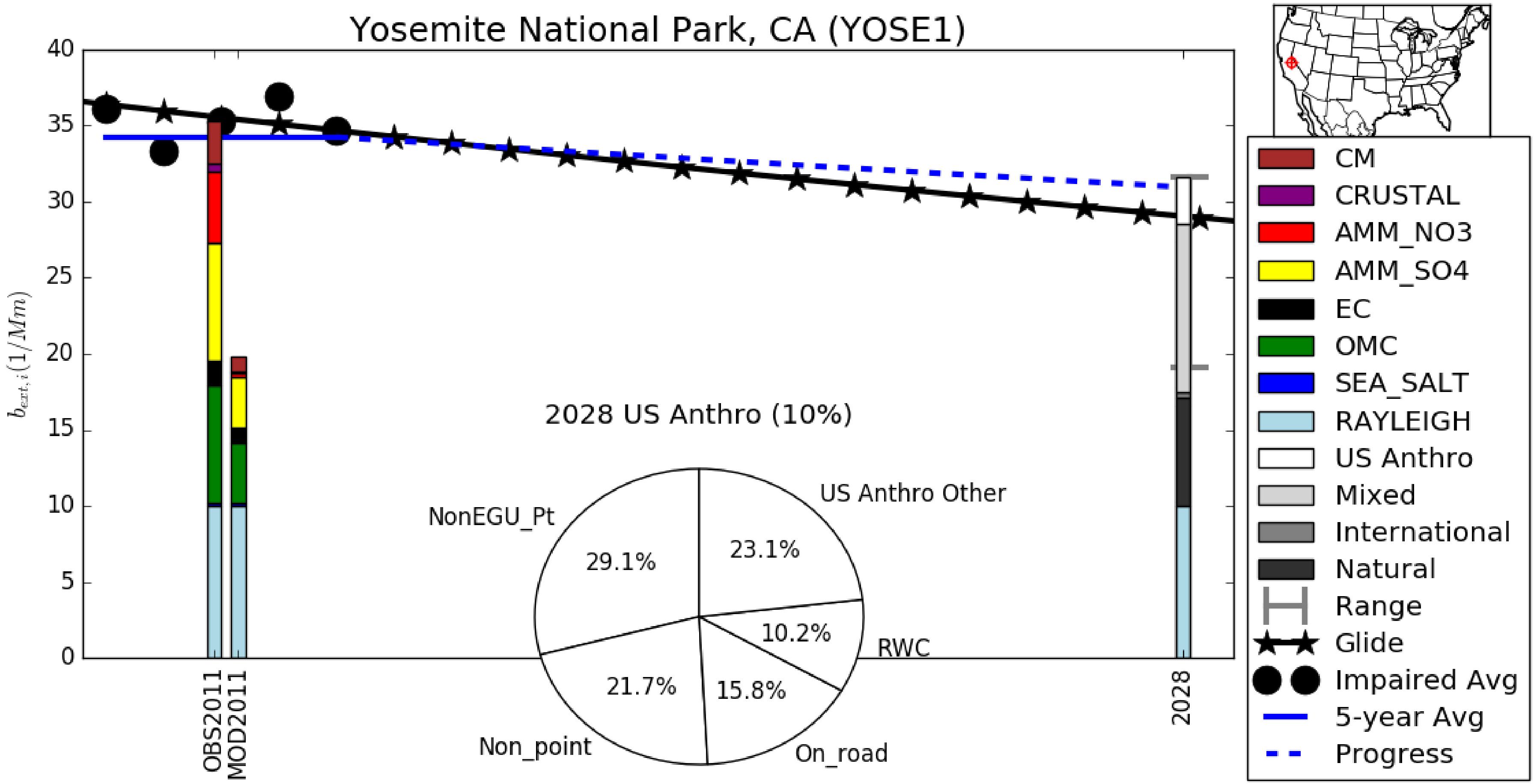


Figure B-25: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Emigrant Wilderness (CA) and Yosemite National Park (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Southern California

- Agua Tibia Wilderness (CA)(AGTI1)
- Joshua Tree National Monument (CA)(JOSH1)
- Cucamonga Wilderness (CA) and San Gabriel Wilderness (CA)(SAGA1)
- San Gorgonio Wilderness (CA) and San Jacinto Wilderness (CA)(SAGO1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, nitrate
Model visibility performance summary (on 20% most impaired days)	Large nitrate underpredictions, except at SAGA1 Sulfate underpredicted at AGTI1
Uncertainty in sector contributions	Relatively high "mixed" sector contribution percentage (44%-59%).
2028 US anthropogenic percent contribution	20-37%
Largest US anthropogenic sector contributions	Nonpoint, nonEGU point, On-road, and Non-road

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

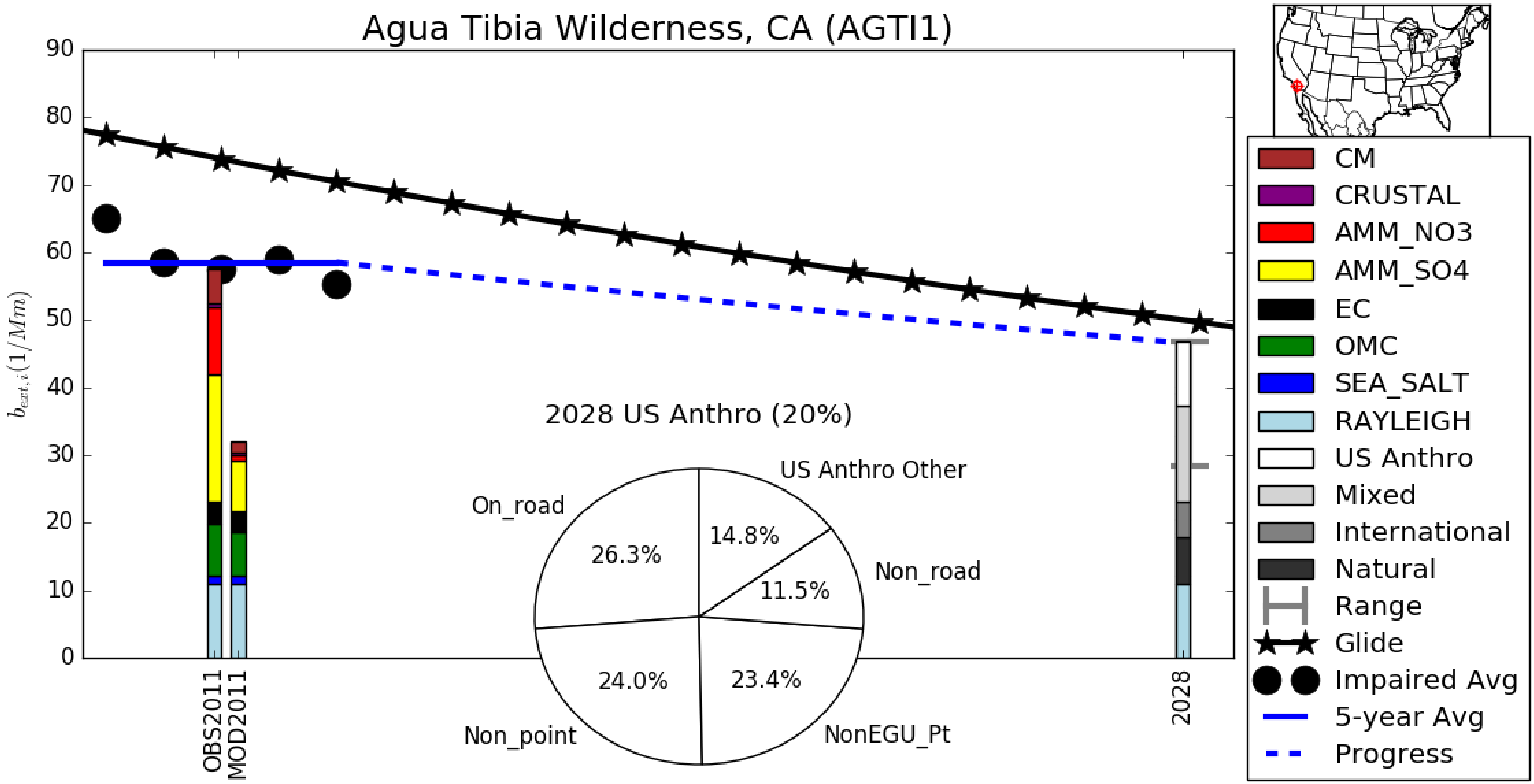


Figure B-26: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Agua Tibia Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

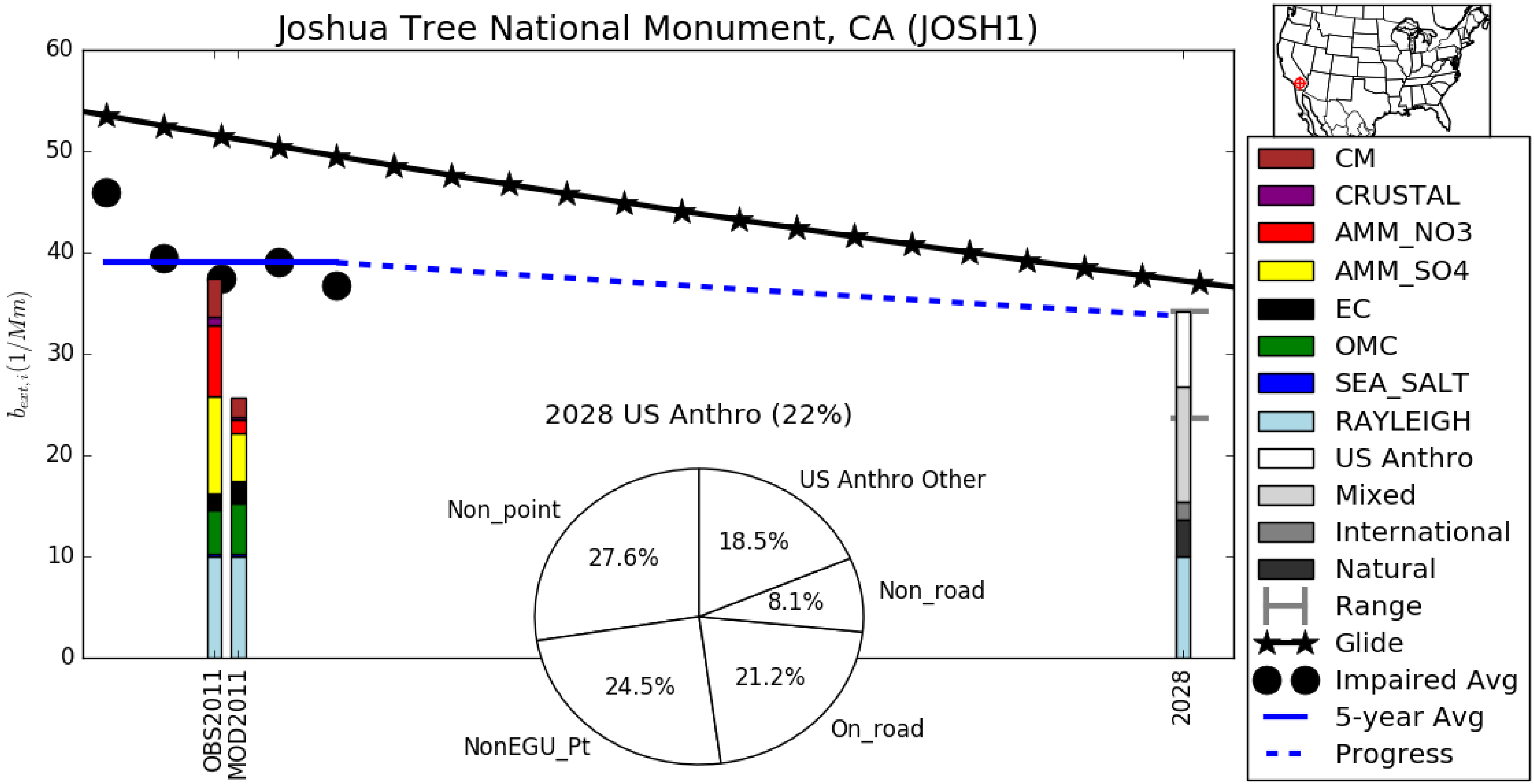


Figure B-27: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Joshua Tree National Monument (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

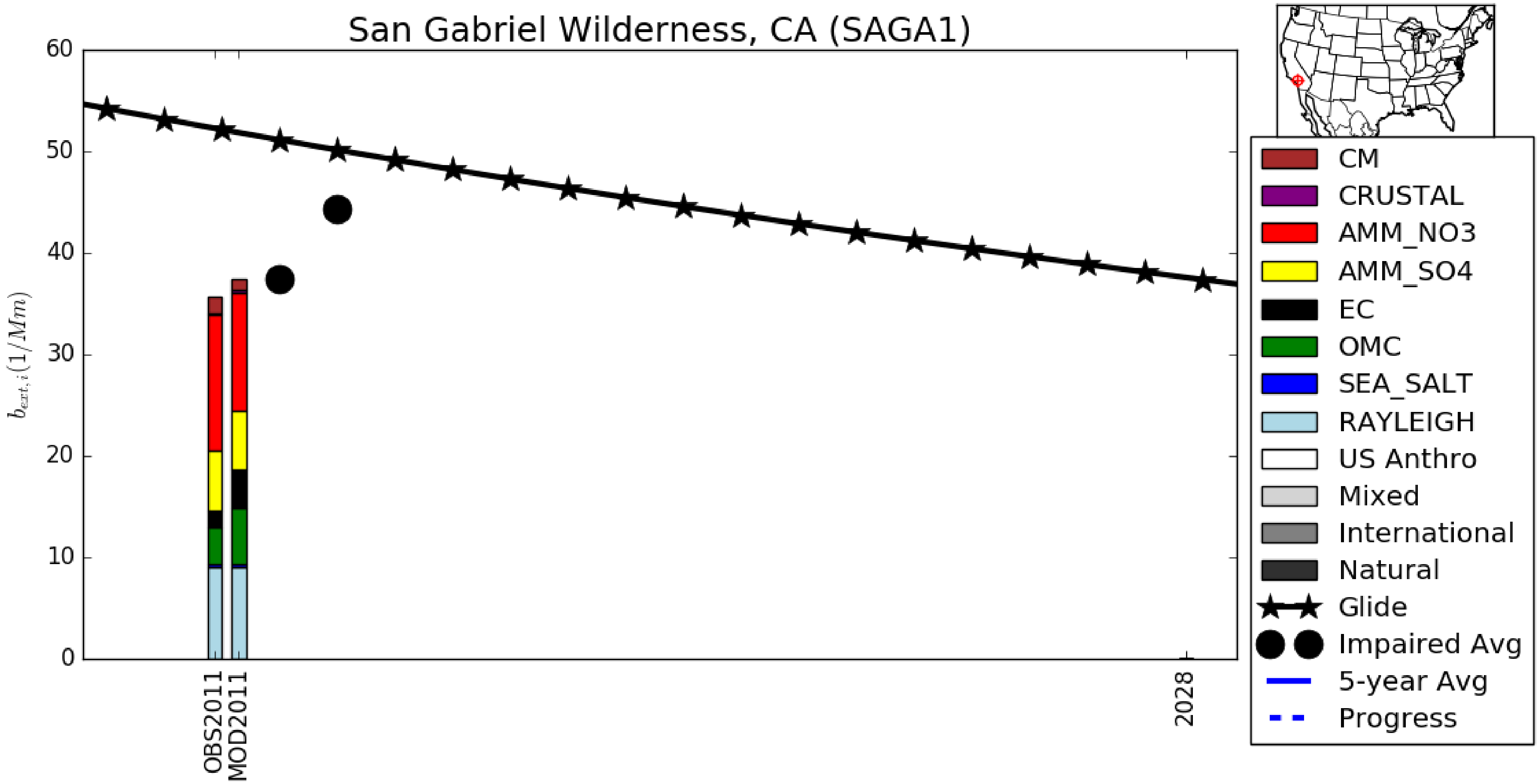


Figure B-28: 2011 IMPROVE observations and 2011 CAMx model predictions at Cucamonga Wilderness (CA) and San Gabriel Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

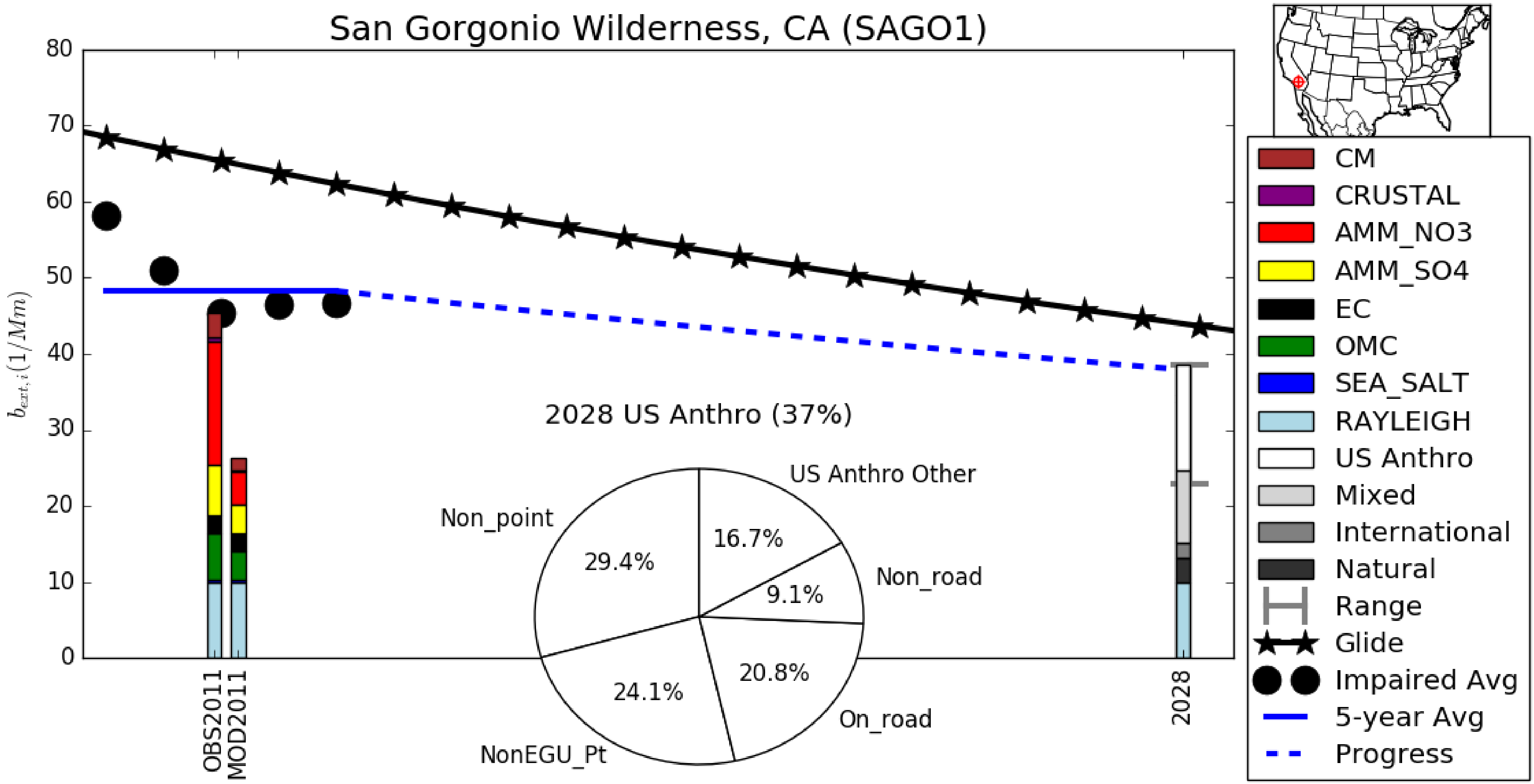


Figure B-29: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at San Gorgonio Wilderness (CA) and San Jacinto Wilderness (CA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Northern Rocky Mountains

- Bridger Wilderness (WY) and Fitzpatrick Wilderness (WY)(BRID1)
- Cabinet Mountains Wilderness (MT)(CABI1)
- Gates of the Mountains Wilderness (MT)(GAMO1)
- Glacier National Park (MT)(GLAC1)
- Bob Marshall Wilderness (MT), Mission Mountains Wilderness (MT), and Scapegoat Wilderness (MT)(MONT1)
- North Absaroka Wilderness (WY) and Washakie Wilderness (WY)(NOAB1)
- Anaconda-Pintler Wilderness (MT) and Selway-Bitterroot Wilderness (MT)(SULA1)
- Grand Teton National Park (WY), Red Rock Lakes (WY), Teton Wilderness (WY), and Yellowstone National Park (WY)(YELL2)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, organic carbon, nitrate
Model visibility performance summary (on 20% most impaired days)	Performance generally good Large nitrate underprediction at YELL2
Uncertainty in sector contributions	High "mixed" sector contribution percentage (>60% at all sites except MONT1 [52%]).
2028 US anthropogenic percent contribution	4-10%
Largest US anthropogenic sector contributions	Residential wood, Nonpoint, nonEGU point, On-road (at YELL2), EGU and Oil & gas (at BRID1), Prescribed fires (at CABI1)

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

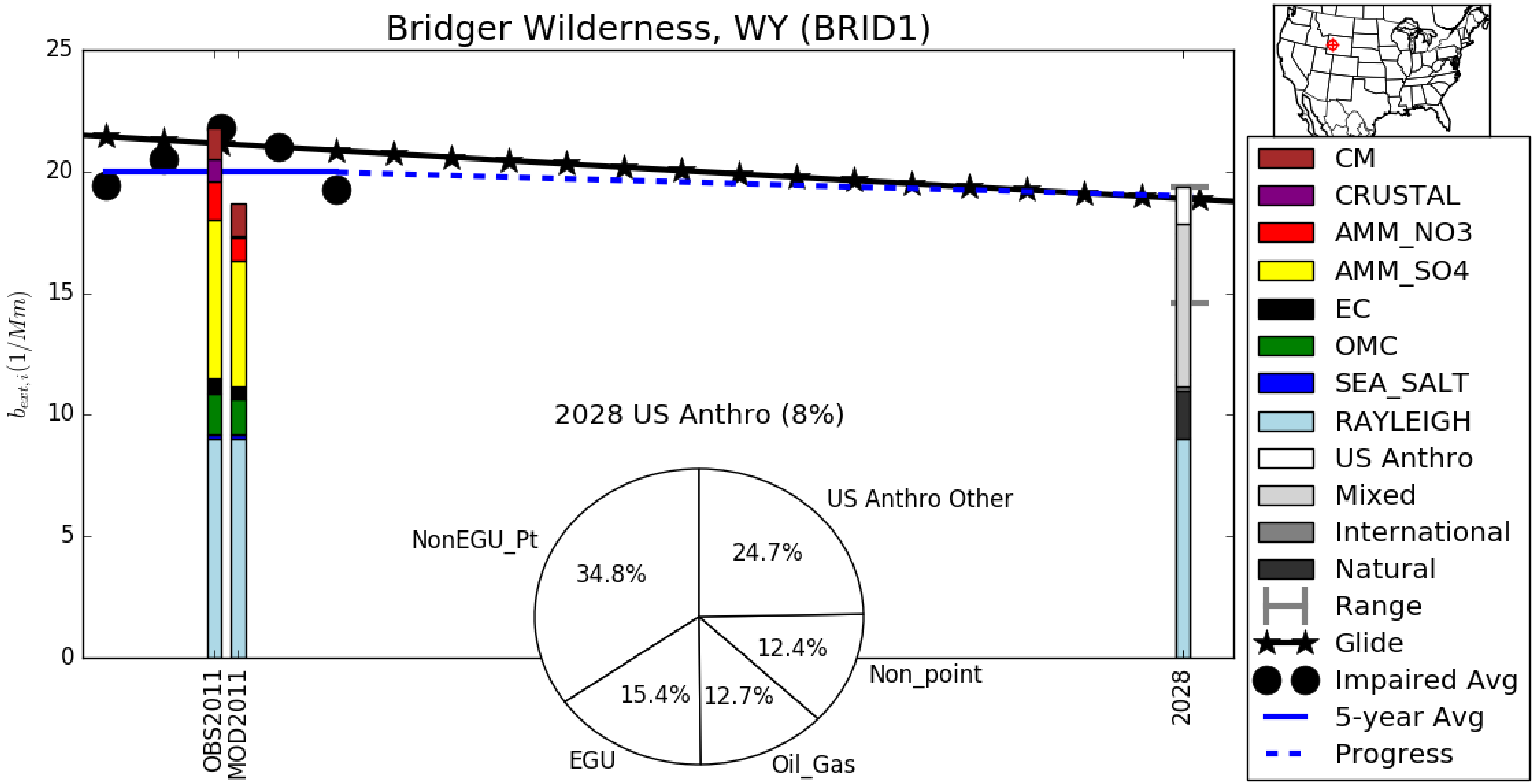


Figure B-30: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Bridger Wilderness (WY) and Fitzpatrick Wilderness (WY).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

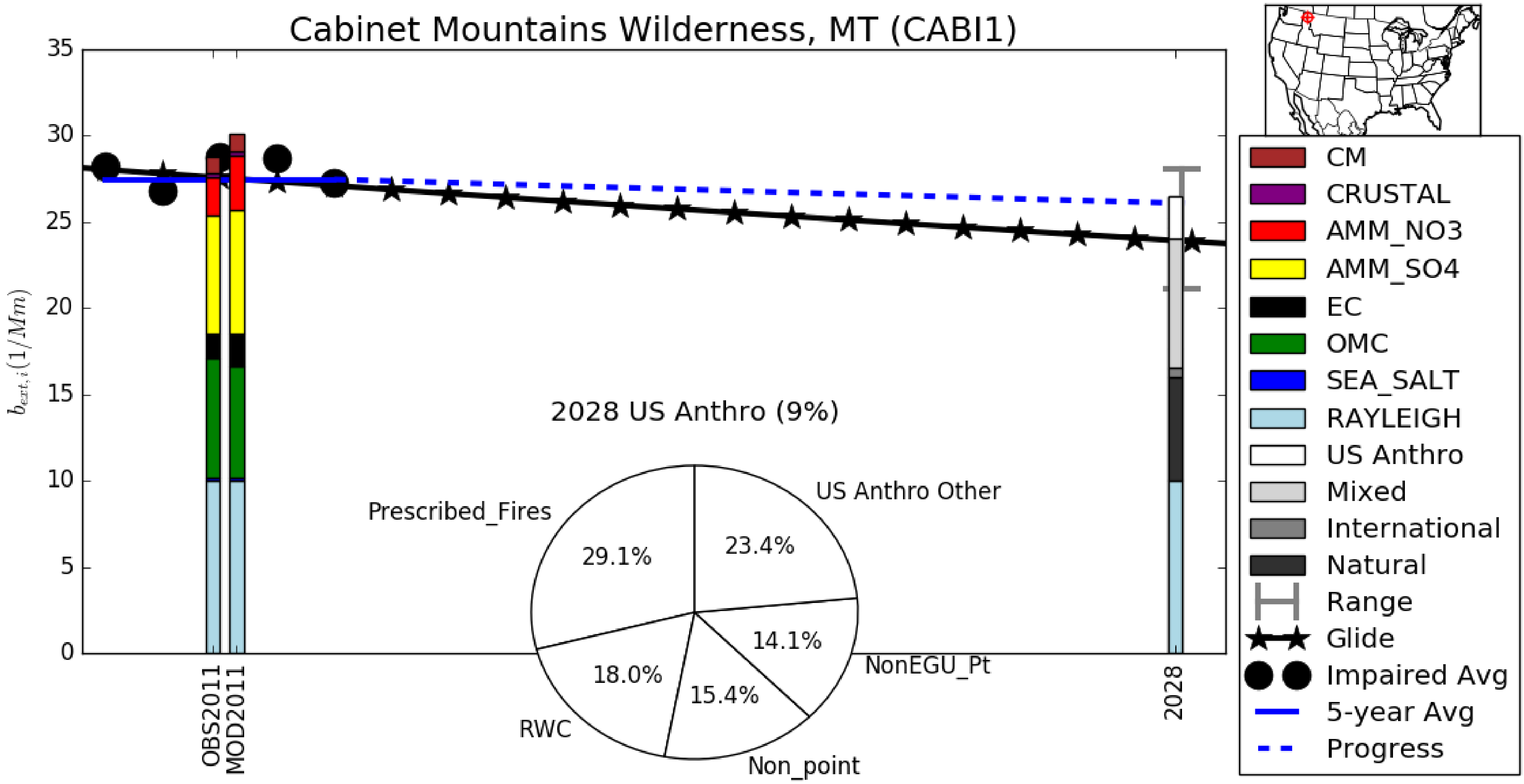


Figure B-31: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Cabinet Mountains Wilderness (MT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

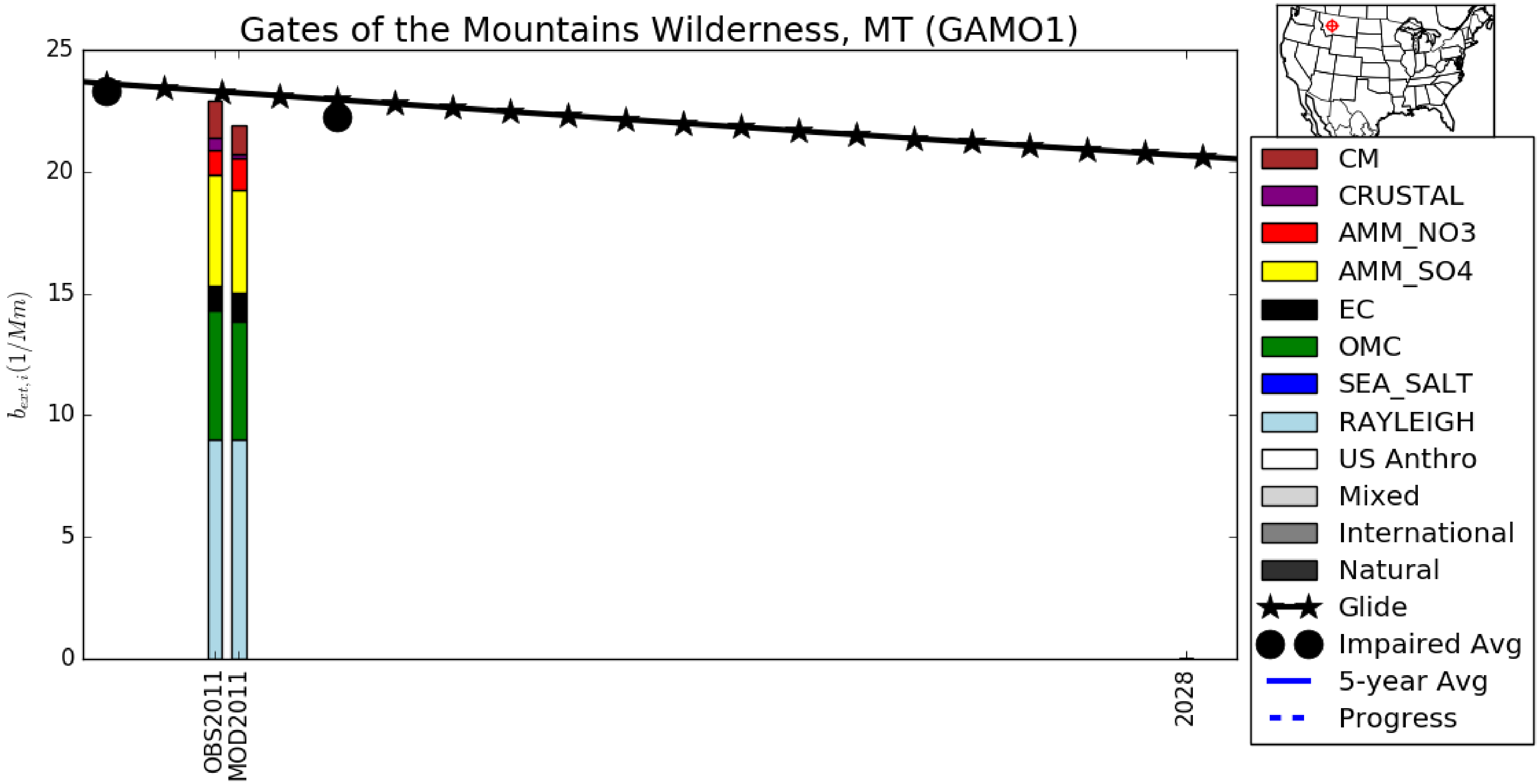


Figure B-32: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Gates of the Mountains Wilderness (MT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

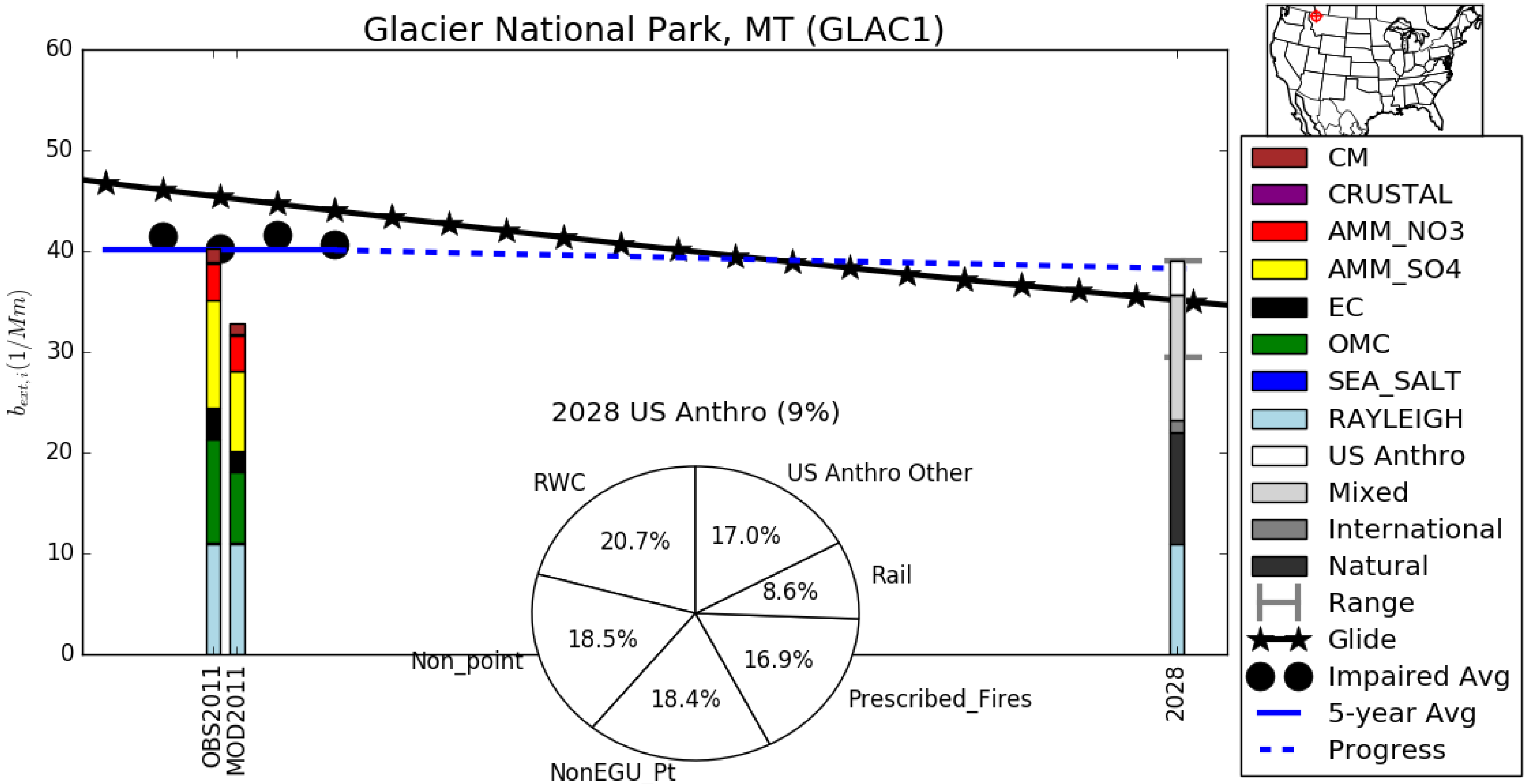


Figure B-33: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Glacier National Park (MT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

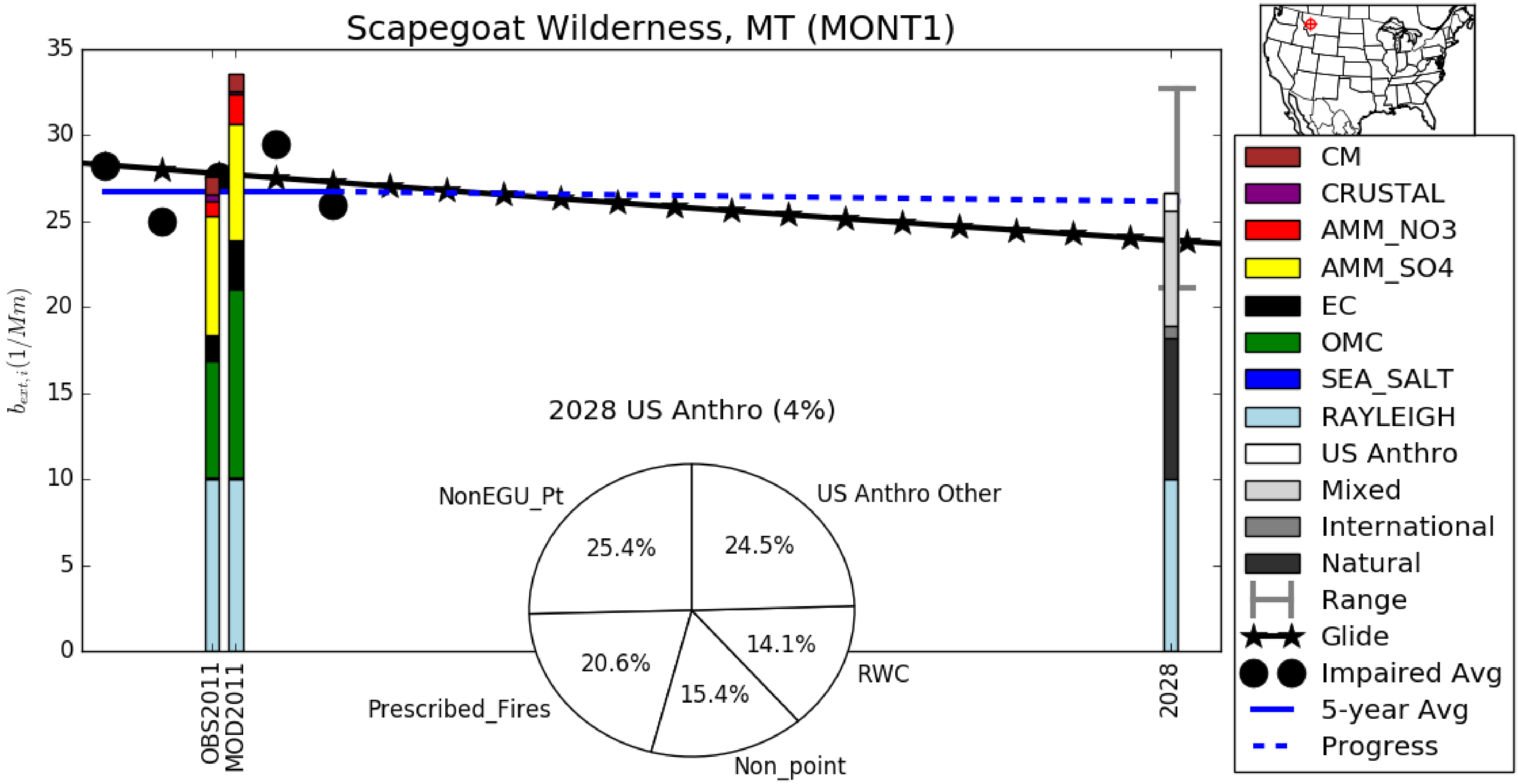


Figure B-34: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Bob Marshall Wilderness (MT), Mission Mountains Wilderness (MT), and Scapegoat Wilderness (MT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

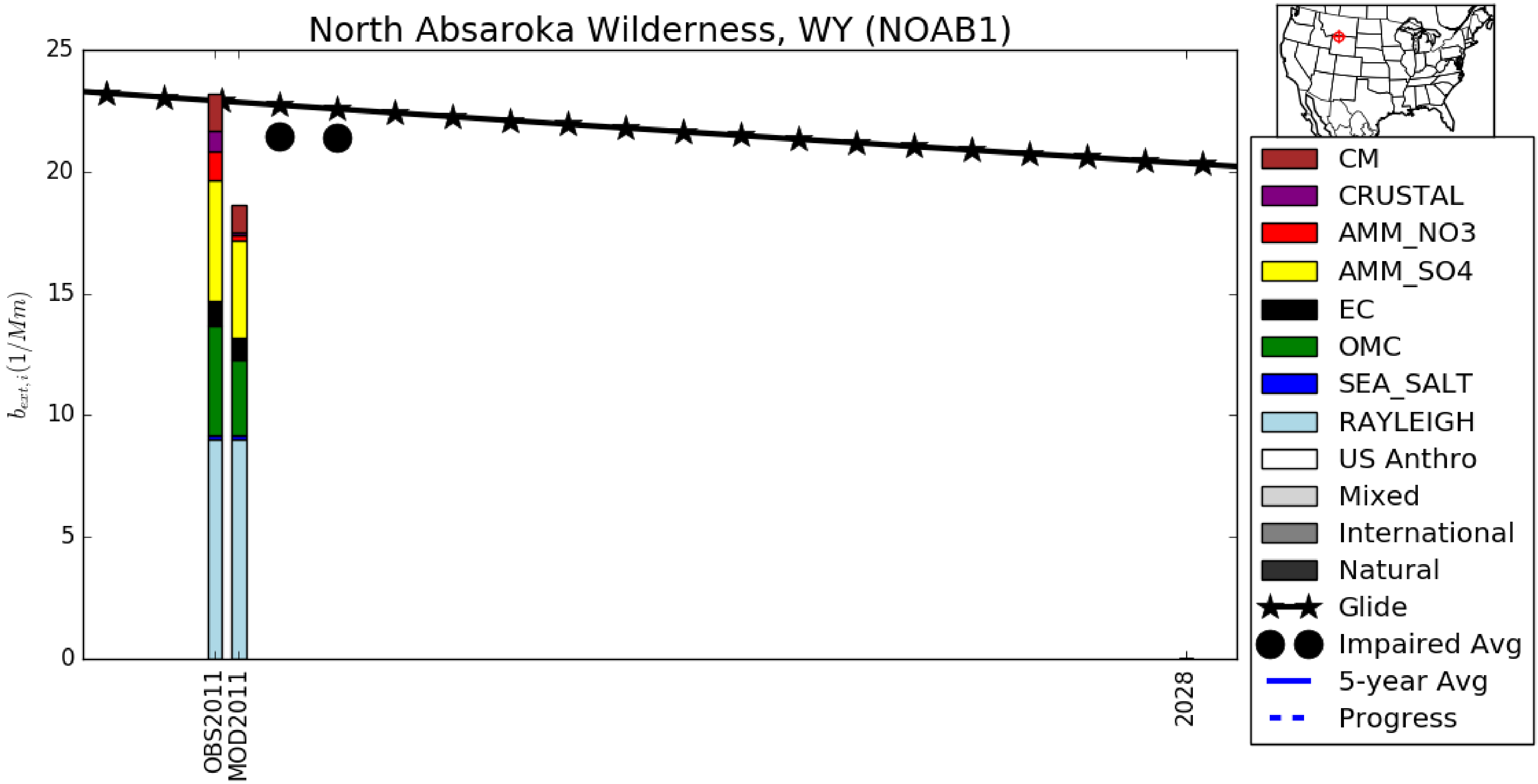


Figure B-35: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at North Absaroka Wilderness (WY) and Washakie Wilderness (WY).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

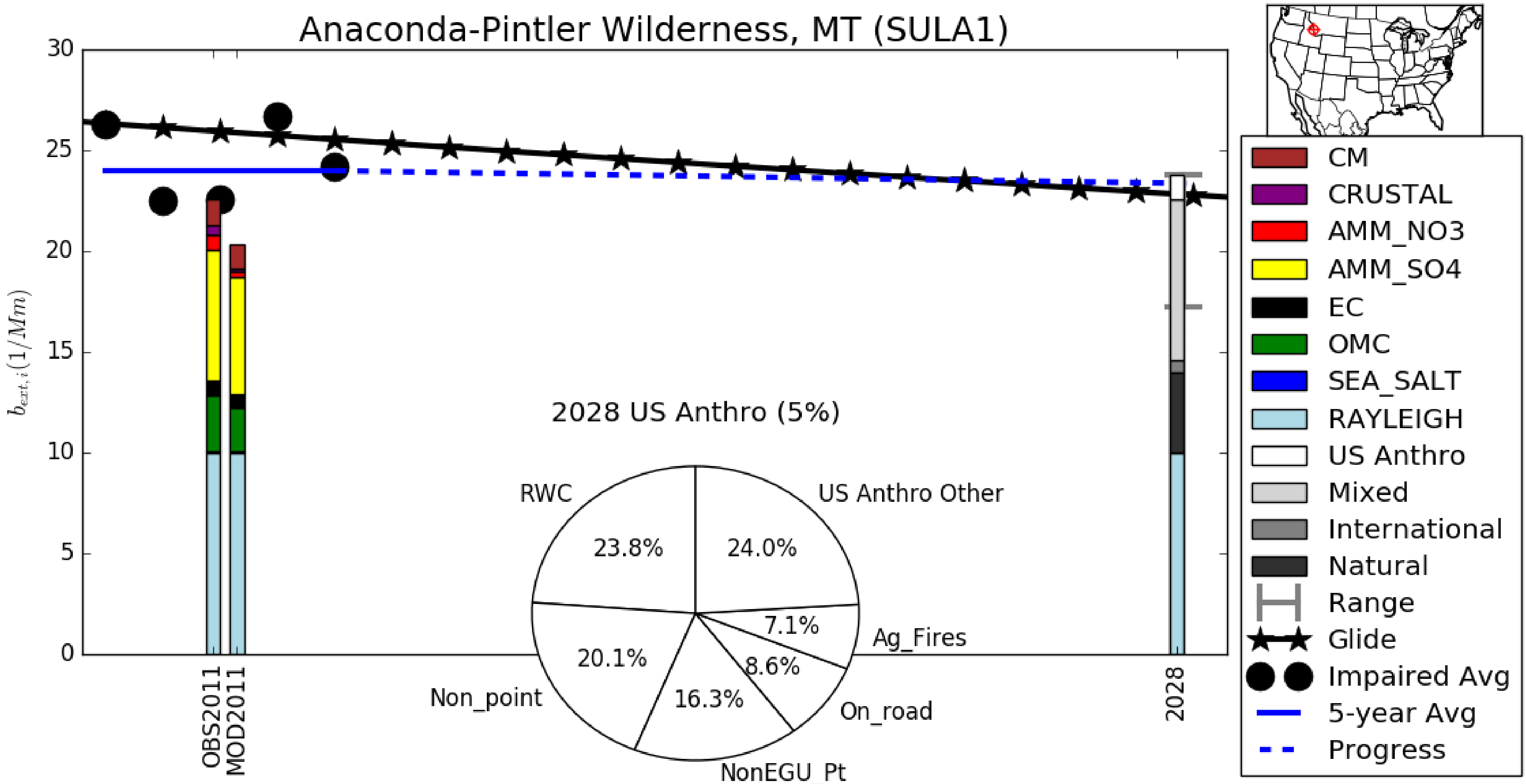


Figure B-36: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Anaconda-Pintler Wilderness (MT) and Selway-Bitterroot Wilderness (MT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

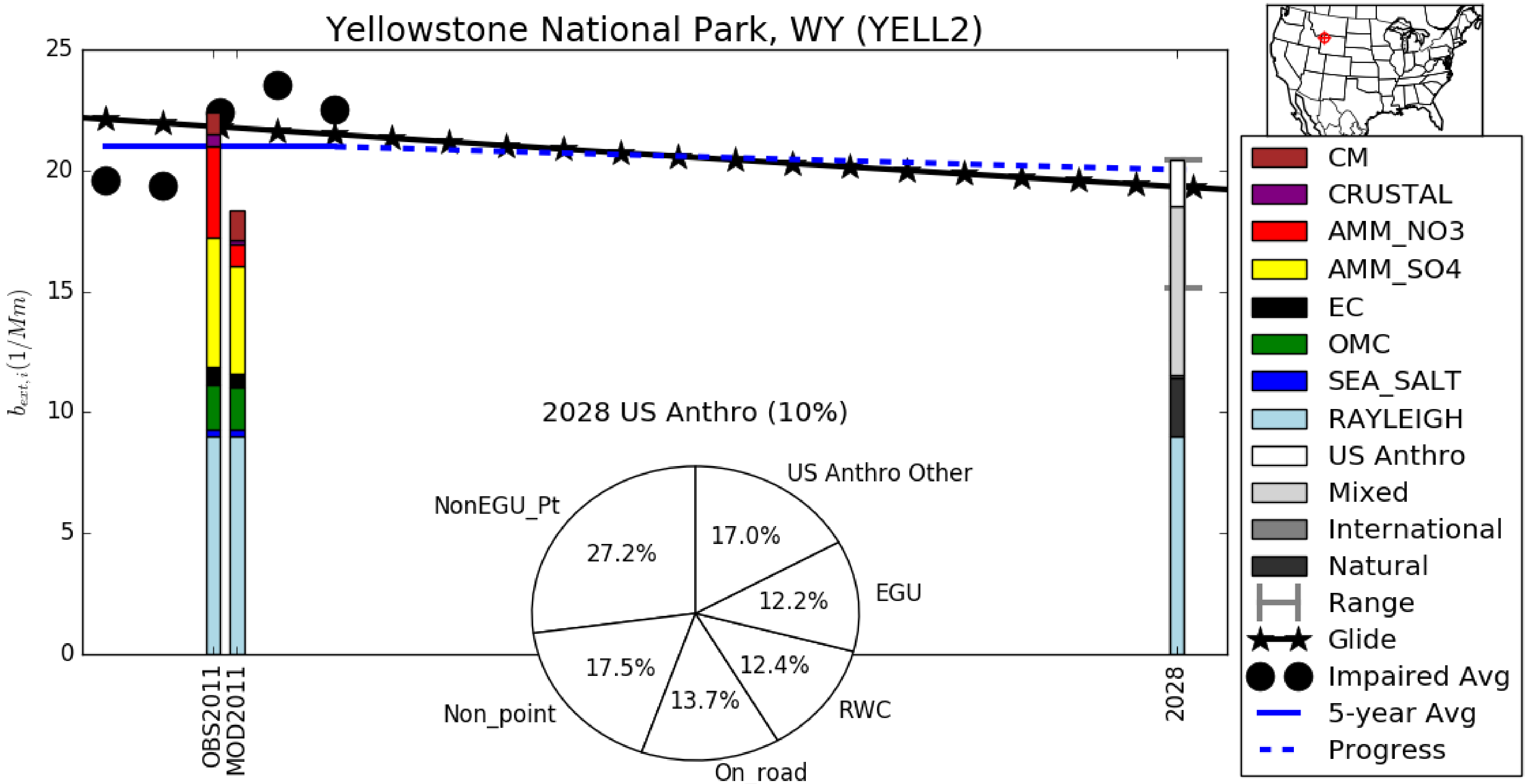


Figure B-37: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Grand Teton National Park (WY), Red Rock Lakes (WY), Teton Wilderness (WY), and Yellowstone National Park (WY).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Hells Canyon and Great Basin

- Craters of the Moon National Monument (ID)(CRMO1)
- Hells Canyon Wilderness (OR)(HECA1)
- Sawtooth Wilderness (ID)(SAWT1)
- Eagle Cap Wilderness (OR) and Strawberry Mountain Wilderness (OR)(STAR1)
- Jarbidge Wilderness (NV)(JARB1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Nitrate, sulfate, organic carbon
Model visibility performance summary (on 20% most impaired days)	Large nitrate underprediction at CRMO1, HECA1, and STAR1 Much smaller nitrate contribution at SAWT1 and JARB1
Uncertainty in sector contributions	High "mixed" sector contribution percentage (>60% at all sites except HECA1 [52%]).
2028 US anthropogenic percent contribution	12-23% at CRMO1, HECA1, and STAR1 4% at SAWT1 and JARB1
Largest US anthropogenic sector contributions	Residential wood, Nonpoint, nonEGU point, On-road (largest component at CRMO1 and HECA1)

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

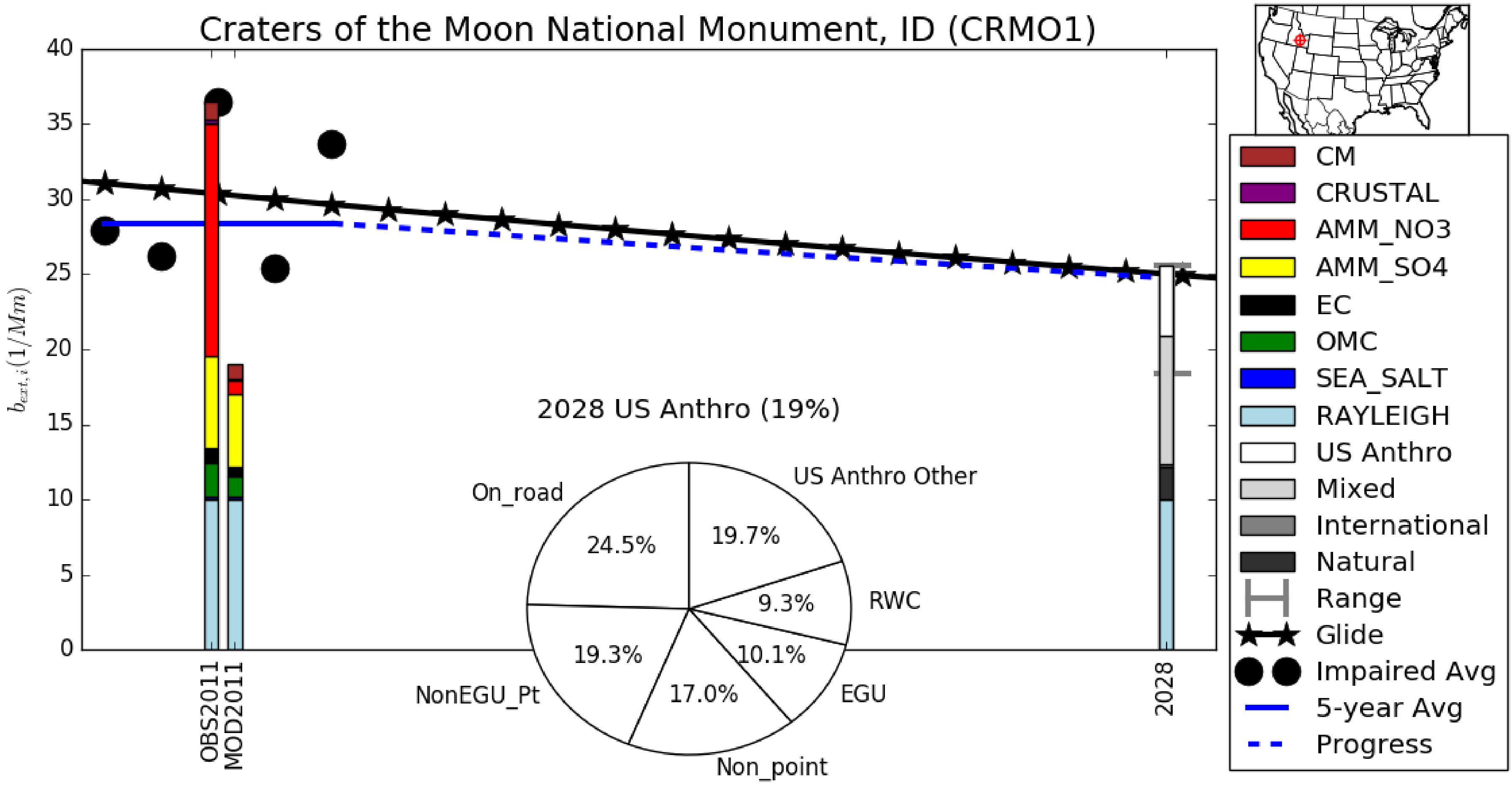


Figure B-38: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Craters of the Moon National Monument (ID).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

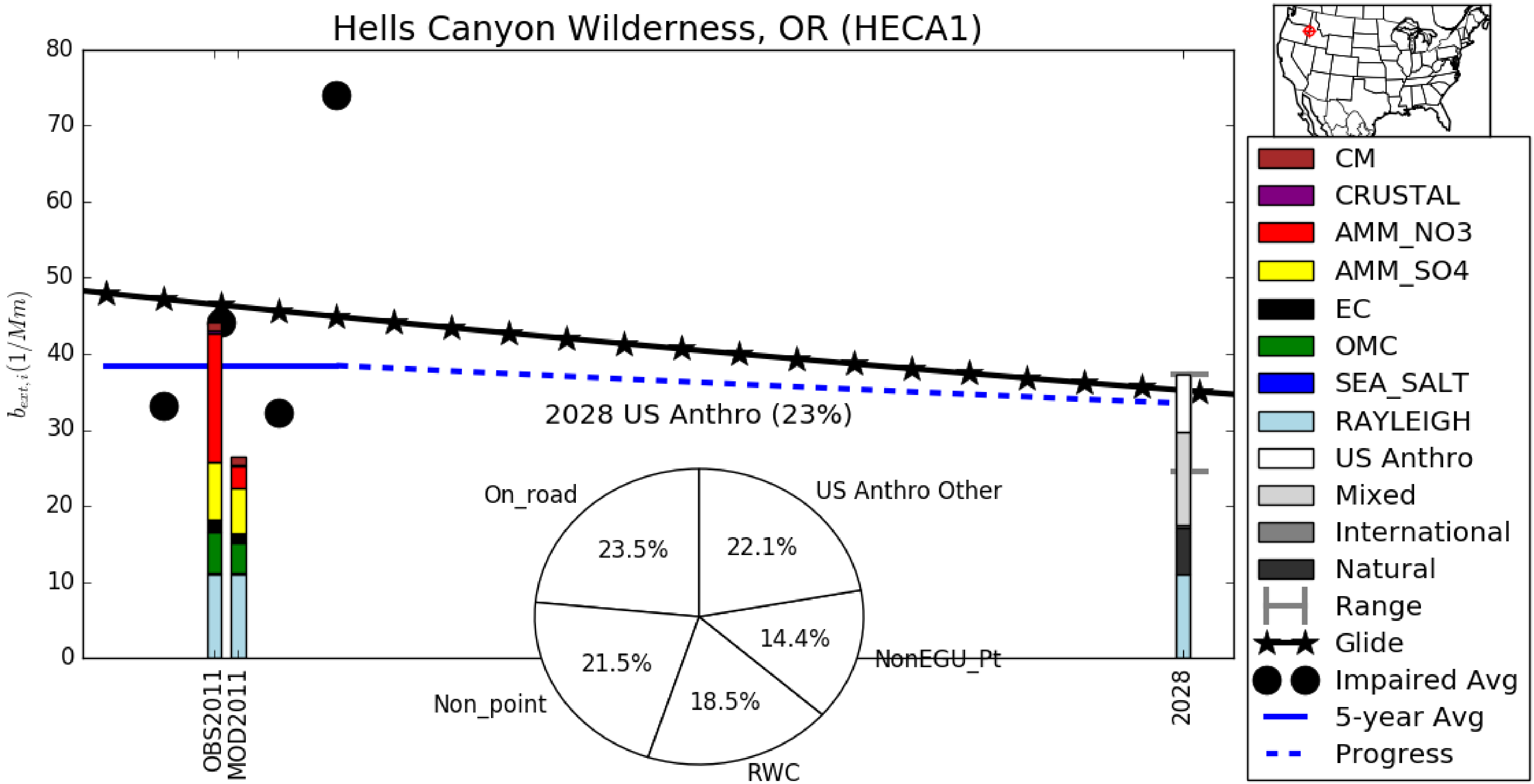


Figure B-39: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Hells Canyon Wilderness (OR).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

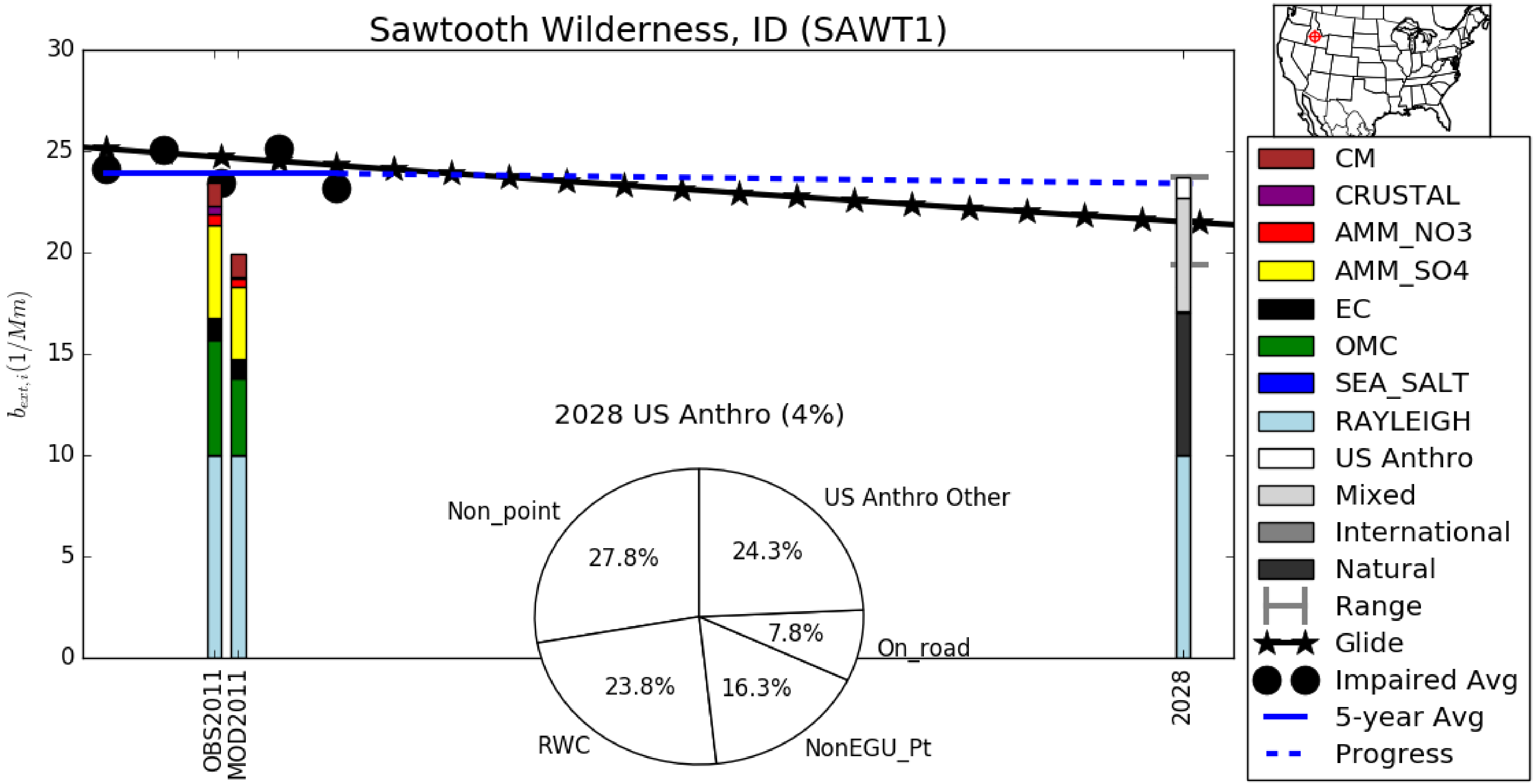


Figure B-40: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Sawtooth Wilderness (ID).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

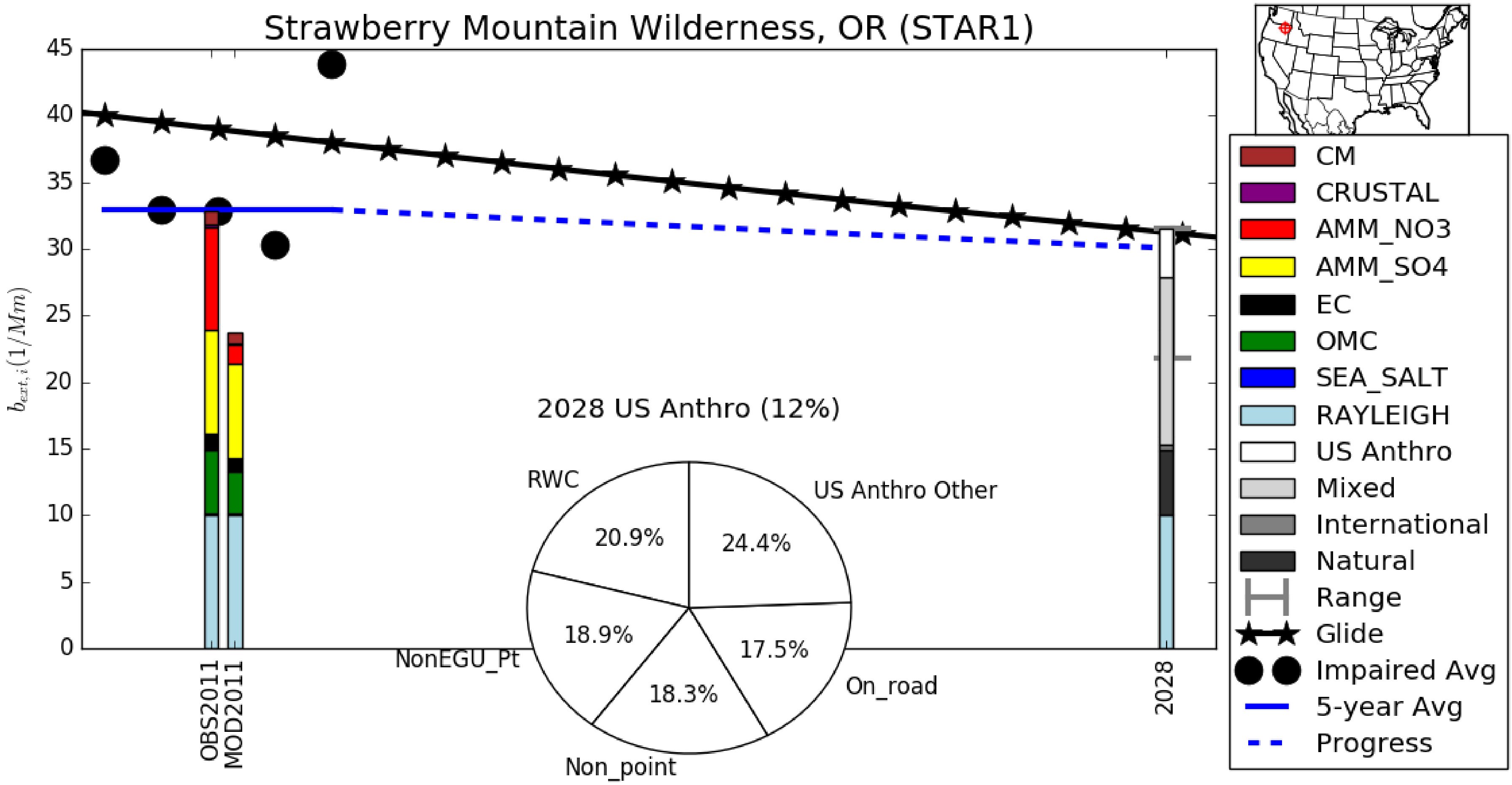


Figure B-41: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Eagle Cap Wilderness (OR) and Strawberry Mountain Wilderness (OR).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

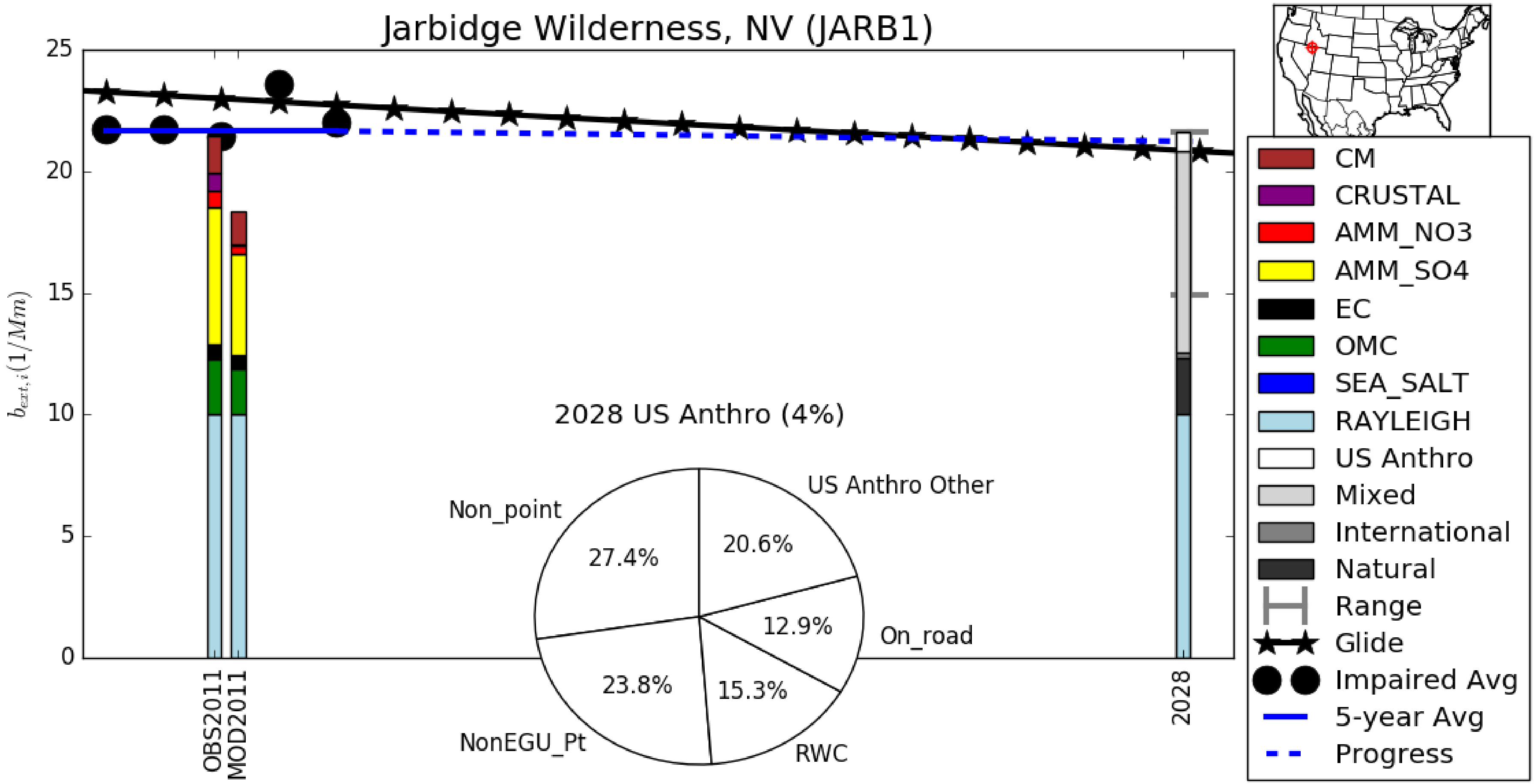


Figure B-42: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Jarbidge Wilderness (NV).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Central Rocky Mountains

- Great Sand Dunes National Monument (CO)(GRSA1)
- Mount Zirkel Wilderness (CO) and Rawah Wilderness (CO)(MOZI1)
- Rocky Mountain National Park (CO)(ROMO1)
- Pecos Wilderness (NM) and Wheeler Peak Wilderness (NM)(WHPE1)
  Eagles Nest Wilderness (CO), Flat Tops Wilderness (CO), Maroon Bells-Snowmass Wilderness (CO), and West Elk Wilderness (CO)(WHRI1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, organic carbon, coarse mass (at GRSA1)
Model visibility performance summary (on 20% most impaired days)	Sulfate generally underpredicted, organic carbon overpredicted at ROMO1, coarse mass underpredicted at GRSA1
Uncertainty in sector contributions	High "mixed" sector contribution percentage (>60% at all sites except ROMO1 [49%]).
2028 US anthropogenic percent contribution	10-17%
Largest US anthropogenic sector contributions	EGU, nonEGU point, Oil & gas

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

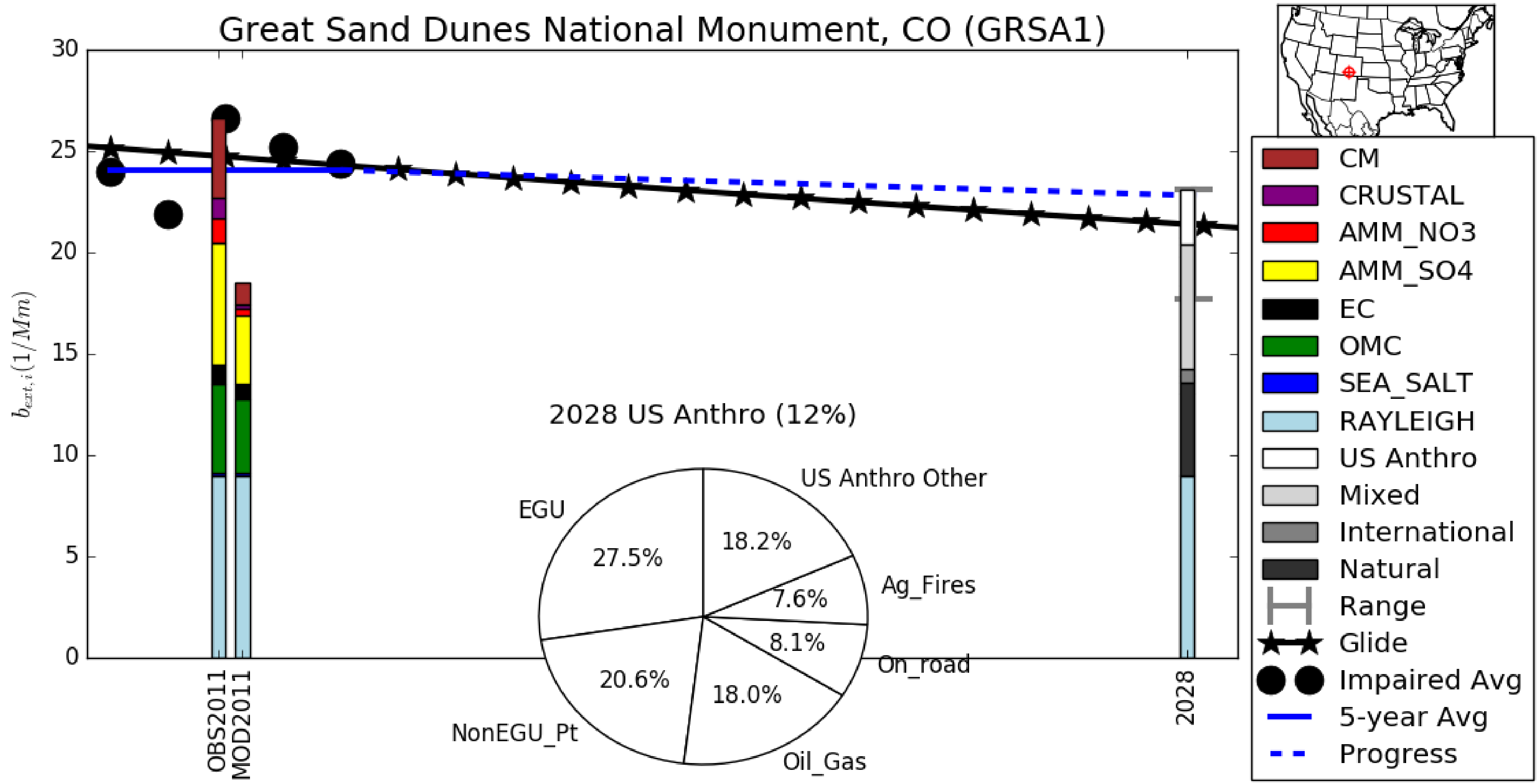


Figure B-43: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Great Sand Dunes National Monument (CO).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

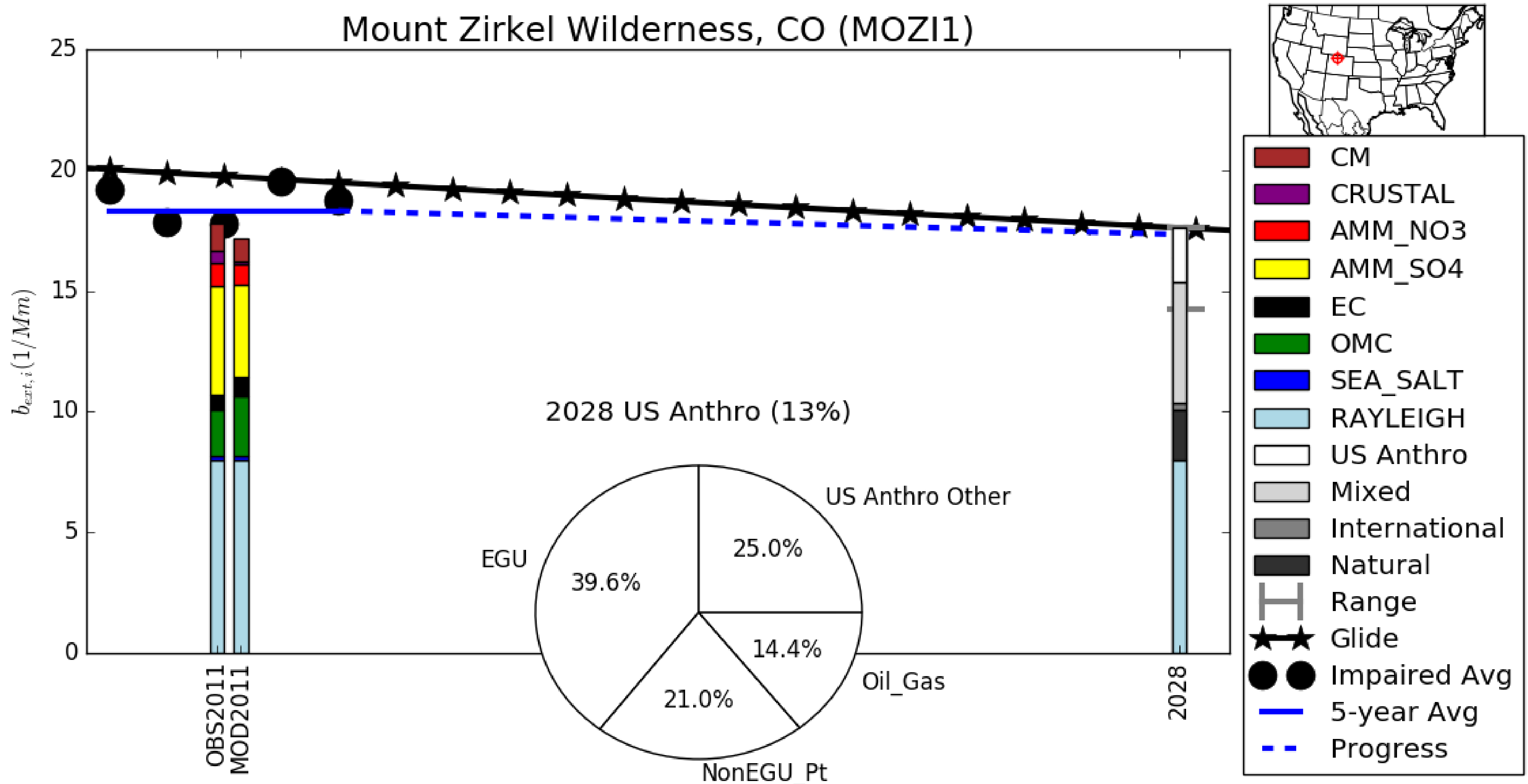


Figure B-44: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Mount Zirkel Wilderness (CO) and Rawah Wilderness (CO).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

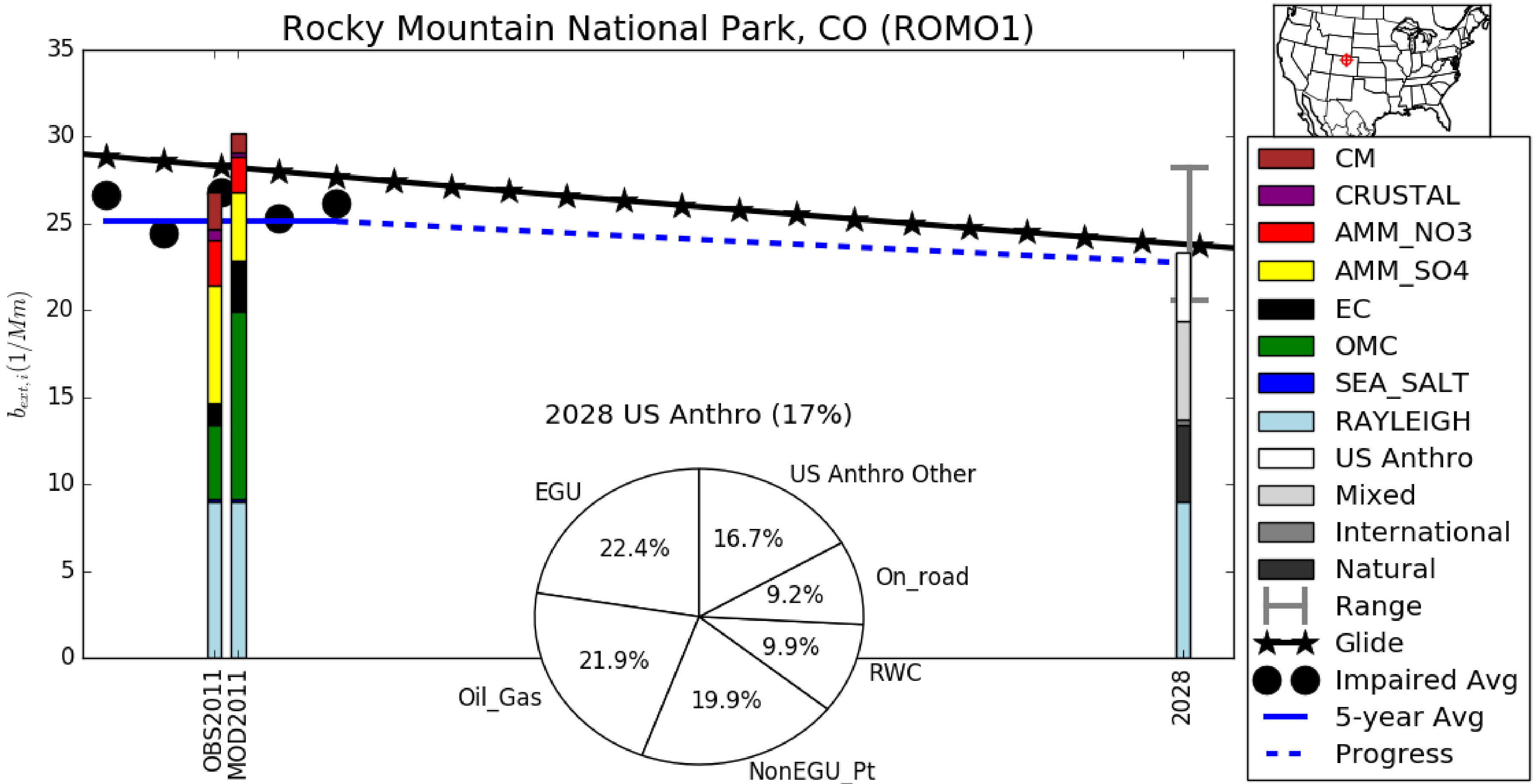


Figure B-45: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Rocky Mountain National Park (CO).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

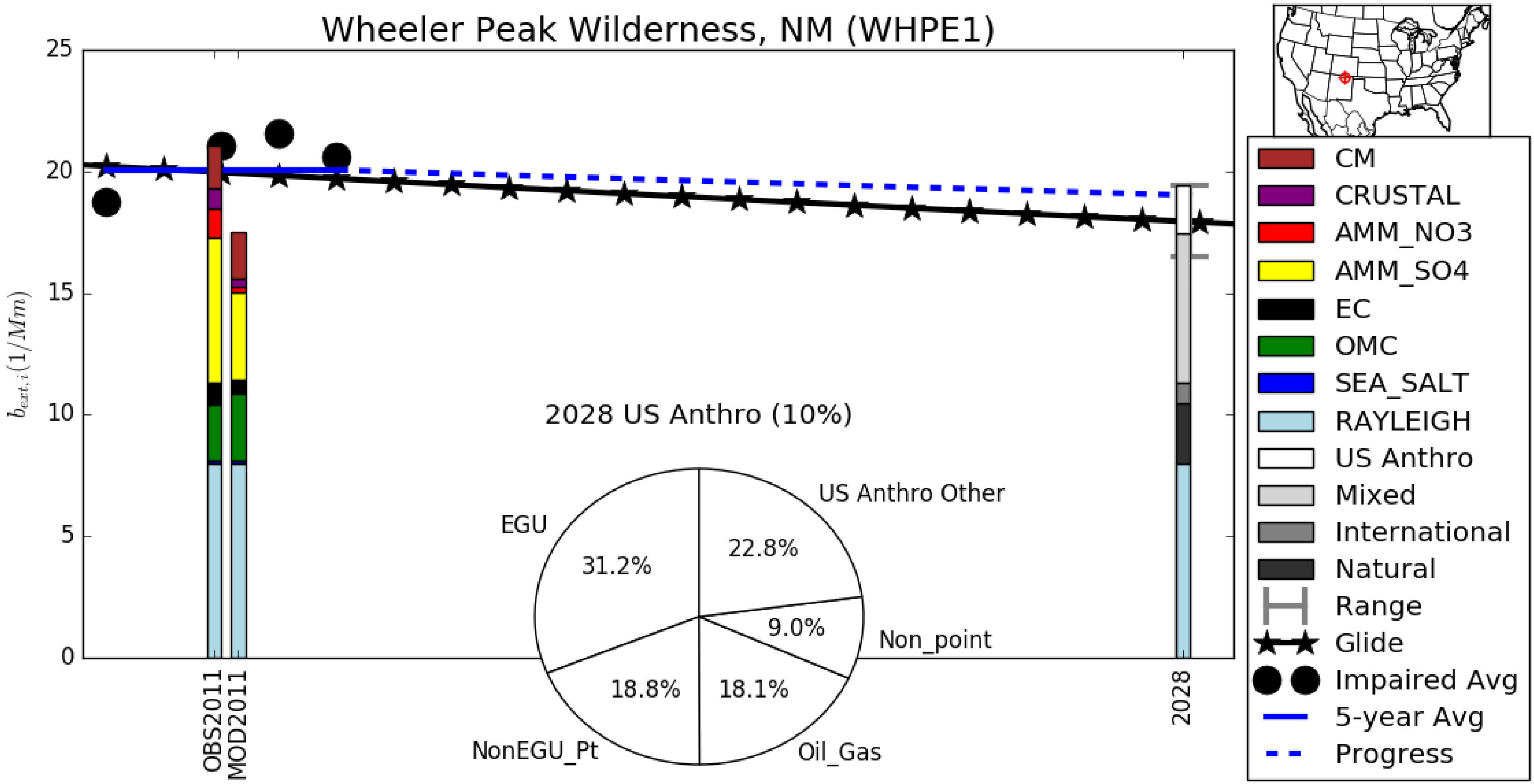


Figure B-46: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Pecos Wilderness (NM) and Wheeler Peak Wilderness (NM).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

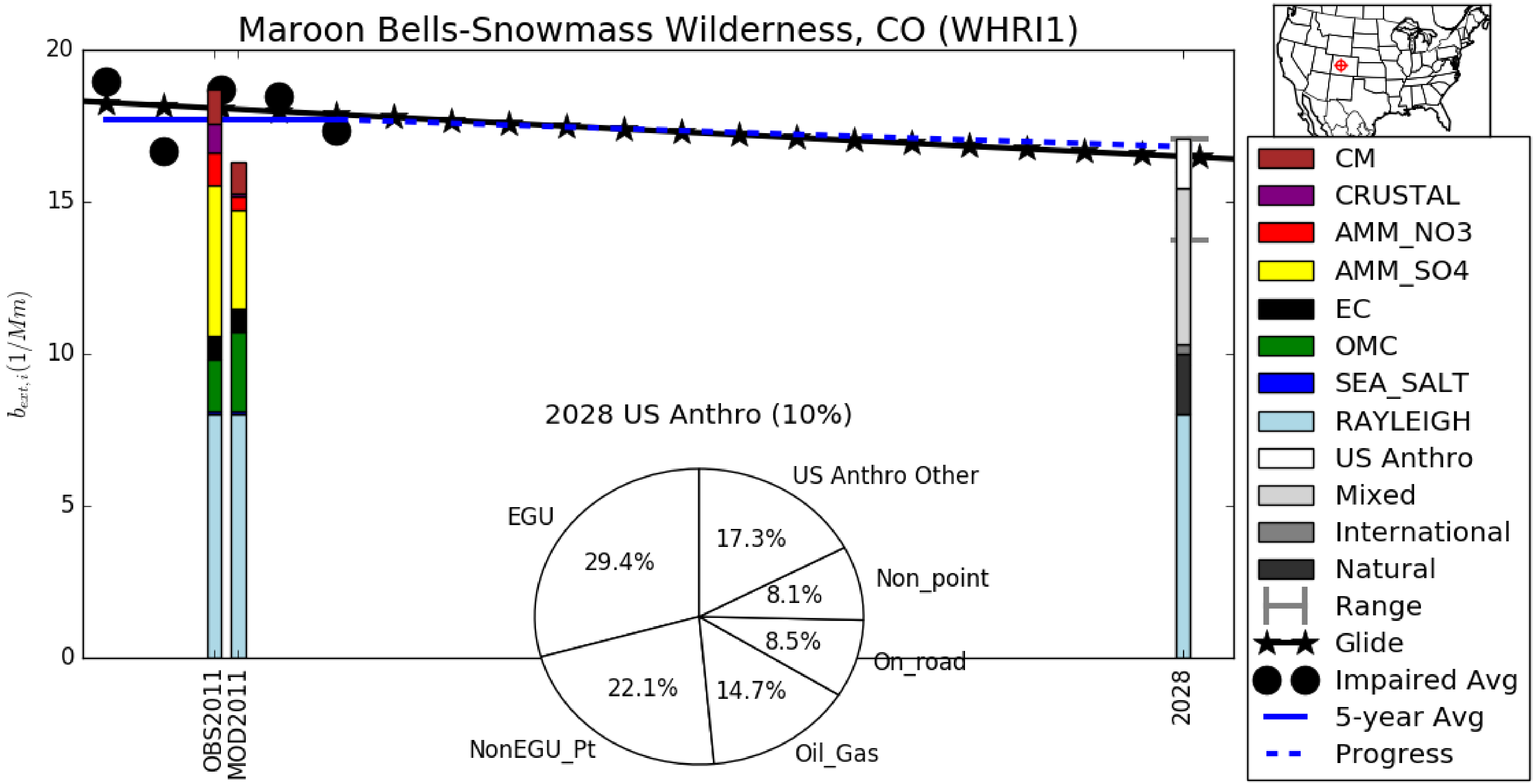


Figure B-47: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Eagles Nest Wilderness (CO), Flat Tops Wilderness (CO), Maroon Bells-Snowmass Wilderness (CO), and West Elk Wilderness (CO).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Colorado Plateau

- Bandelier National Monument (NM)(BAND1)
- Bryce Canyon National Park (UT)(BRCA1)
- Arches National Park (UT) and Canyonlands National Park (UT)(CANY1)
- Capitol Reef National Park (UT)(CAPI1)
- Grand Canyon National Park (AZ)(GRCA2)
- Mesa Verde National Park (CO)(MEVE1)
- San Pedro Parks Wilderness (NM)(SAPE1)
- Black Canyon of the Gunnison National Monument (CO), La Garita Wilderness (CO), and Weminuche Wilderness (CO)(WEMI1) Zion National Park (UT)(ZICA1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, coarse mass, nitrate (at BRCA1, CANY1, and CAPI1)
Model visibility performance summary (on 20% most impaired days)	Sulfate underpredicted, nitrate severely underpredicted at most sites, especially BRCA1, CANY1, CAPI1, GRCA2,
Uncertainty in sector contributions	High "mixed" sector contribution percentage (>58% at all sites).
2028 US anthropogenic percent contribution	7-17%
Largest US anthropogenic sector contributions	EGU, nonEGU point, Oil & gas

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

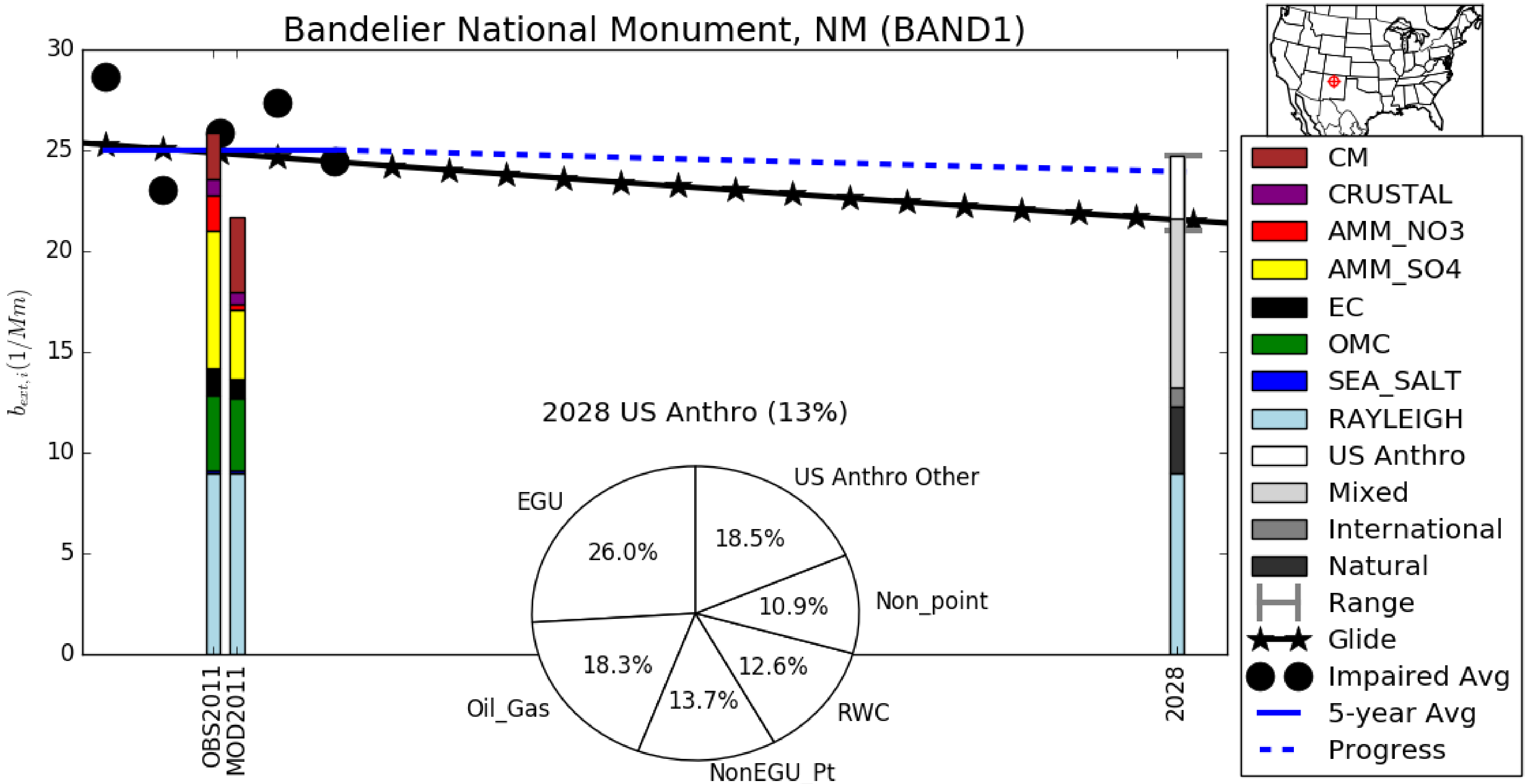


Figure B-48: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Bandelier National Monument (NM).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

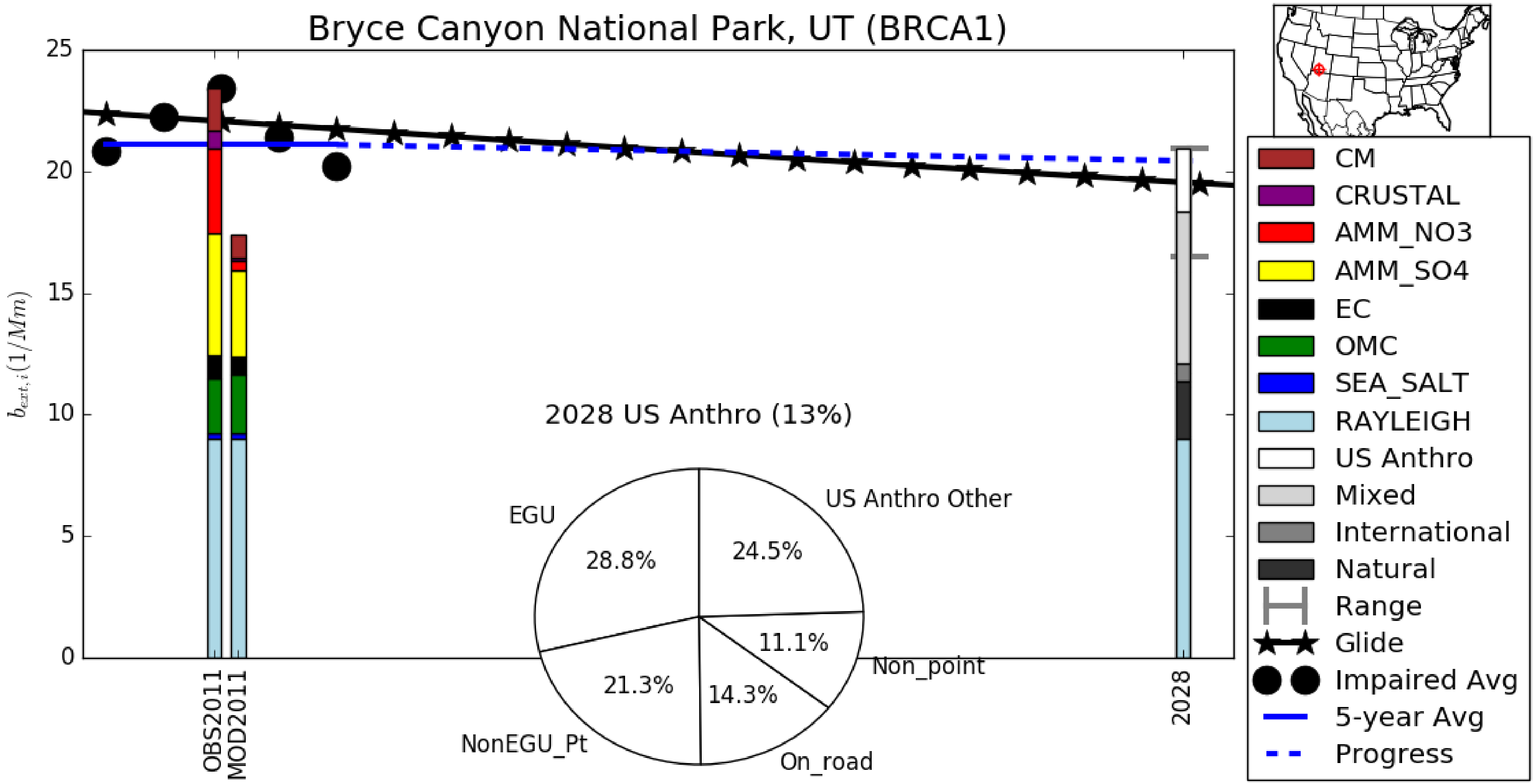


Figure B-49: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Bryce Canyon National Park (UT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

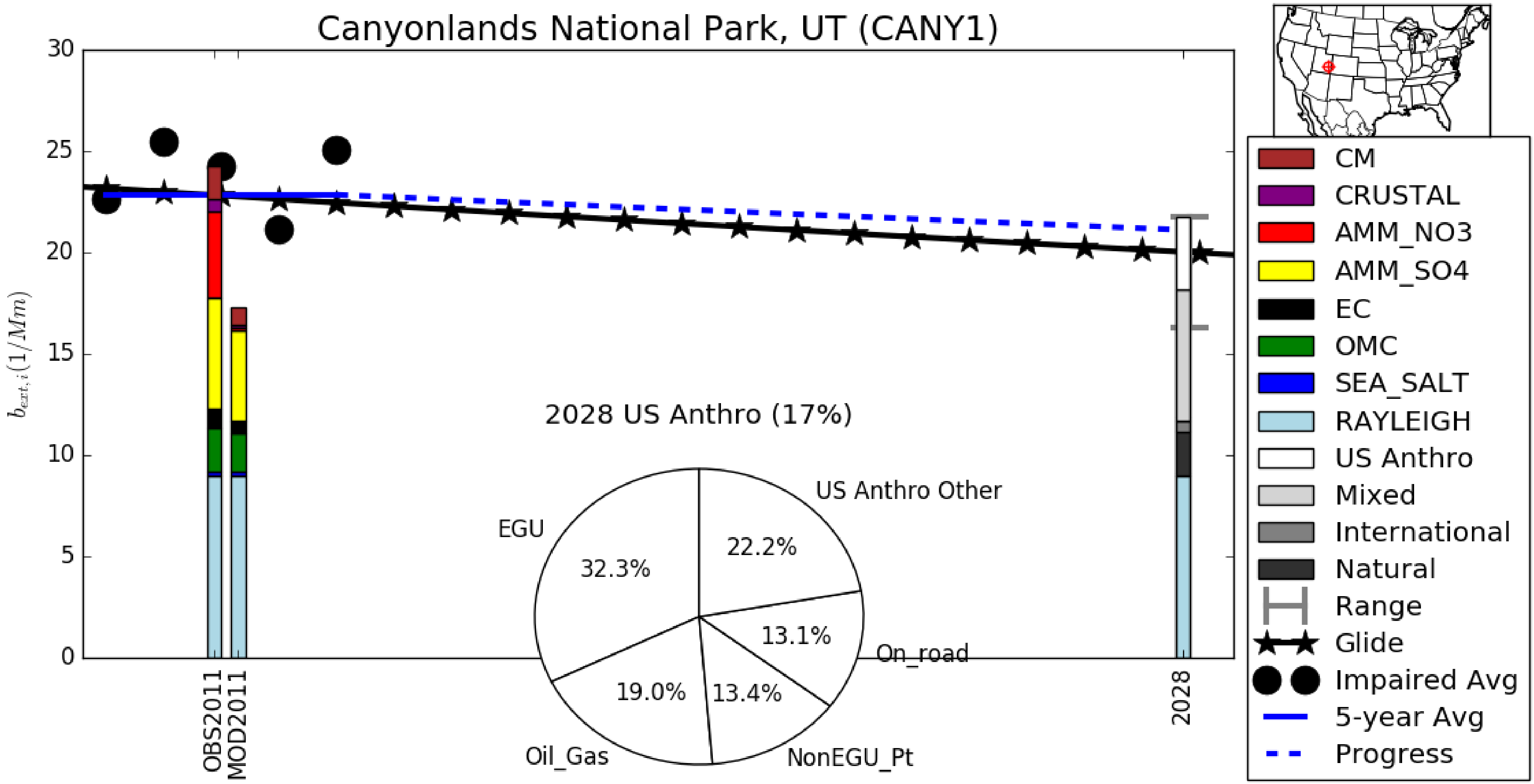


Figure B-50: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Arches National Park (UT) and Canyonlands National Park (UT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

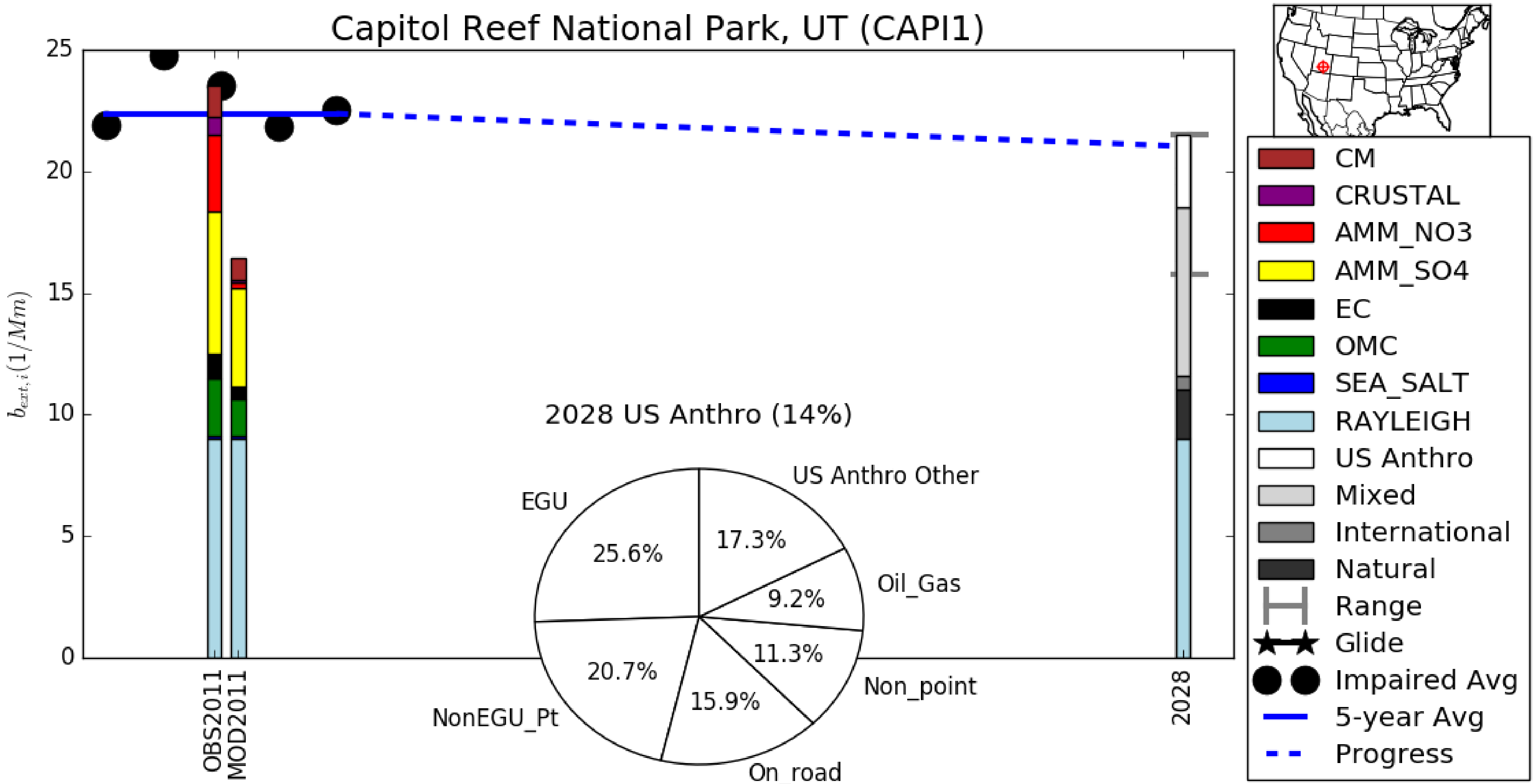


Figure B-51: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Capitol Reef National Park (UT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

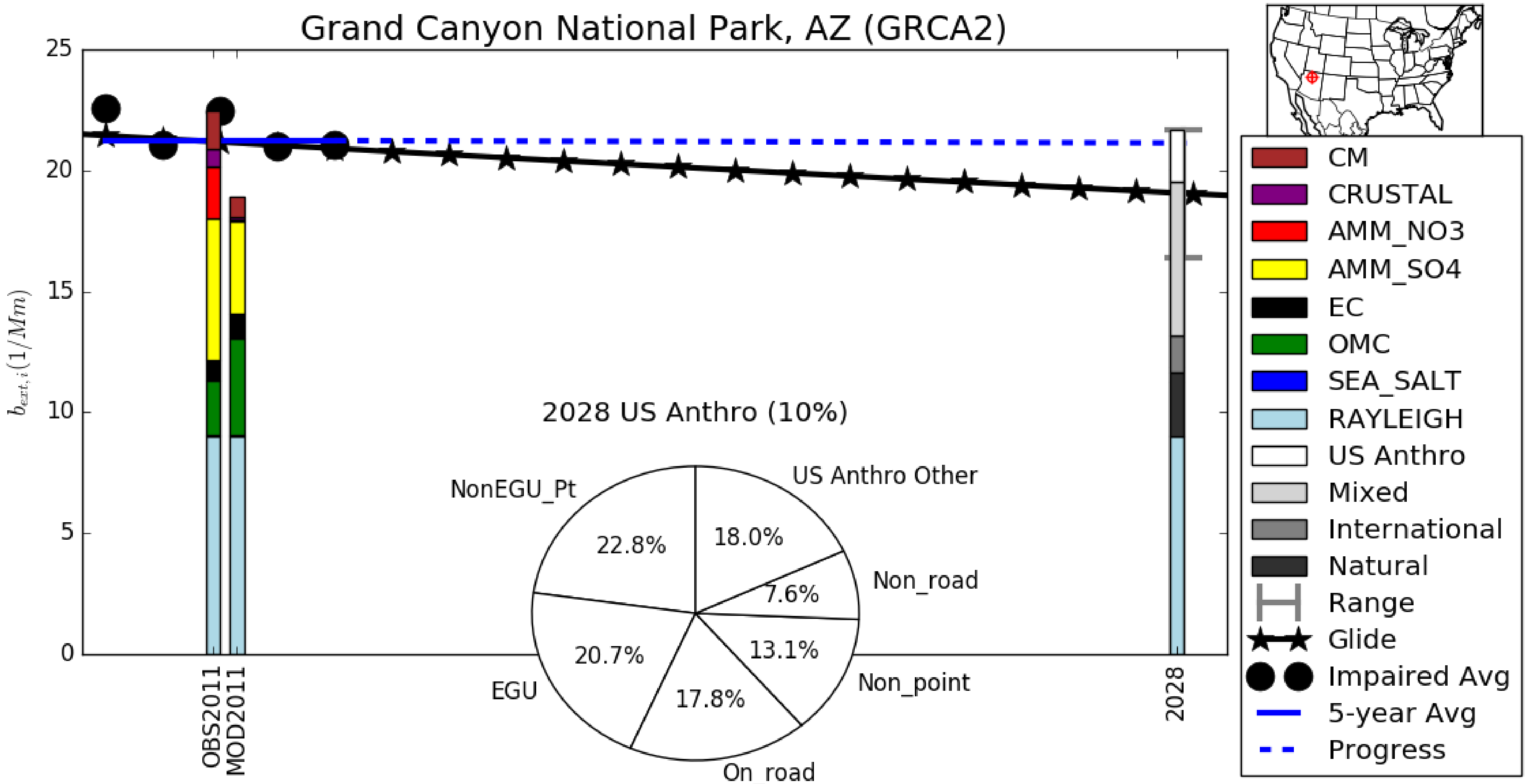


Figure B-52: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Grand Canyon National Park (AZ).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

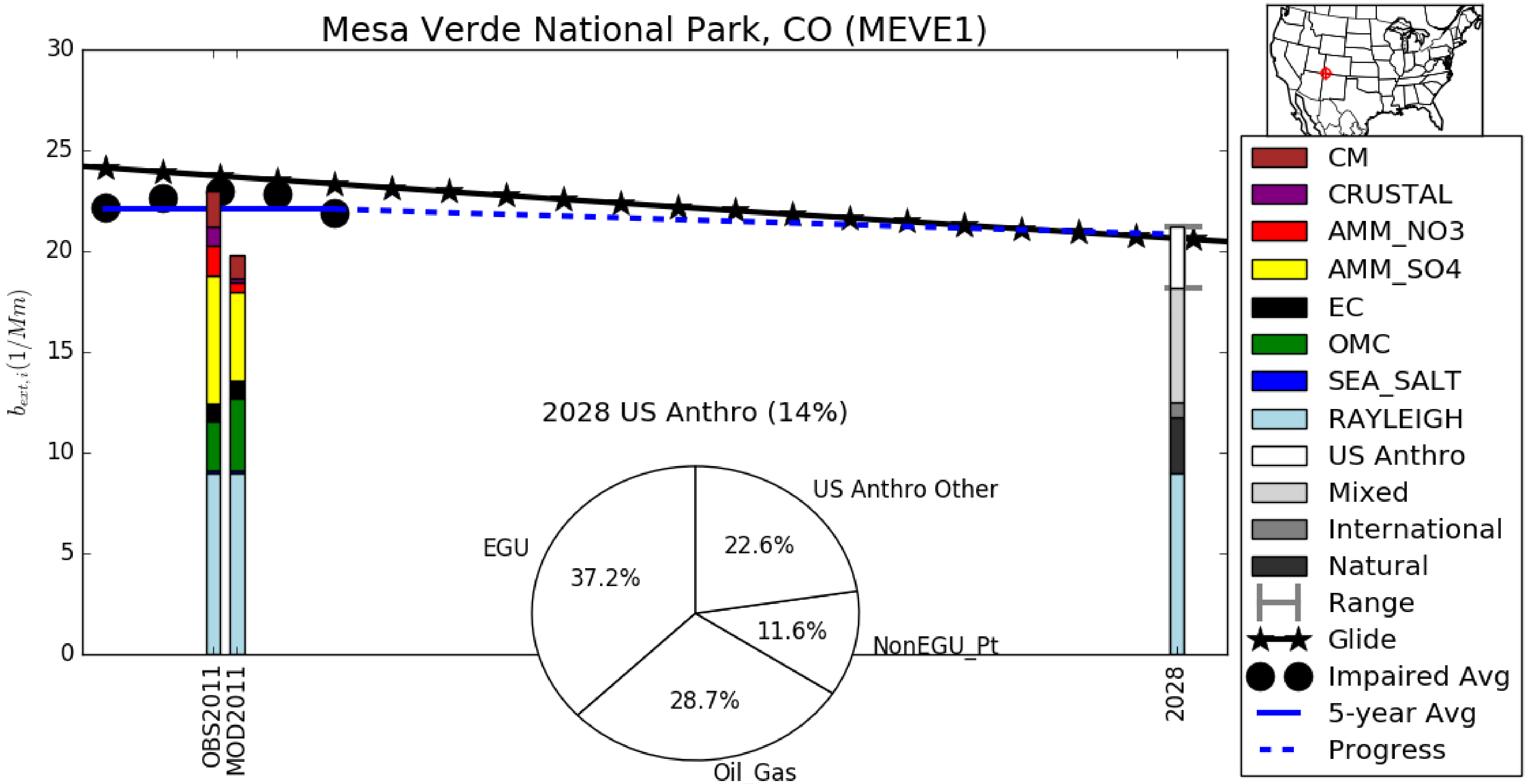


Figure B-53: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Mesa Verde National Park (CO).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

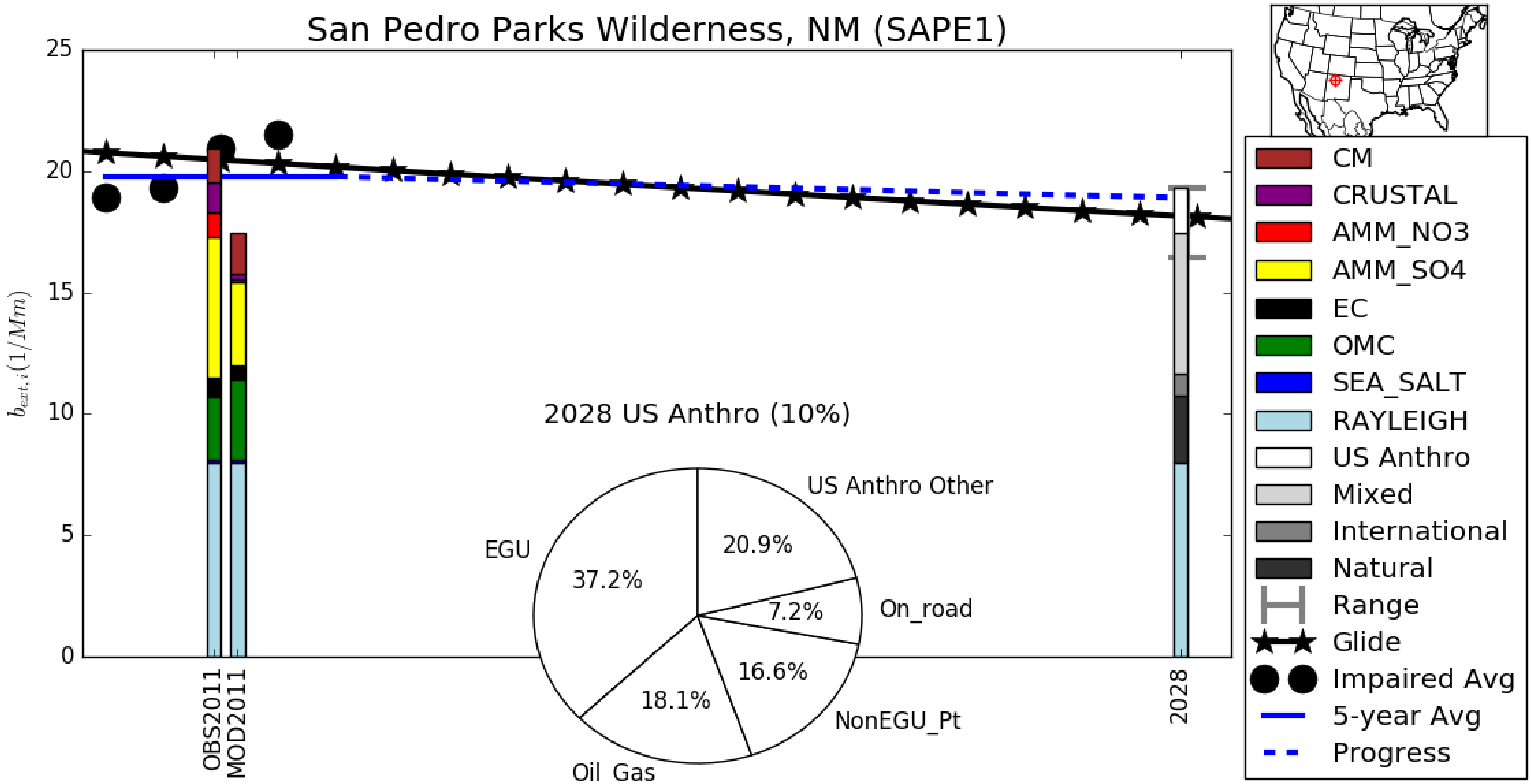


Figure B-54: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at San Pedro Parks Wilderness (NM).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

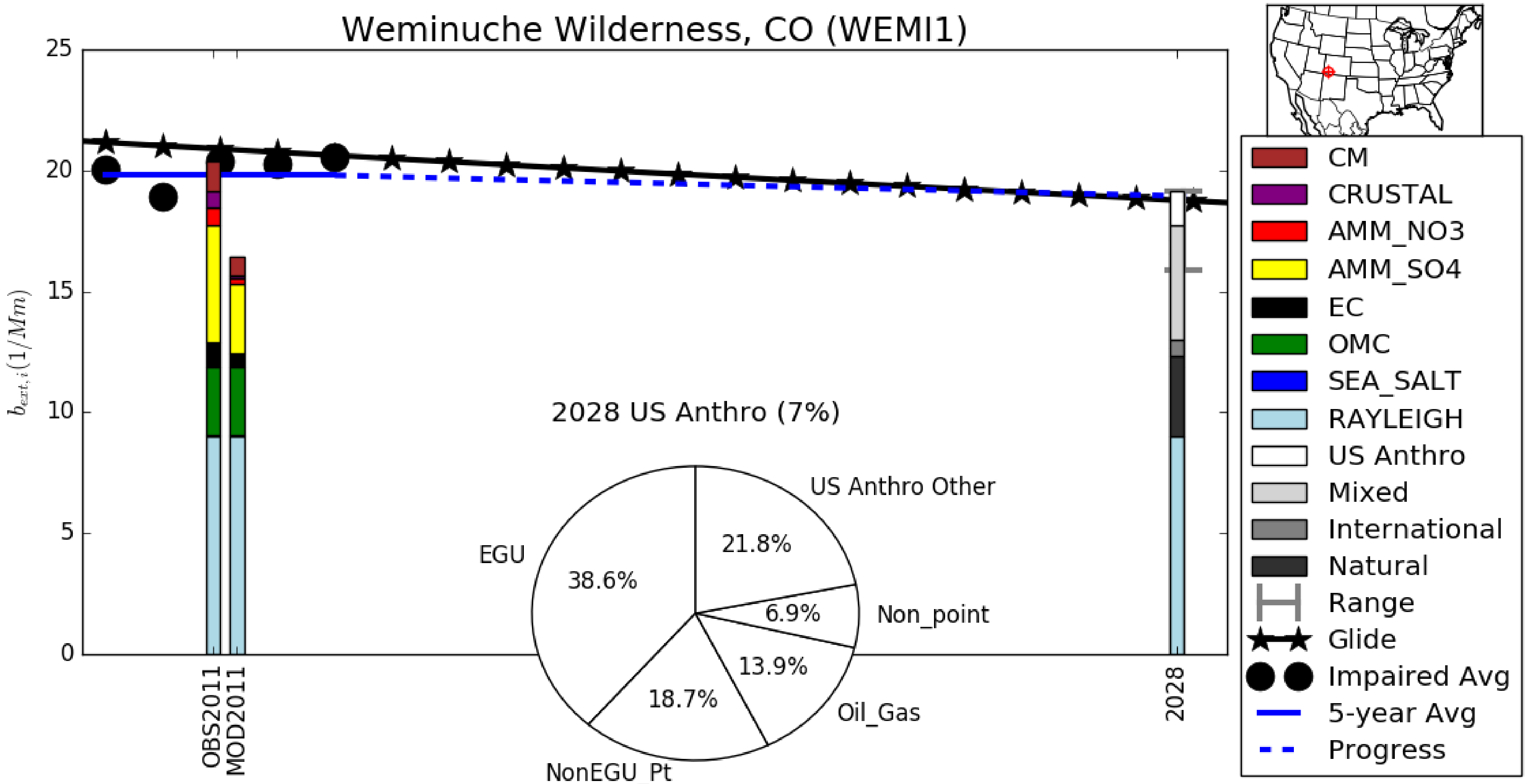


Figure B-55: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Black Canyon of the Gunnison National Monument (CO), La Garita Wilderness (CO), and Weminuche Wilderness (CO).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

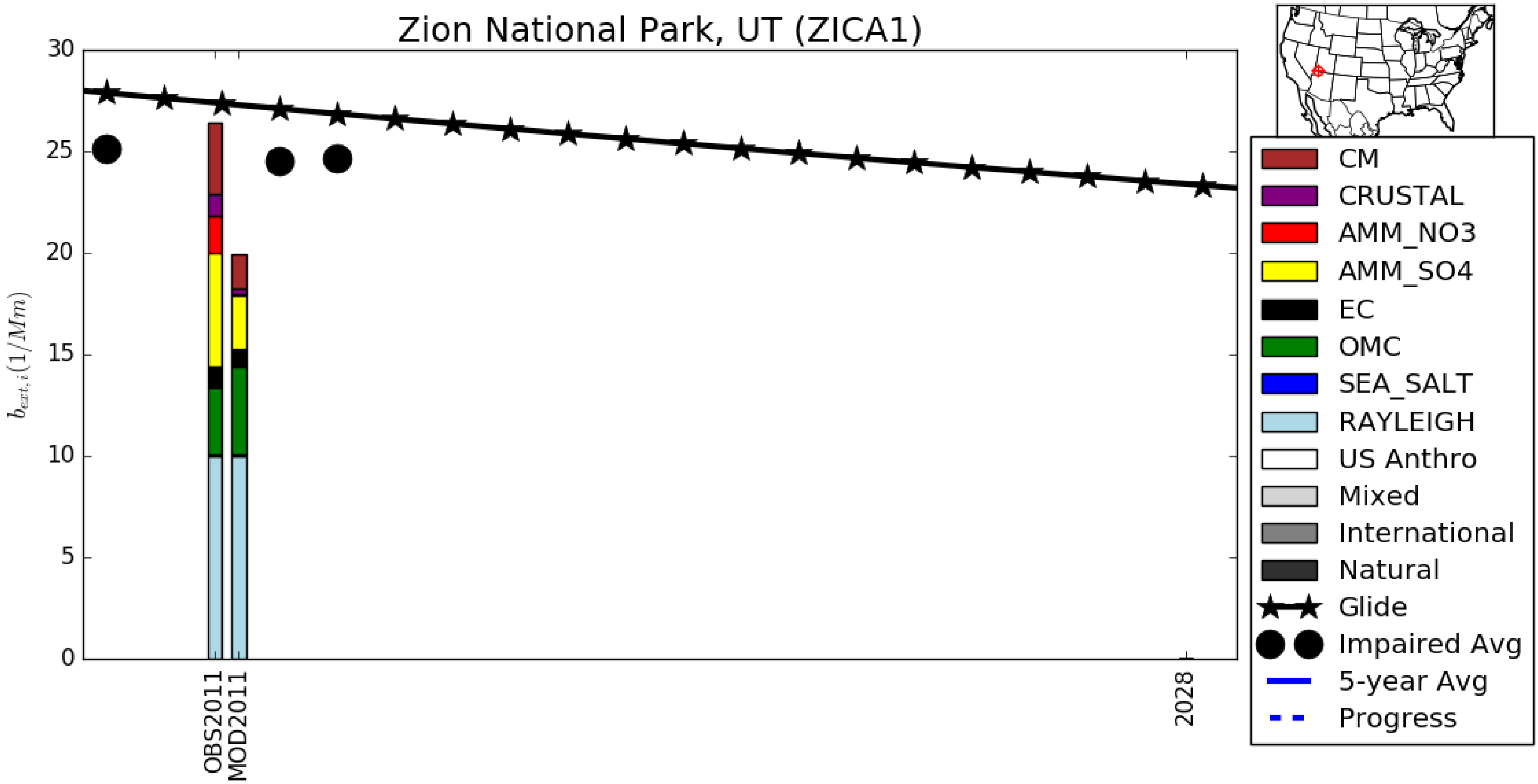


Figure B-56: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Zion National Park (UT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

Mogollon Plateau and Southern Arizona

- Mount Baldy Wilderness (AZ)(BALD1)
- Bosque del Apache (NM)(BOAP1)
- Gila Wilderness (NM)(GICL1)
- Mazatzal Wilderness (AZ) and Pine Mountain Wilderness (AZ)(IKBA1)
- Petrified Forest National Park (AZ)(PEFO1)
- Sierra Ancha Wilderness (AZ)(SIAN1)
- Sycamore Canyon Wilderness (AZ)(SYCA2)
- Superstition Wilderness (AZ)(TONT1)
- White Mountain Wilderness (NM)(WHIT1)
- Chiricahua National Monument (AZ), Chiricahua Wilderness (AZ), and Galiuro Wilderness (AZ) (CHIR1)
- Saguaro National Monument (AZ) (SAGU1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, coarse mass, nitrate (at BOAP1 and IKBA1)
Model visibility performance summary (on 20% most impaired days)	Sulfate underpredicted, nitrate severely underpredicted at most sites, especially Boap1 and IKBA1, coarse mass underpredicted
Uncertainty in sector contributions	High “mixed” sector contribution percentage (>58% at all sites).
2028 US anthropogenic percent contribution	7-12%
Largest US anthropogenic sector contributions	EGU, nonEGU point, Oil & gas, and on-road

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high “mixed” (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

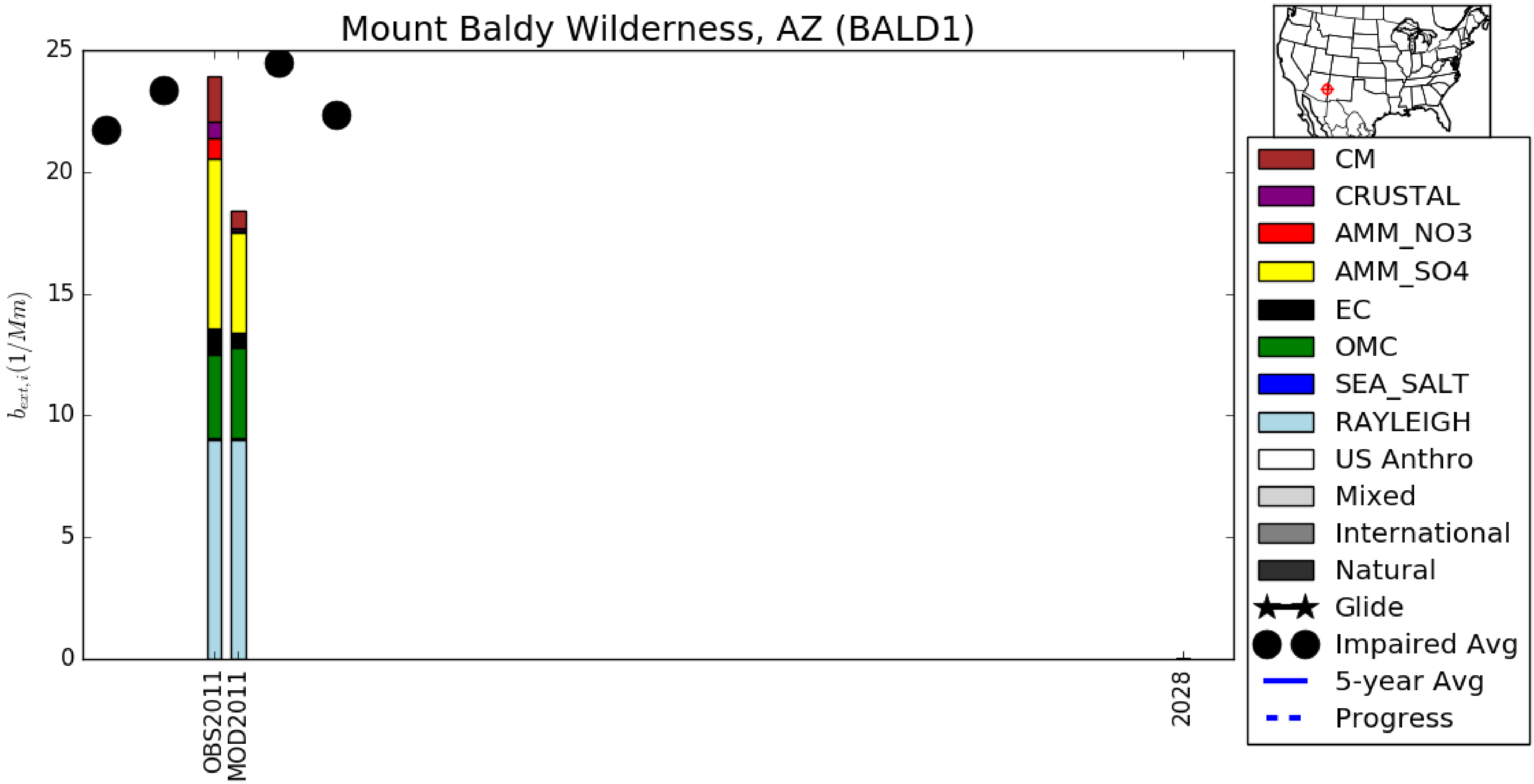


Figure B-57: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Mount Baldy Wilderness (AZ).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

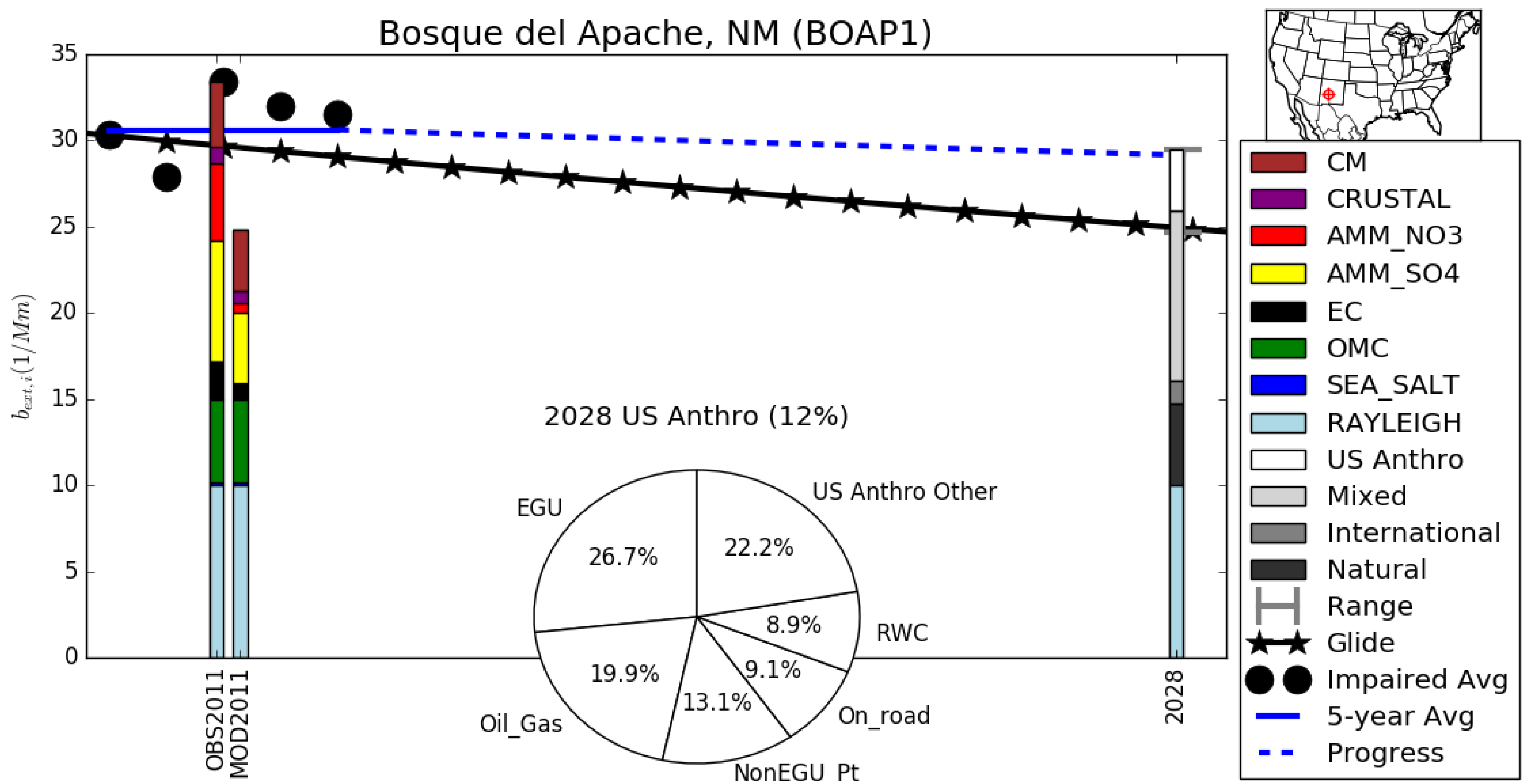


Figure B-58: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Bosque del Apache (NM).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

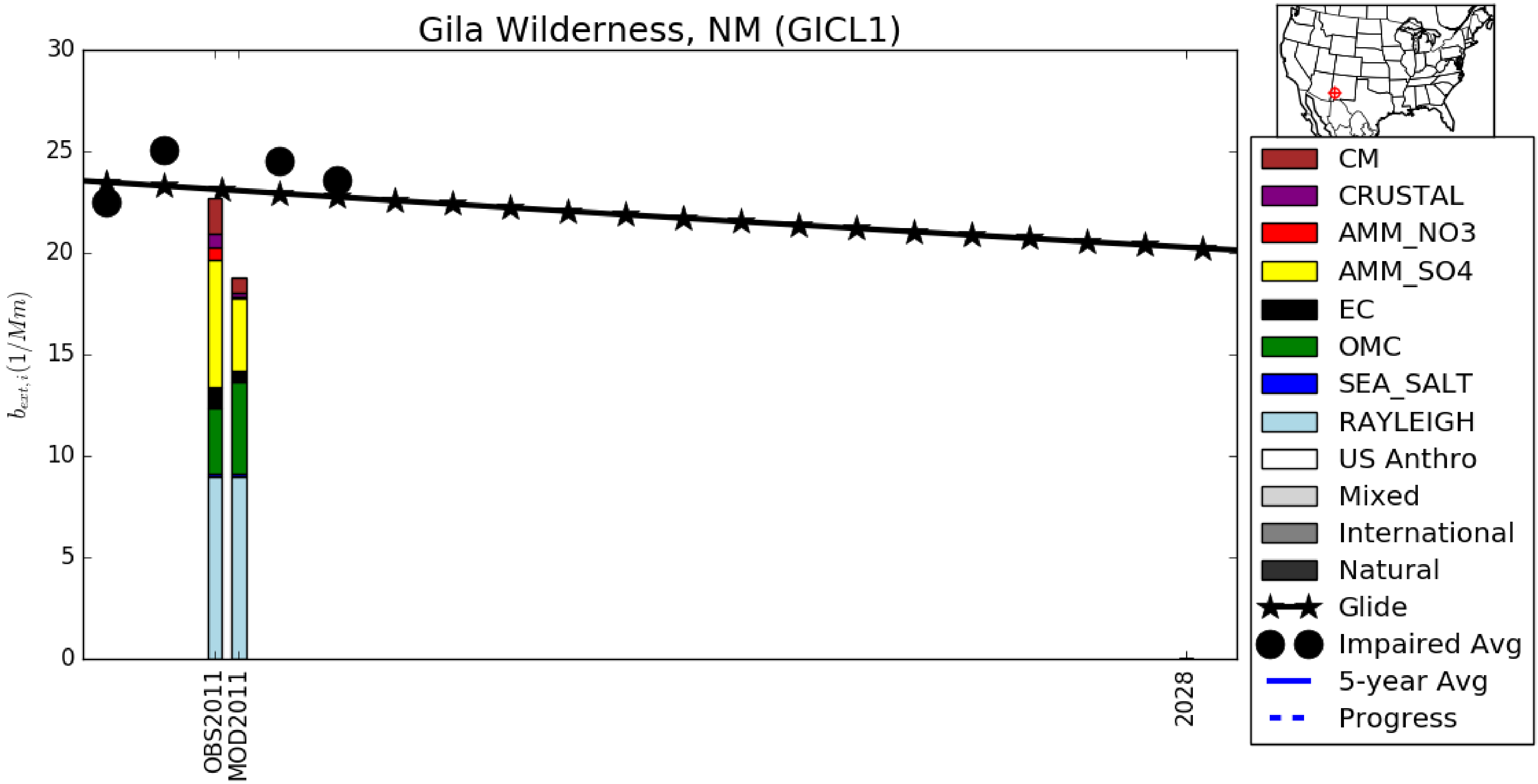


Figure B-59: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Gila Wilderness (NM).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

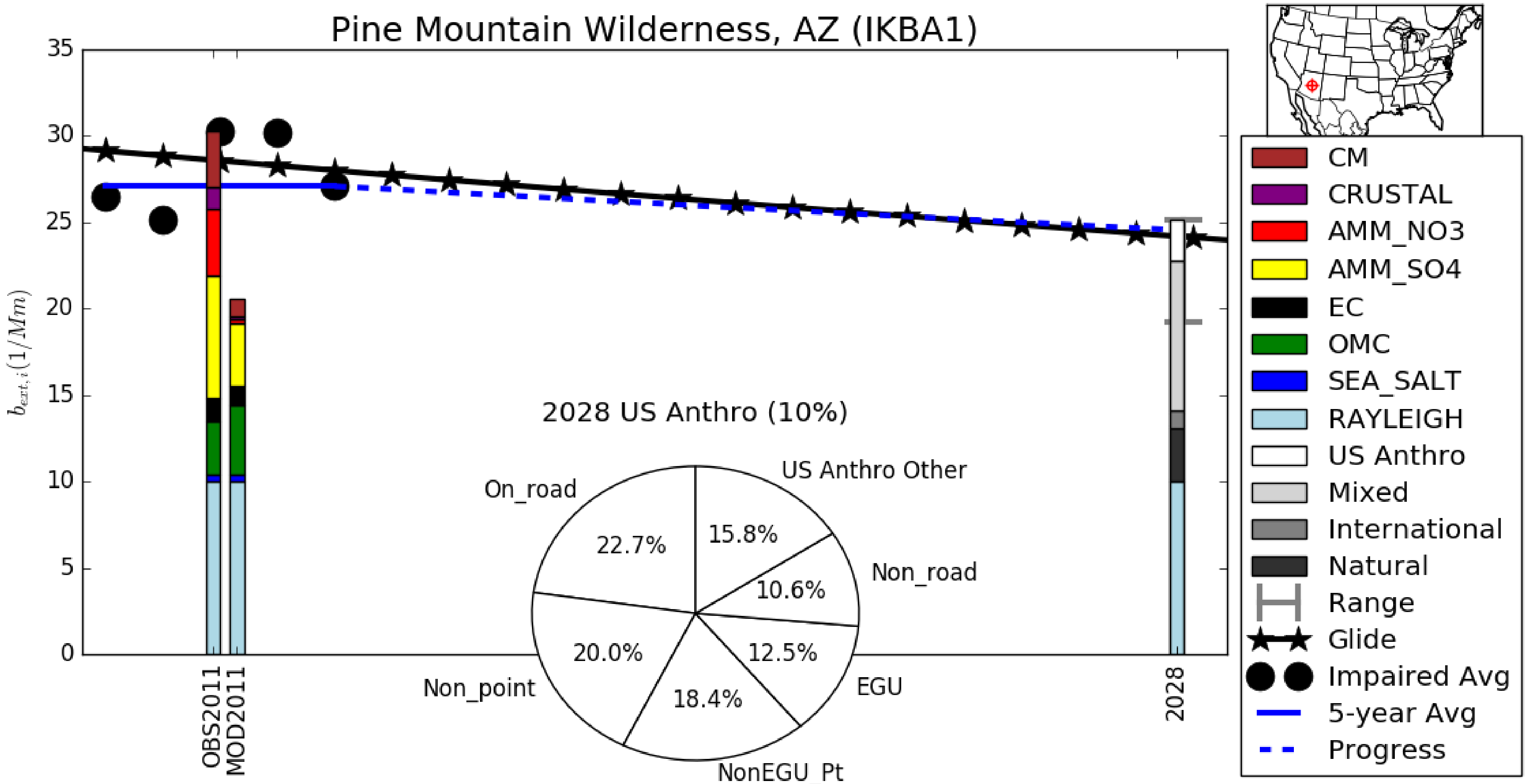


Figure B-60: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Mazatzal Wilderness (AZ) and Pine Mountain Wilderness (AZ).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

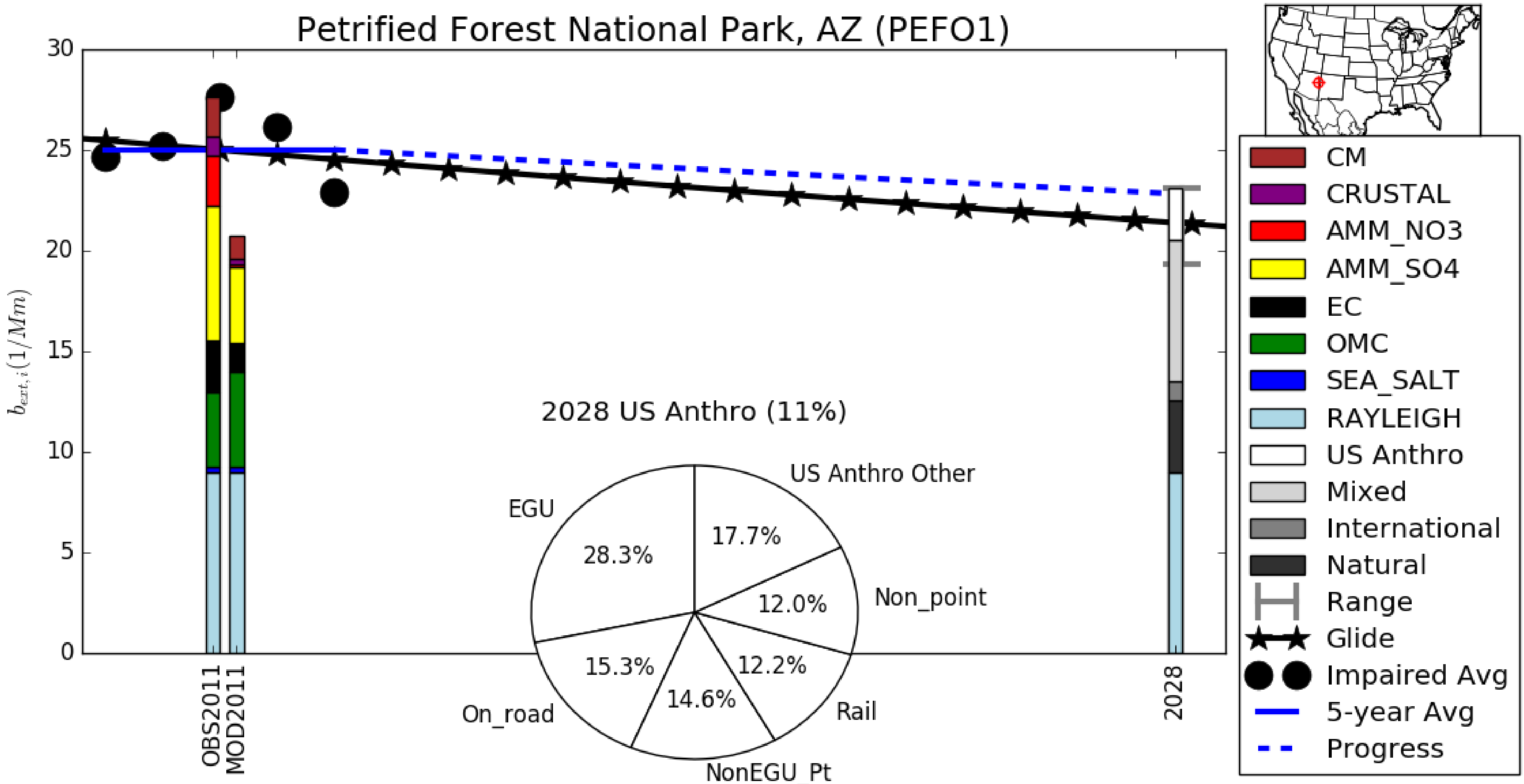


Figure B-61: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Petrified Forest National Park (AZ).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

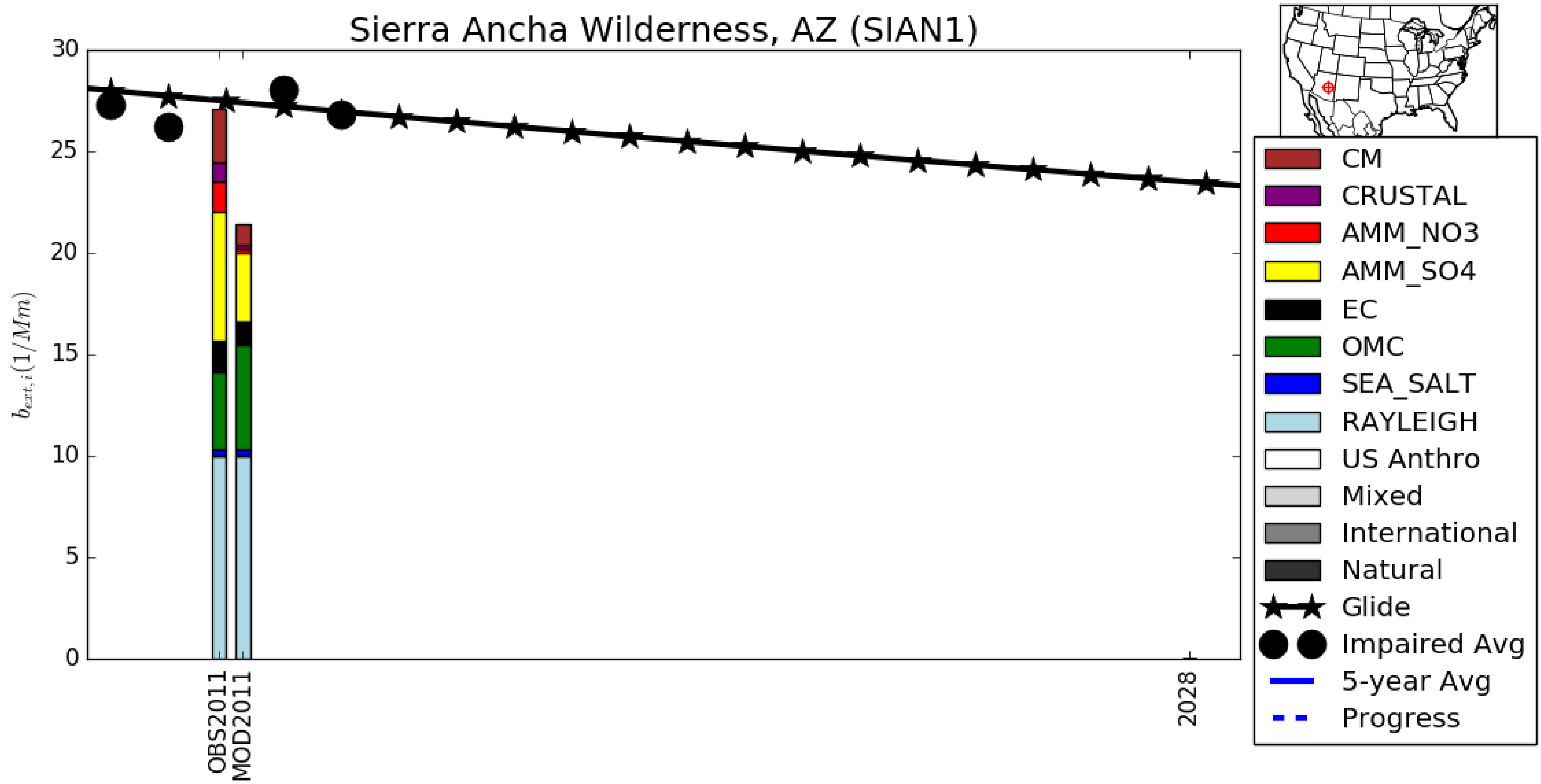


Figure B-62: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Sierra Ancha Wilderness (AZ).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

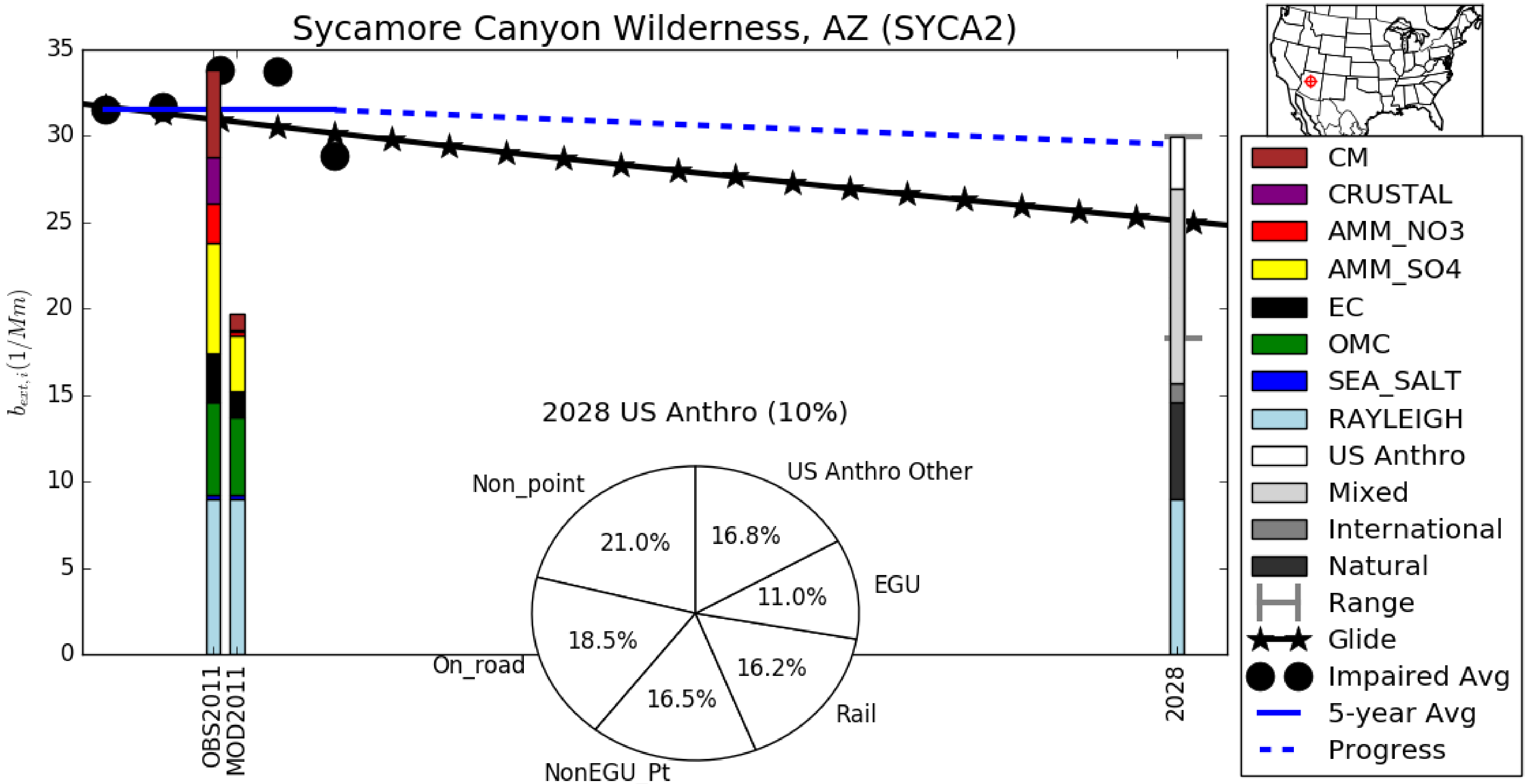


Figure B-63: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Sycamore Canyon Wilderness (AZ).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

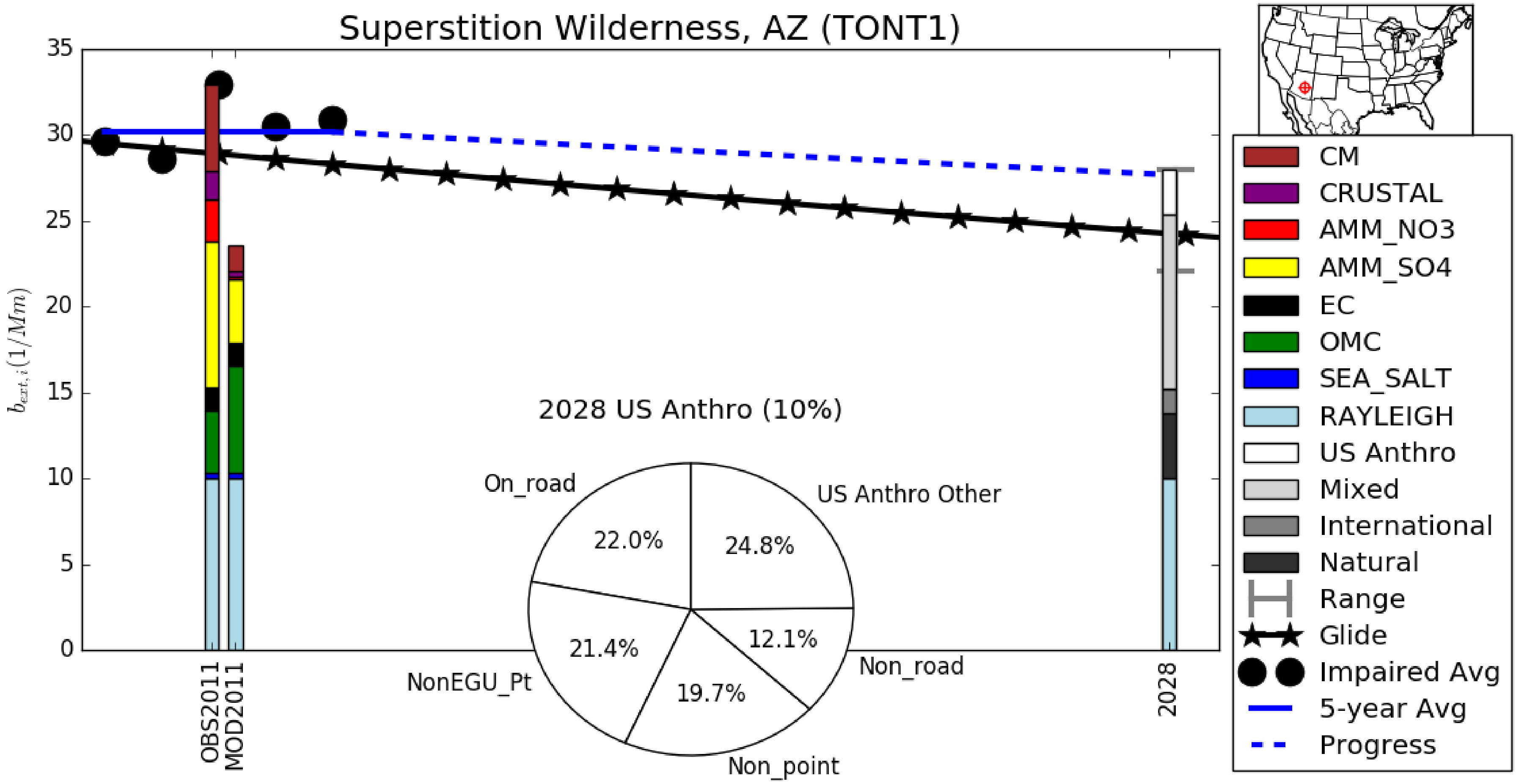


Figure B-64: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Superstition Wilderness (AZ).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

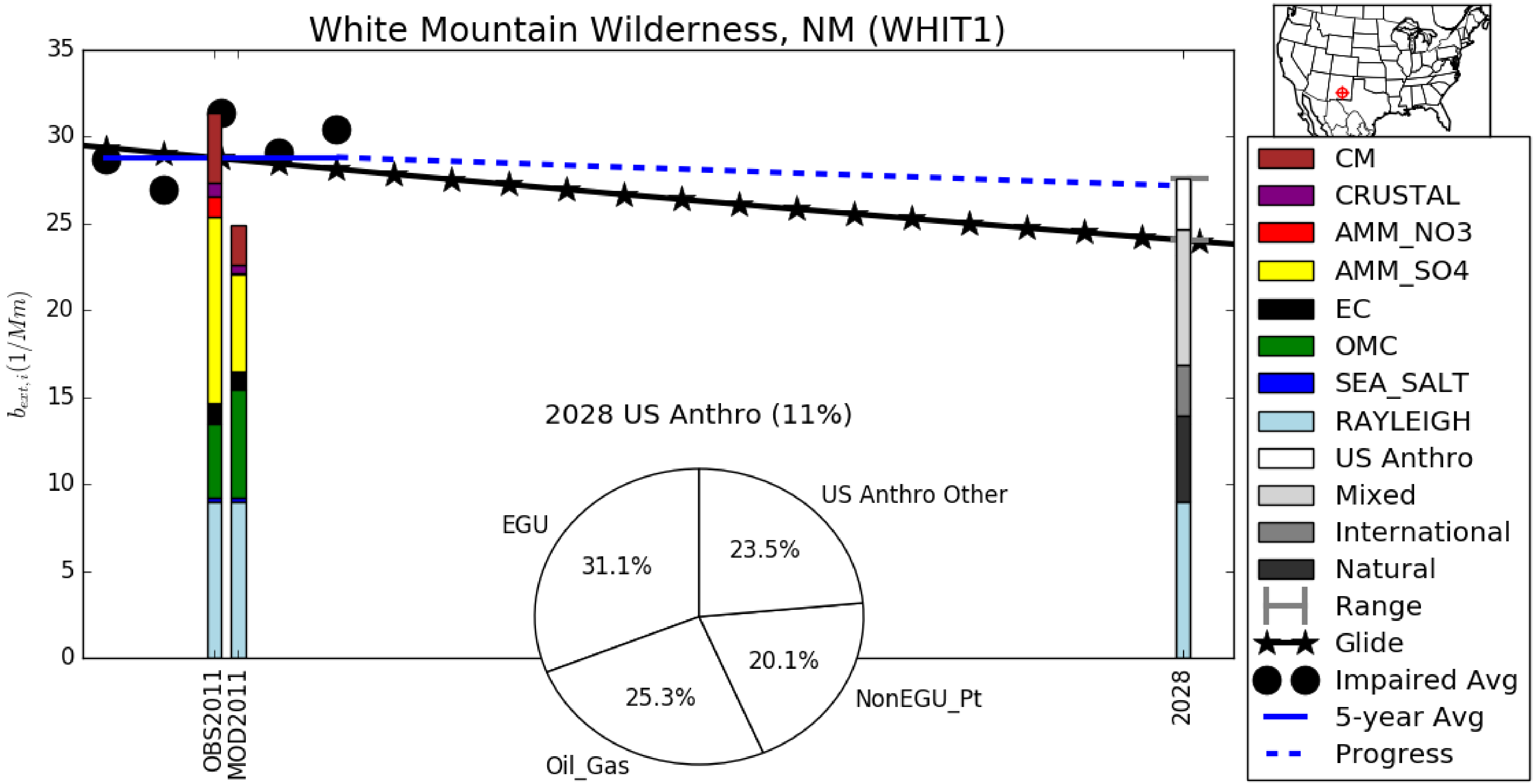


Figure B-65: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at White Mountain Wilderness (NM).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

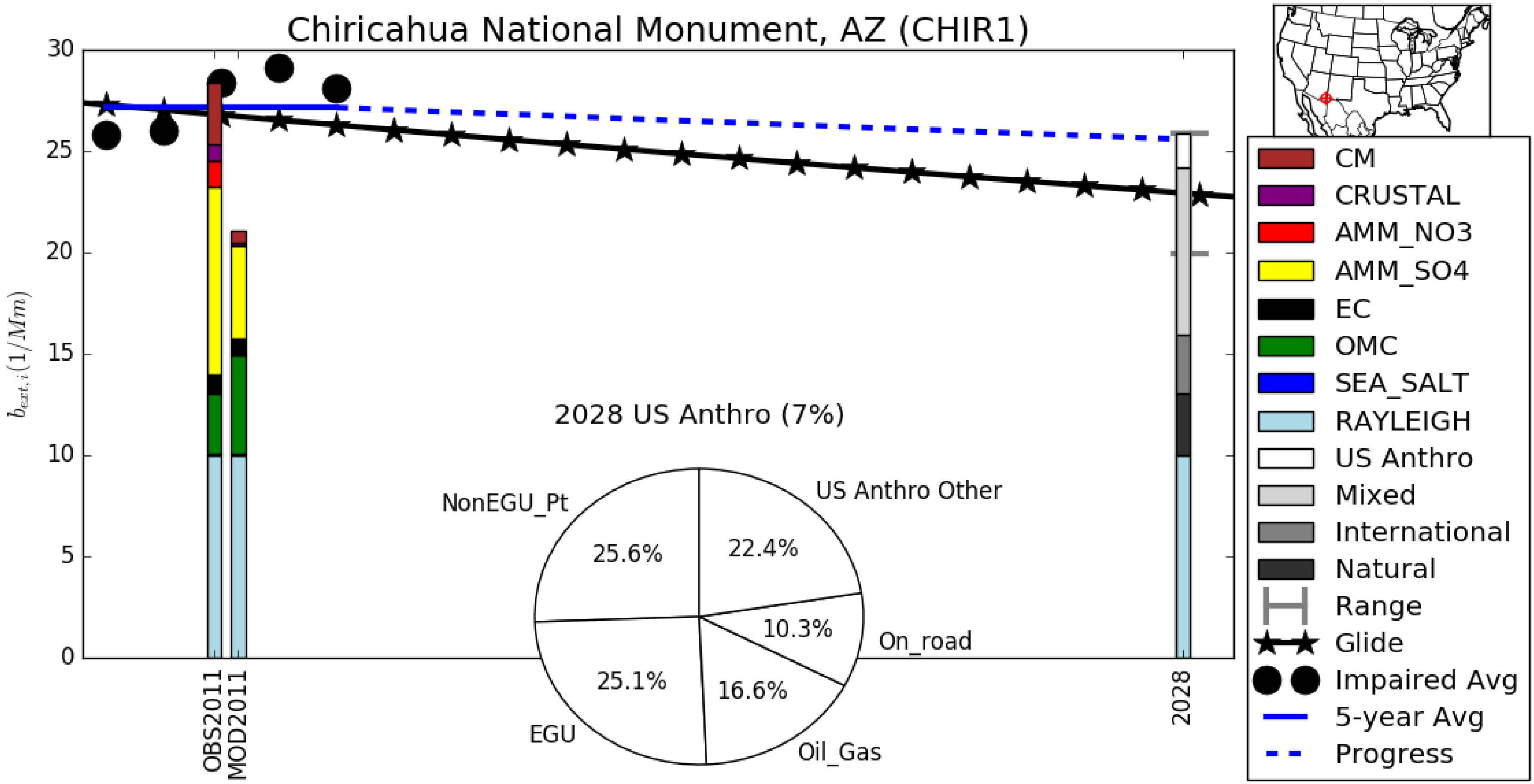


Figure B-66: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Chiricahua National Monument (AZ), Chiricahua Wilderness (AZ), and Galiuro Wilderness (AZ).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

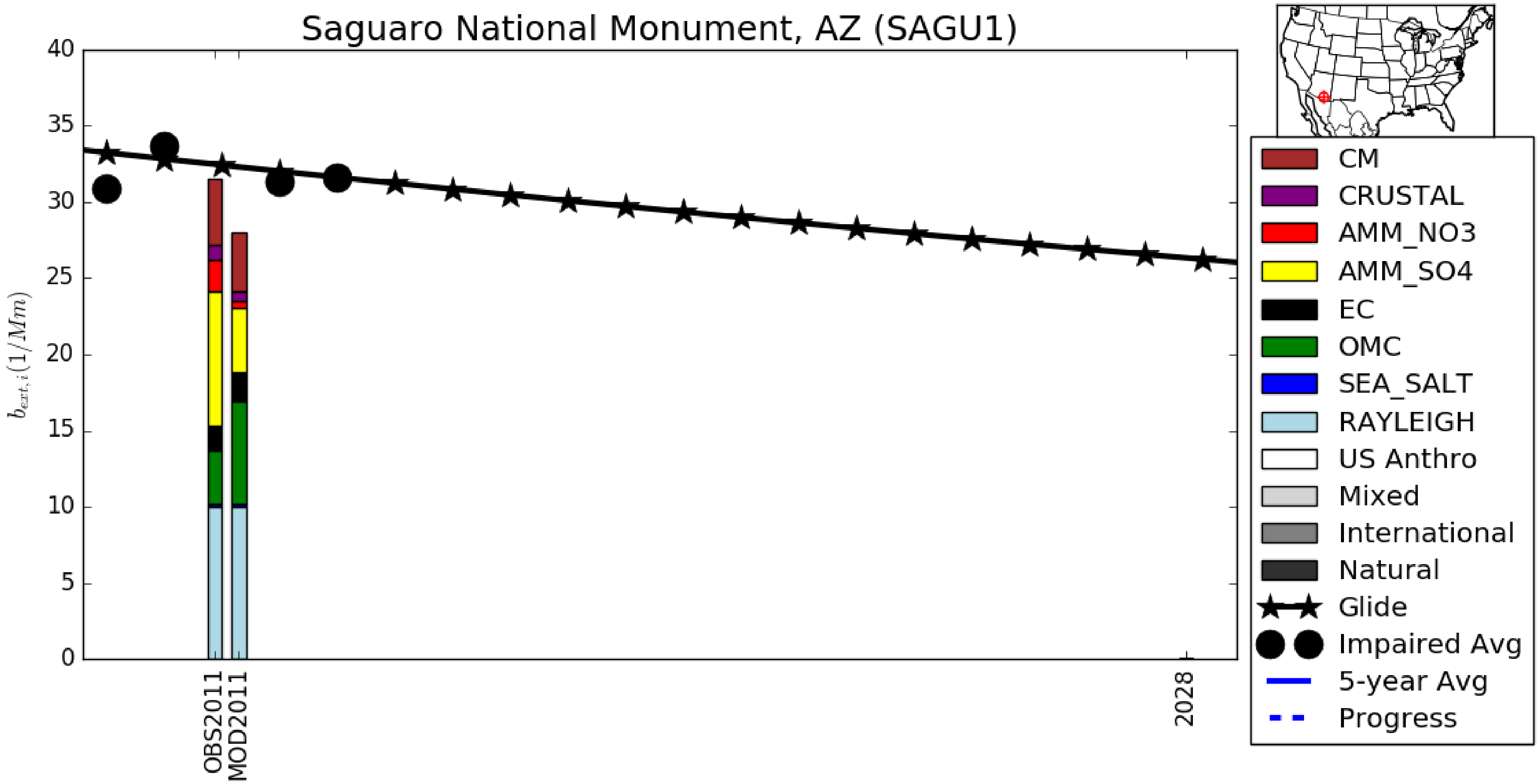


Figure B-67: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Saguaro National Monument (AZ).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

West Texas

- Big Bend National Park (TX)(BIBE1)
- Carlsbad Caverns National Park (TX) and Guadalupe Mountains National Park (TX)(GUMO1)
- Salt Creek (NM)(SACR1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, coarse mass, nitrate (at SACR1)
Model visibility performance summary (on 20% most impaired days)	Sulfate and nitrate underpredicted, coarse mass underpredicted (except overpredicted at SACR1)
Uncertainty in sector contributions	High "mixed" sector contribution percentage (>56% at all sites).
2028 US anthropogenic percent contribution	6-20%
Largest US anthropogenic sector contributions	EGU, nonEGU point, and Oil & gas

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

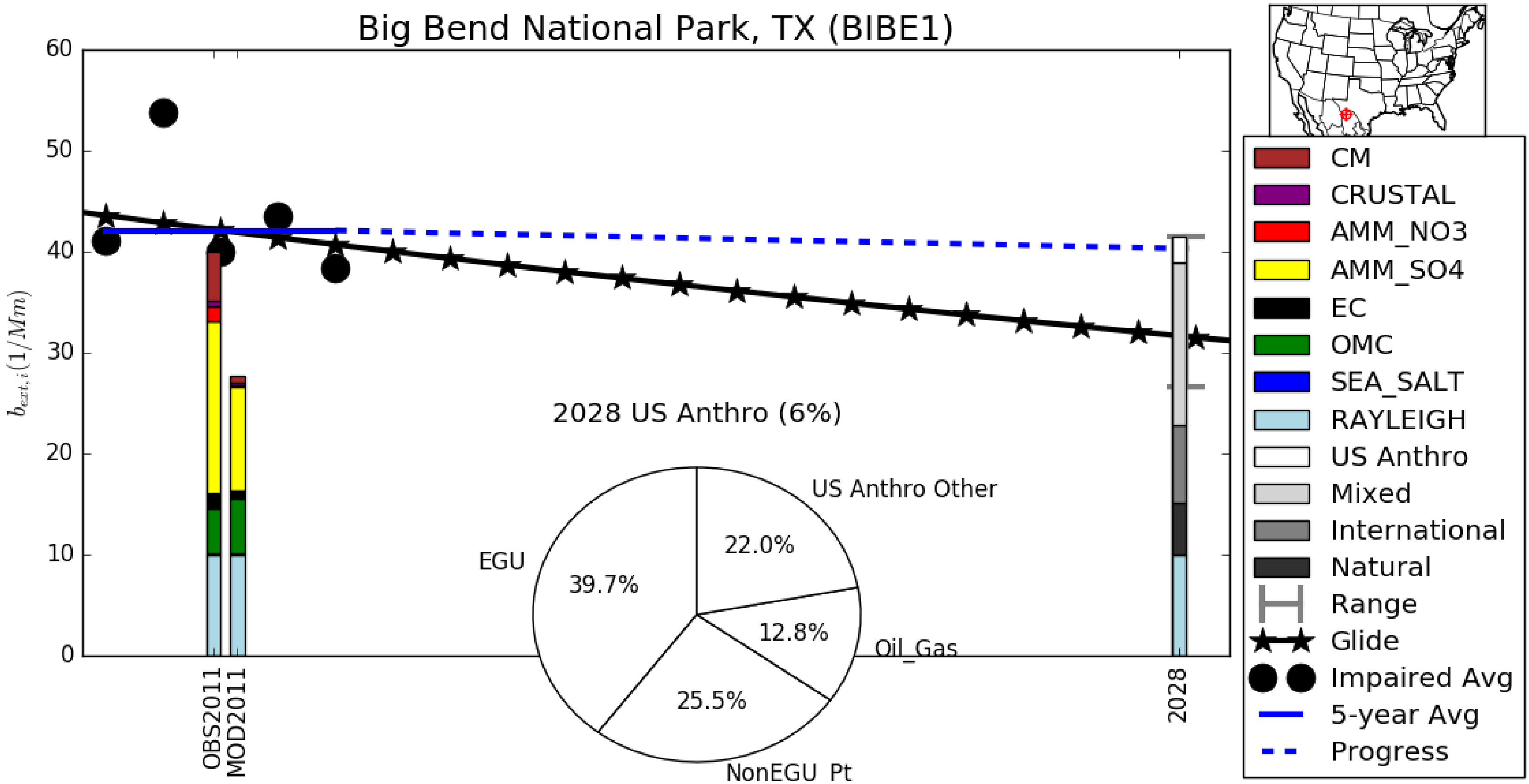


Figure B-68: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Big Bend National Park (TX).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

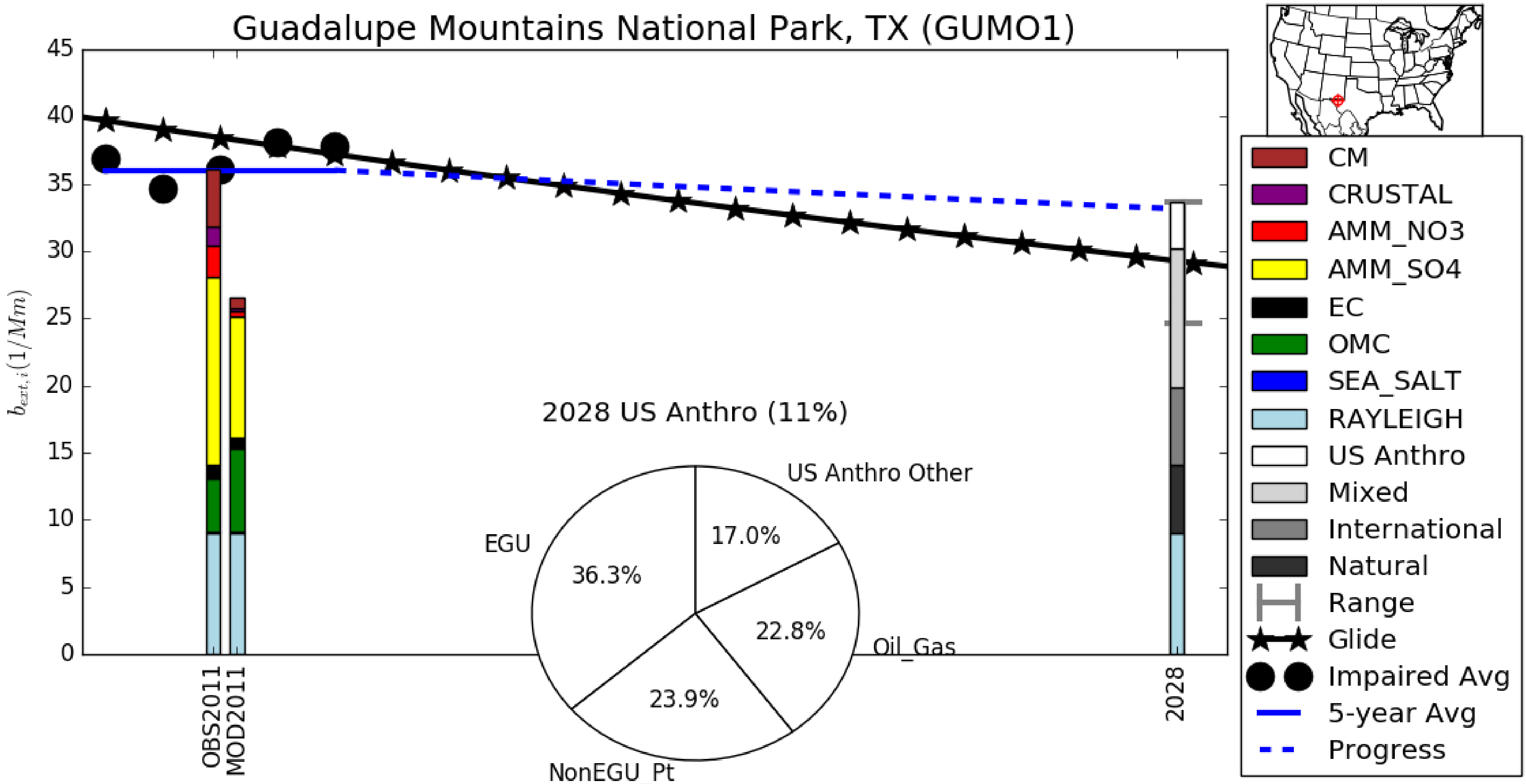


Figure B-69: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Carlsbad Caverns National Park (TX) and Guadalupe Mountains National Park (TX).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

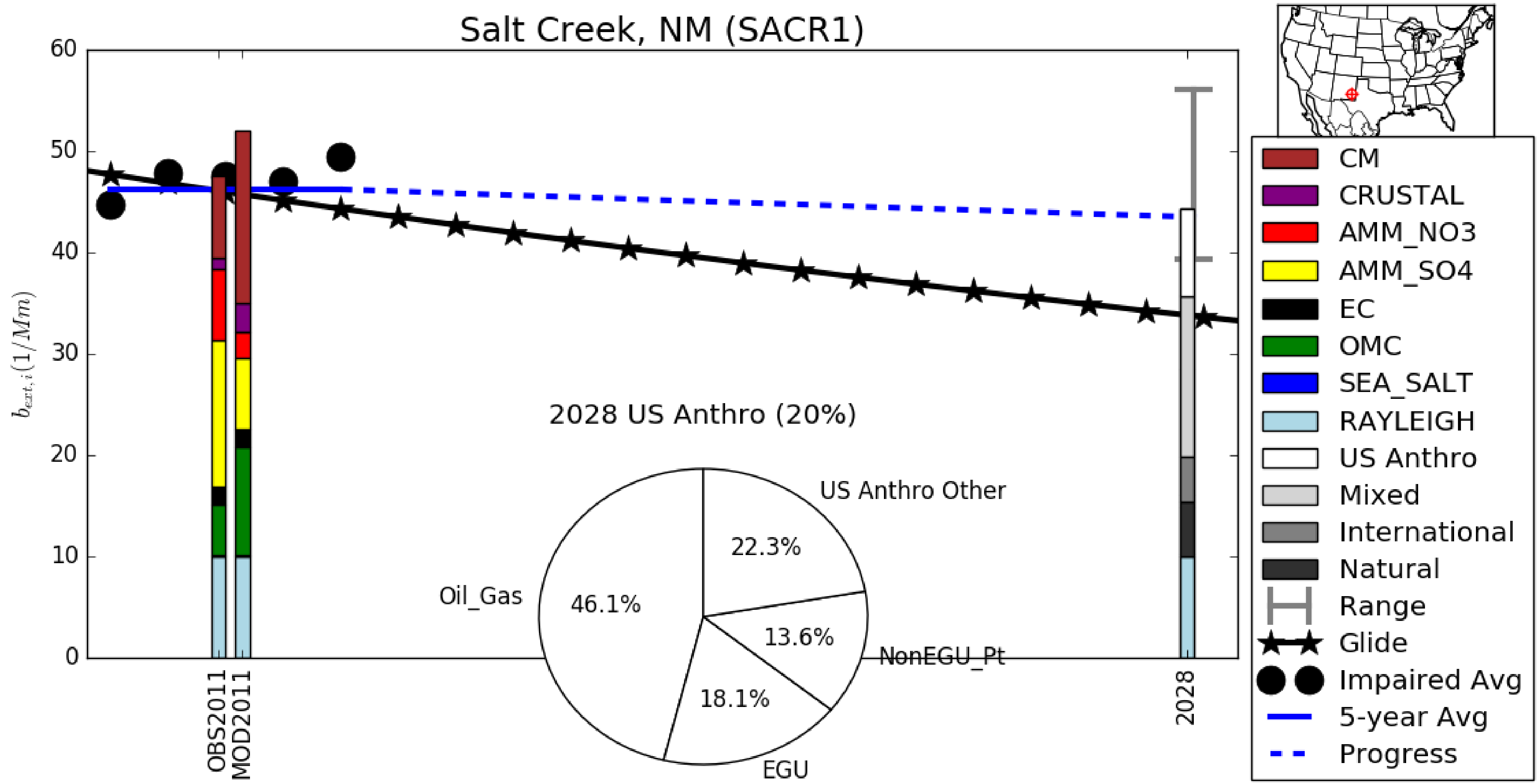


Figure B-70: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Salt Creek (NM).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Northern Great Plains

- Badlands National Park (SD)(BADL1)
- Lostwood (ND)(LOST1)
- Medicine Lake (MT)(MELA1)
- Theodore Roosevelt National Park (ND)(THRO1)
- UL Bend (MT)(ULBE1)
- Wind Cave National Park (SD)(WICA1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, nitrate
Model visibility performance summary (on 20% most impaired days)	Sulfate underpredicted, nitrate overpredicted
Uncertainty in sector contributions	High “mixed” sector contribution percentage (63%-68% except 47% at WICA1 and 54% at BADL1).
2028 US anthropogenic percent contribution	18-19% except 9% at ULBE1
Largest US anthropogenic sector contributions	EGU, Oil & gas, and nonEGU point

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high “mixed” (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

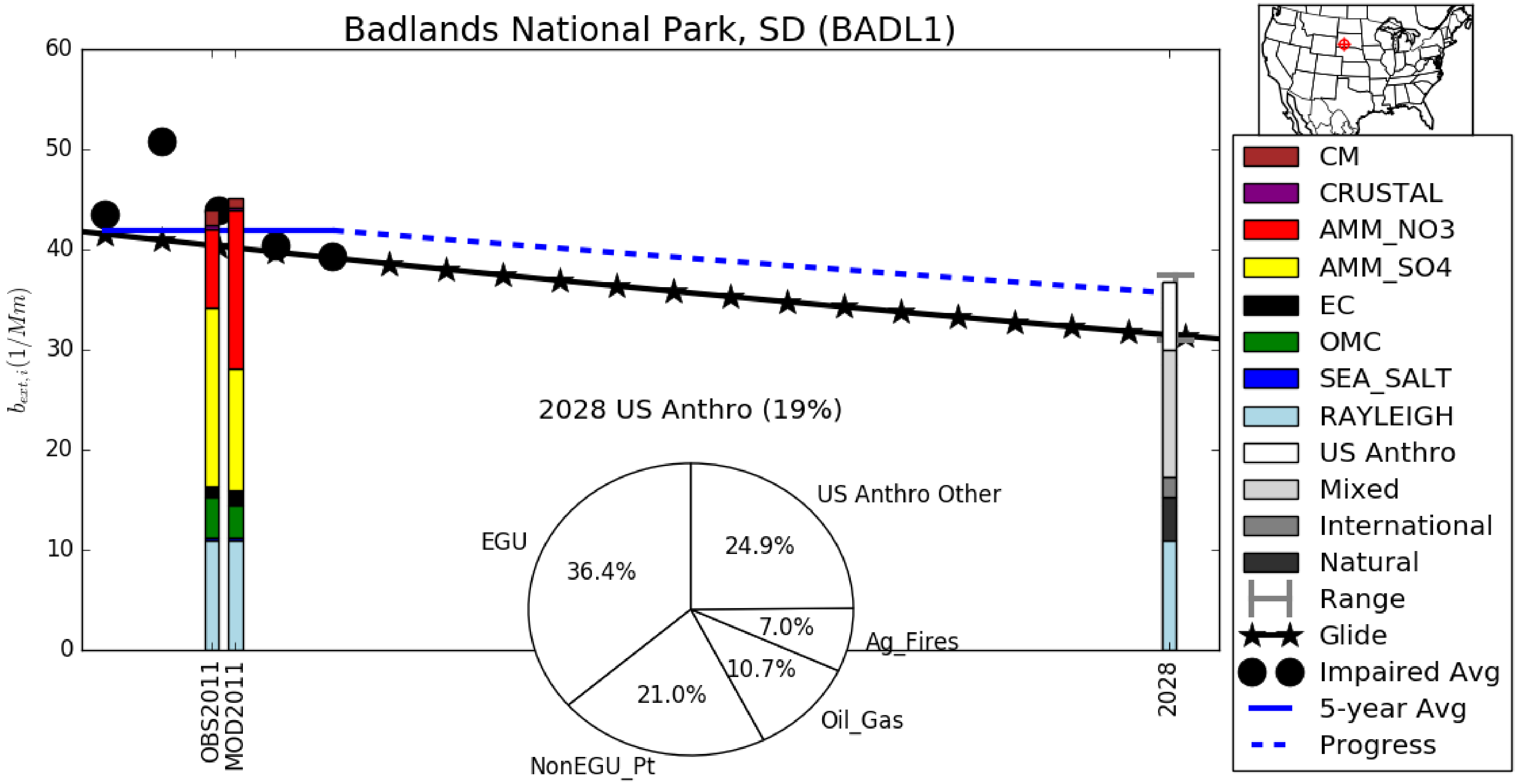


Figure B-71: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Badlands National Park (SD).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

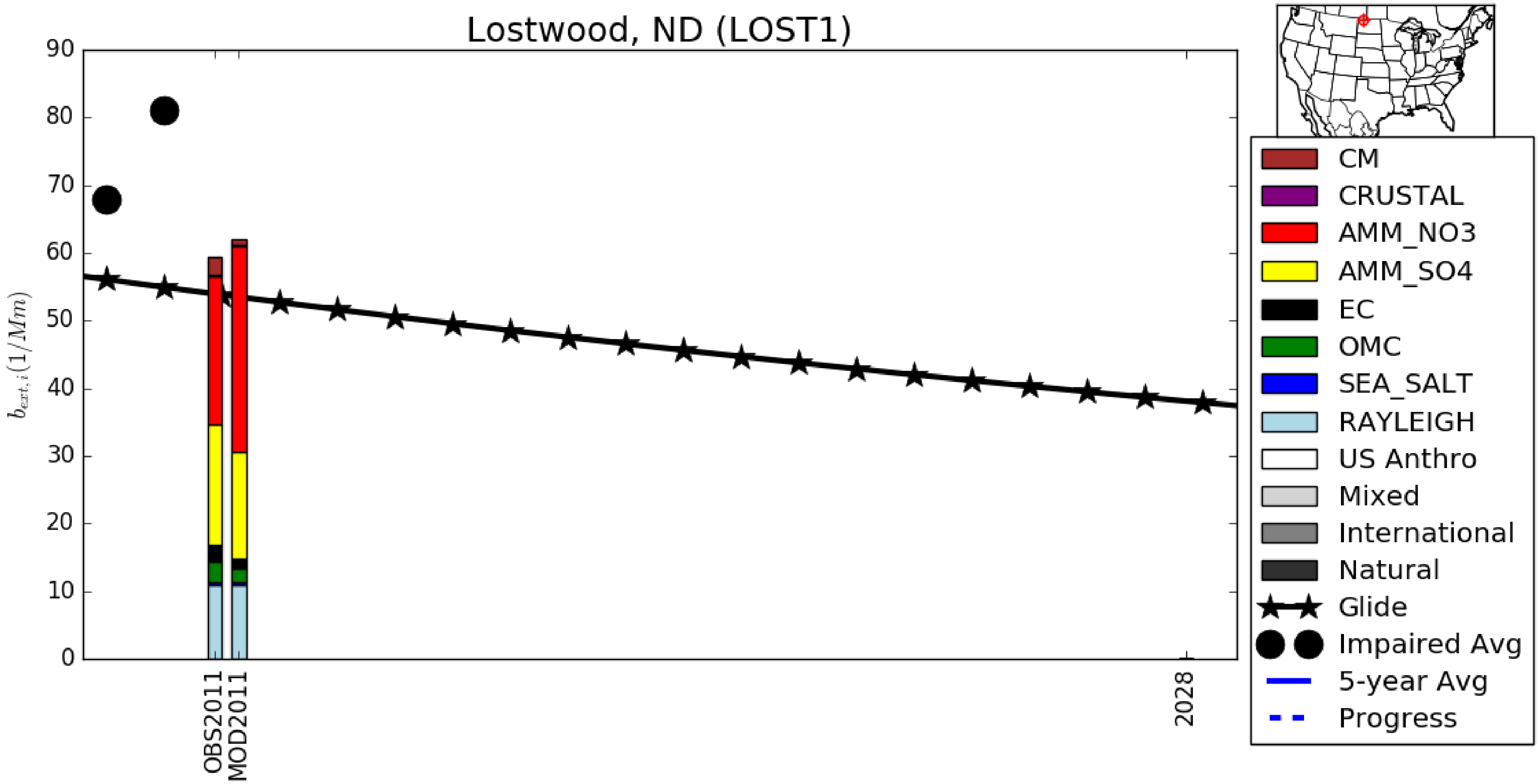


Figure B-72: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Lostwood (ND).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

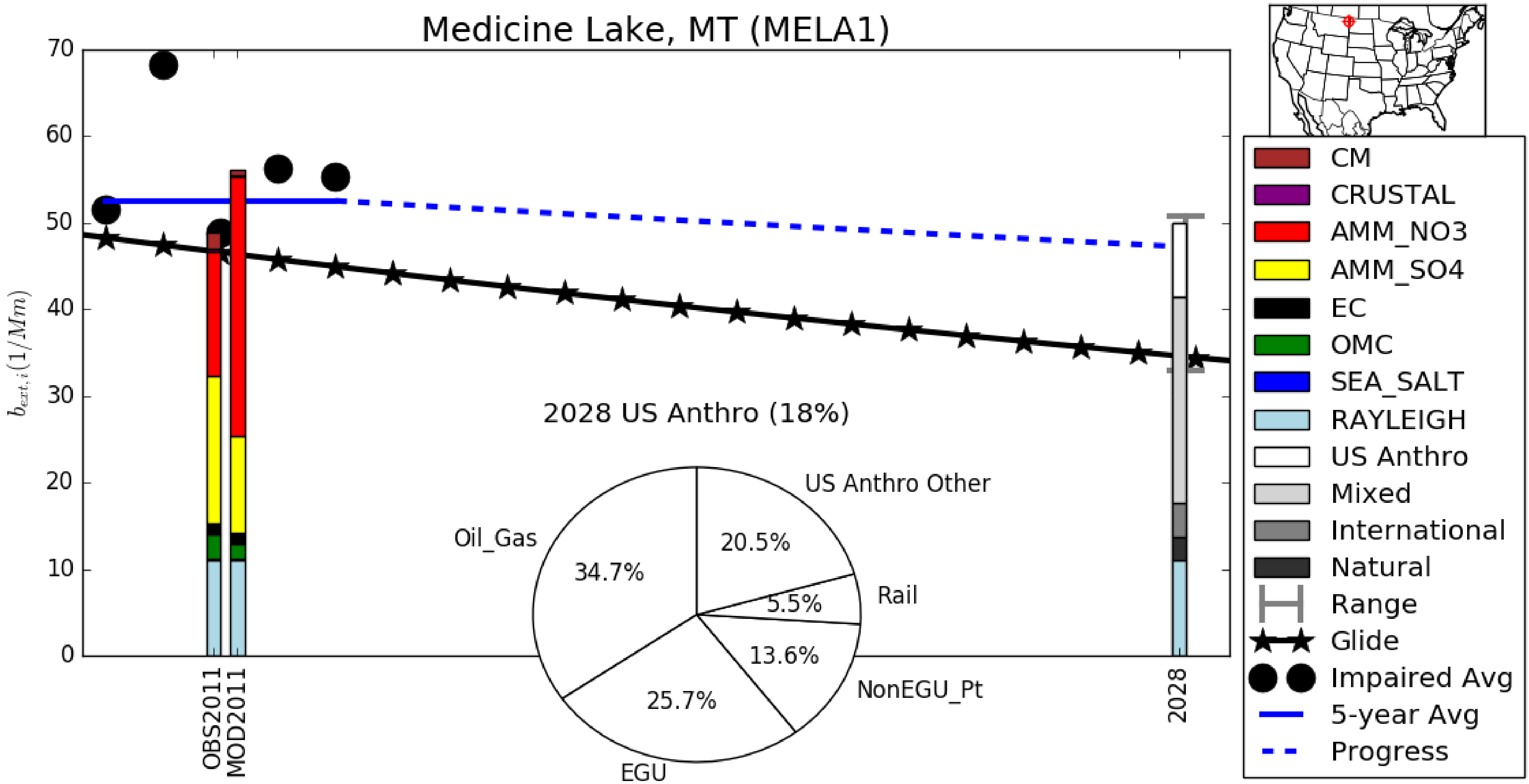


Figure B-73: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Medicine Lake (MT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

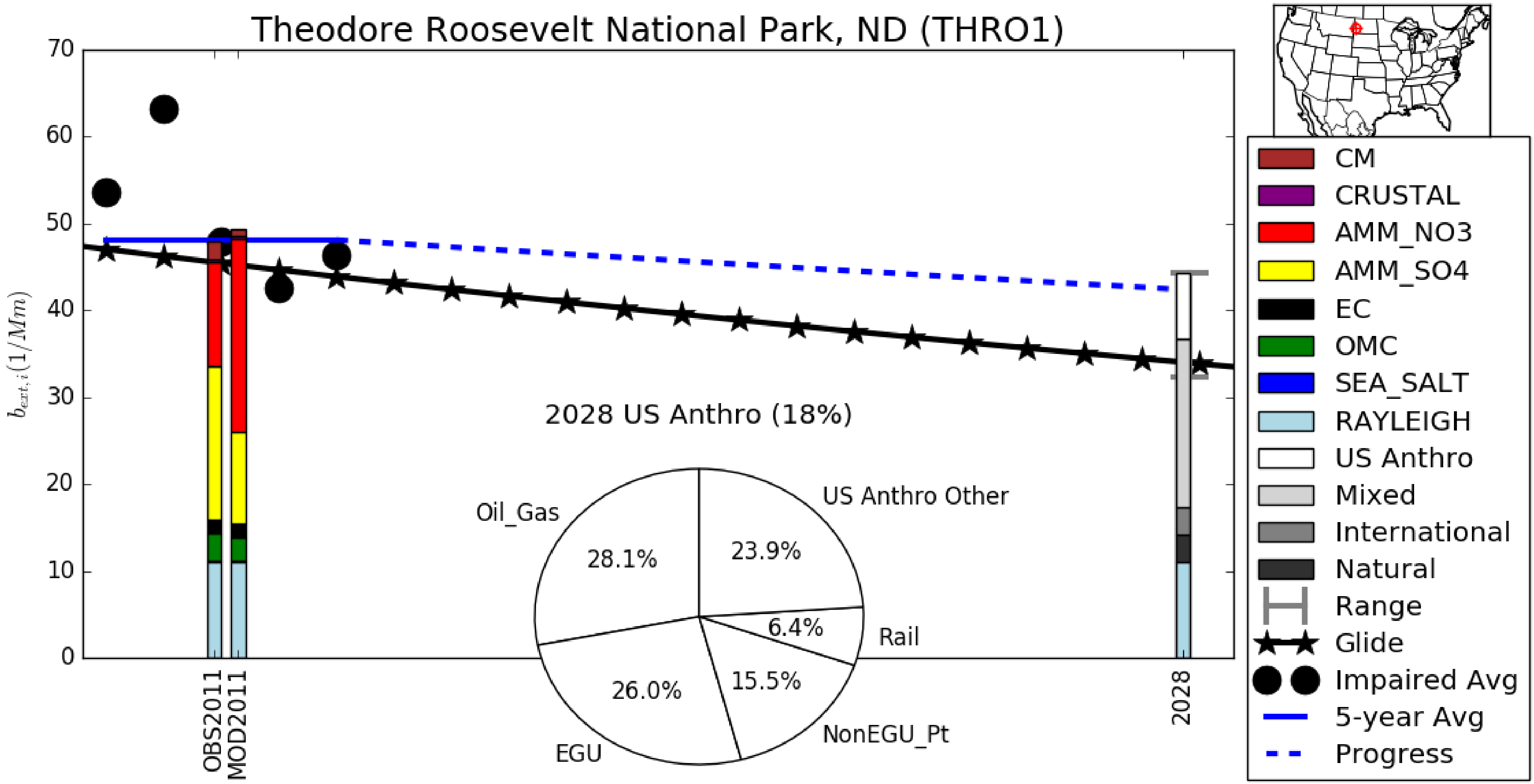


Figure B-74: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Theodore Roosevelt National Park (ND).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

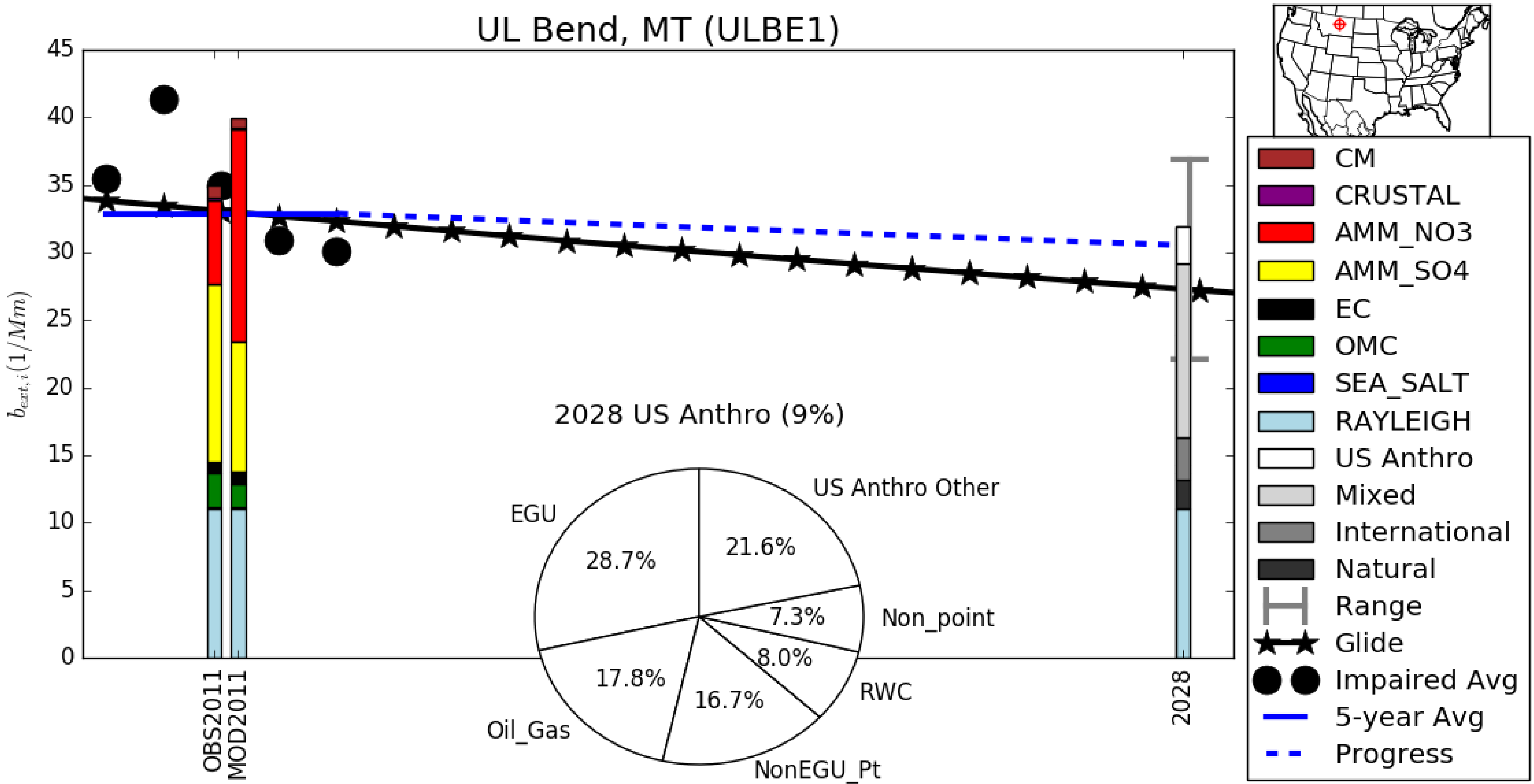


Figure B-75: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at UL Bend (MT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

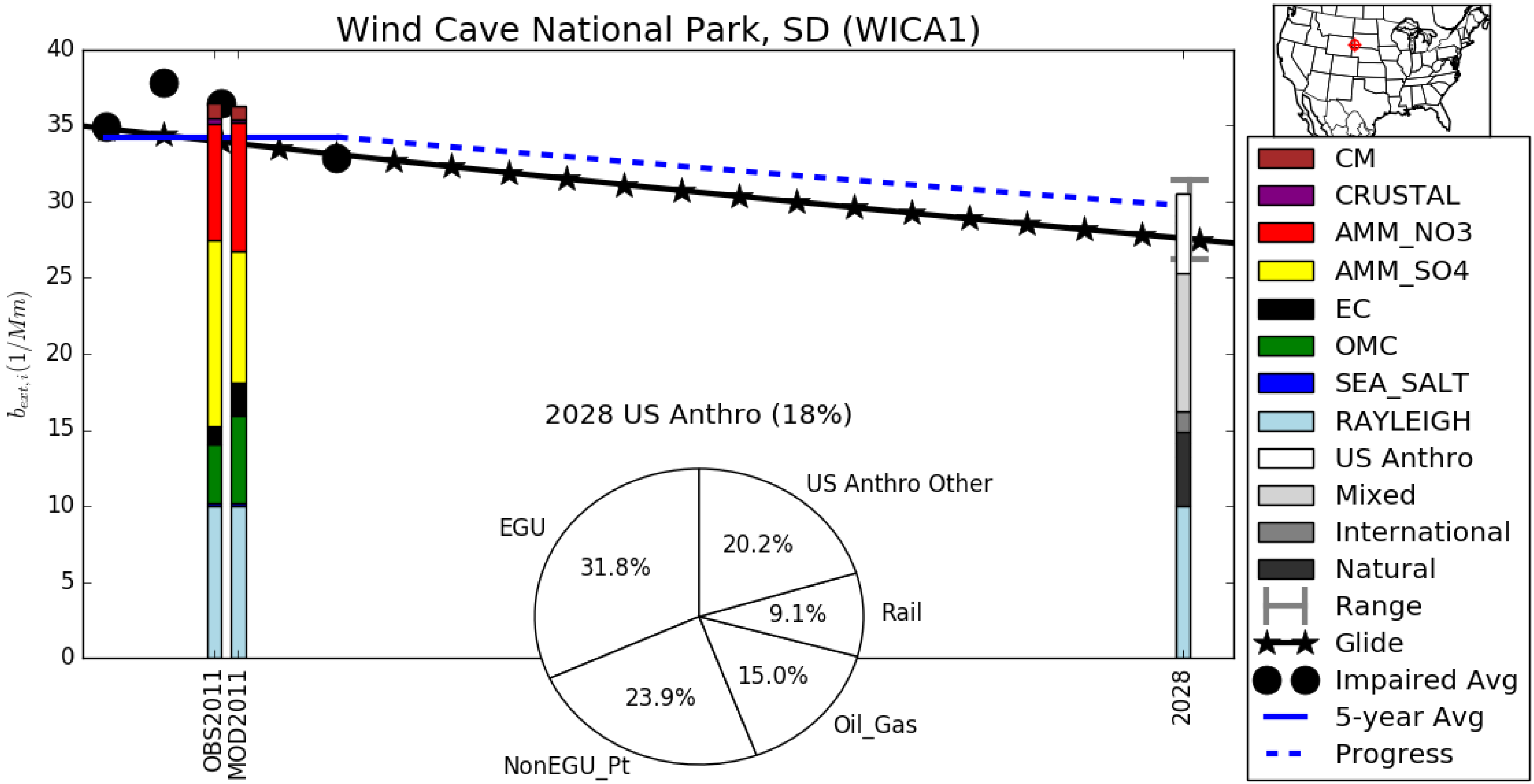


Figure B-76: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Wind Cave National Park (SD).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Mid South

- Caney Creek Wilderness (AR)(CACR1)
- Hercules-Glades Wilderness (MO)(HEGL1)
- Upper Buffalo Wilderness (AR)(UPBU1)
- Wichita Mountains (OK)(WIMO1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, nitrate
Model visibility performance summary (on 20% most impaired days)	Sulfate underpredicted, nitrate underpredicted at HEGL1 and WIMO1
Uncertainty in sector contributions	Relatively low "mixed" sector contribution percentage (26%-44%).
2028 US anthropogenic percent contribution	30-47%
Largest US anthropogenic sector contributions	EGU, nonEGU point, and Oil & gas

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

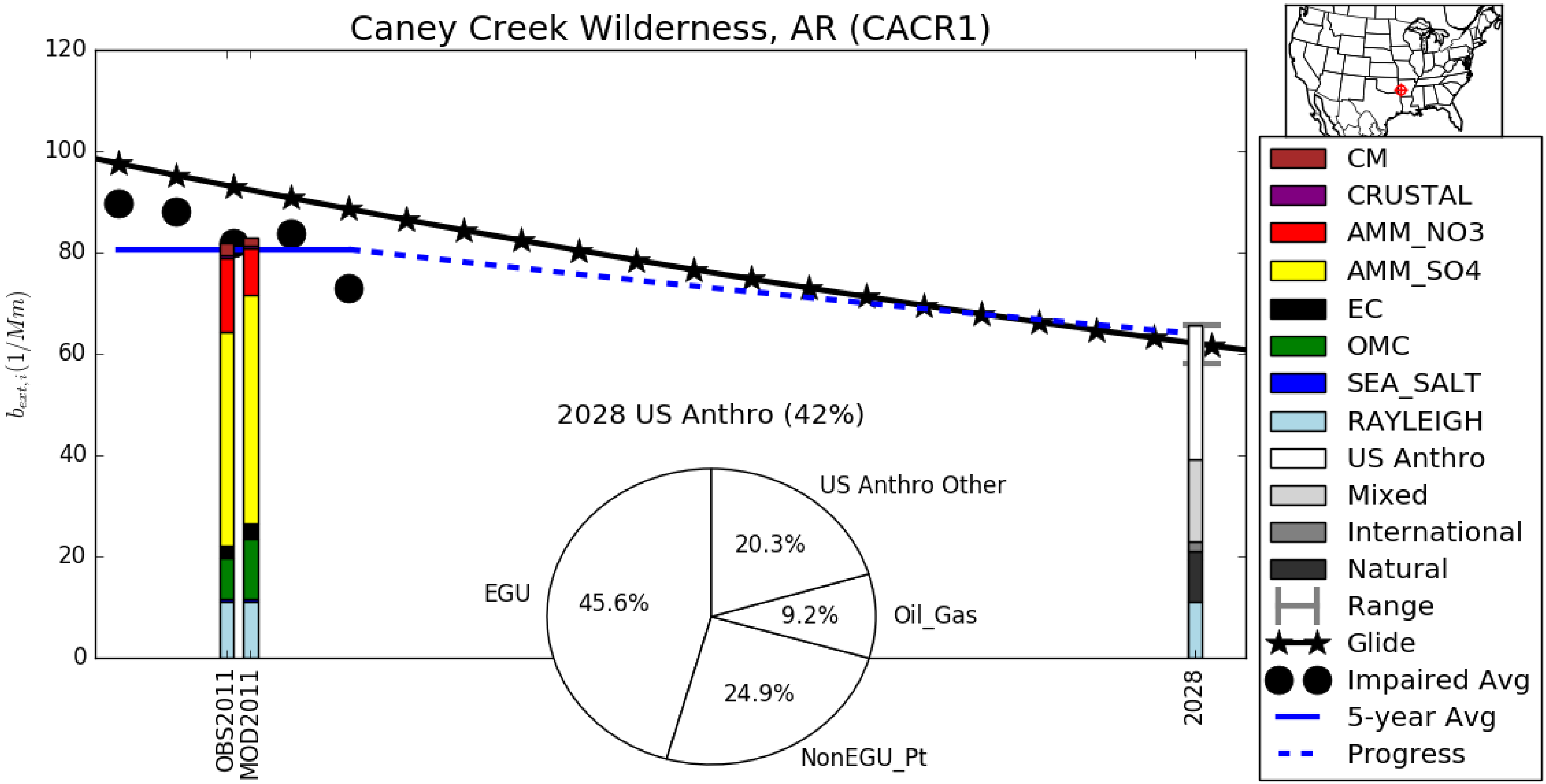


Figure B-77: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Caney Creek Wilderness (AR).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

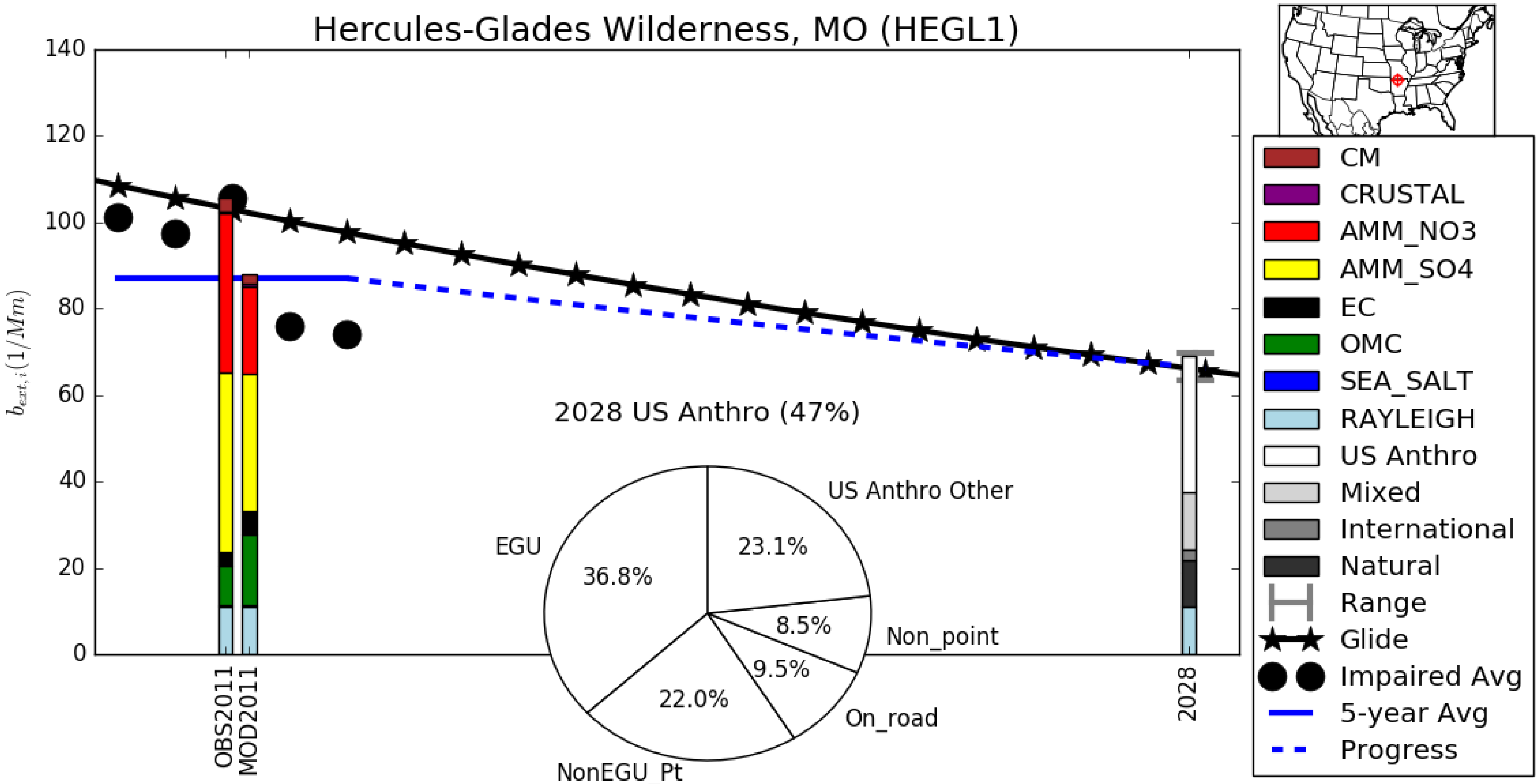


Figure B-78: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Hercules-Glades Wilderness (MO).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

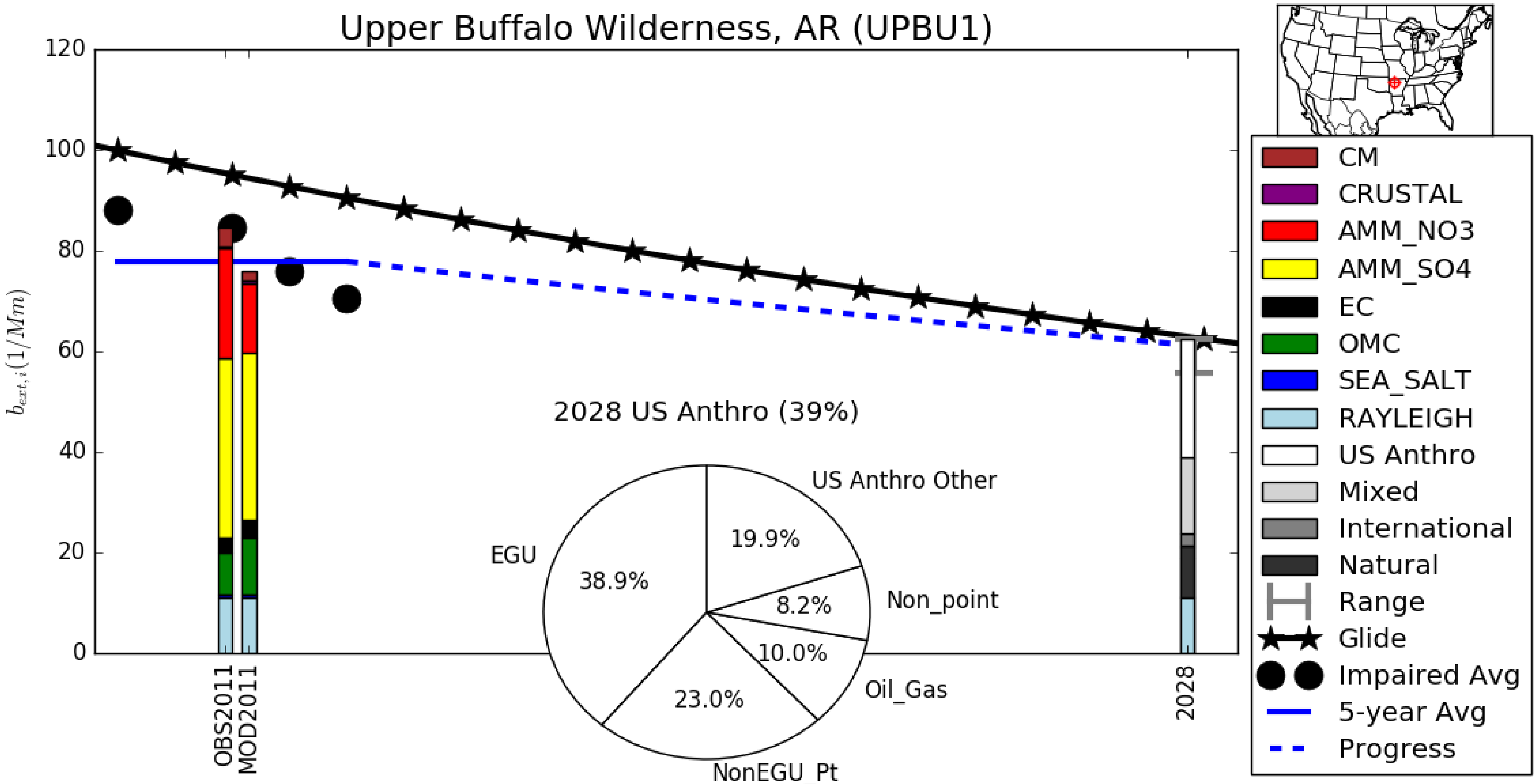


Figure B-79: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Upper Buffalo Wilderness (AR).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

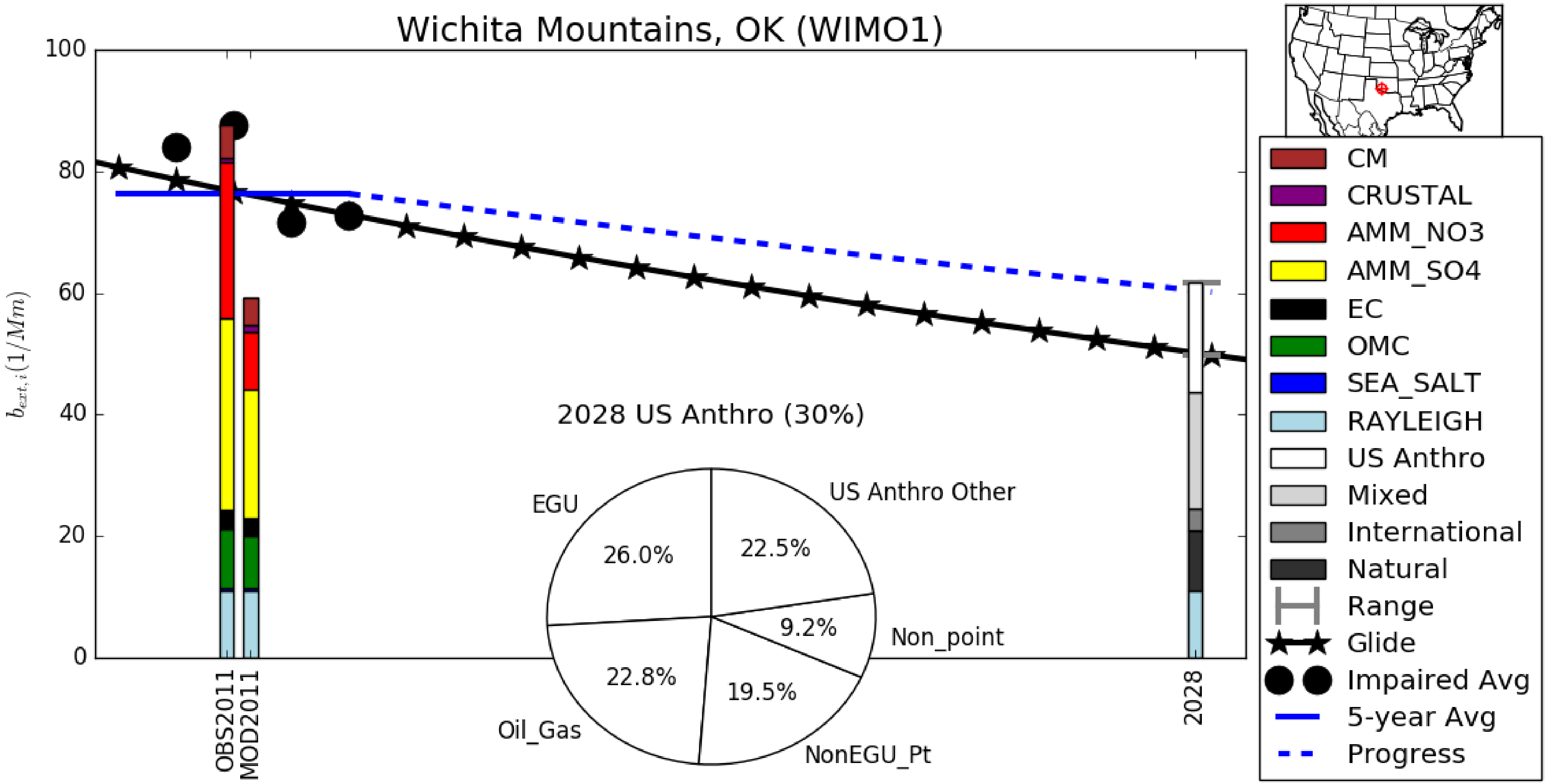


Figure B-80: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Wichita Mountains (OK).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Boundary Waters

- Boundary Waters Canoe Area (M N)(BOWA1)
- Isle Royale National Park (MI)(ISLE1)
- Seney (MI)(SENE1)
- Voyageurs National Park (MN)(VOYA2)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, nitrate
Model visibility performance summary (on 20% most impaired days)	Performance generally good
Uncertainty in sector contributions	Relatively low "mixed" sector contribution percentage (31%-35%).
2028 US anthropogenic percent contribution	41-50%
Largest US anthropogenic sector contributions	NonEGU point, EGU, and RWC

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

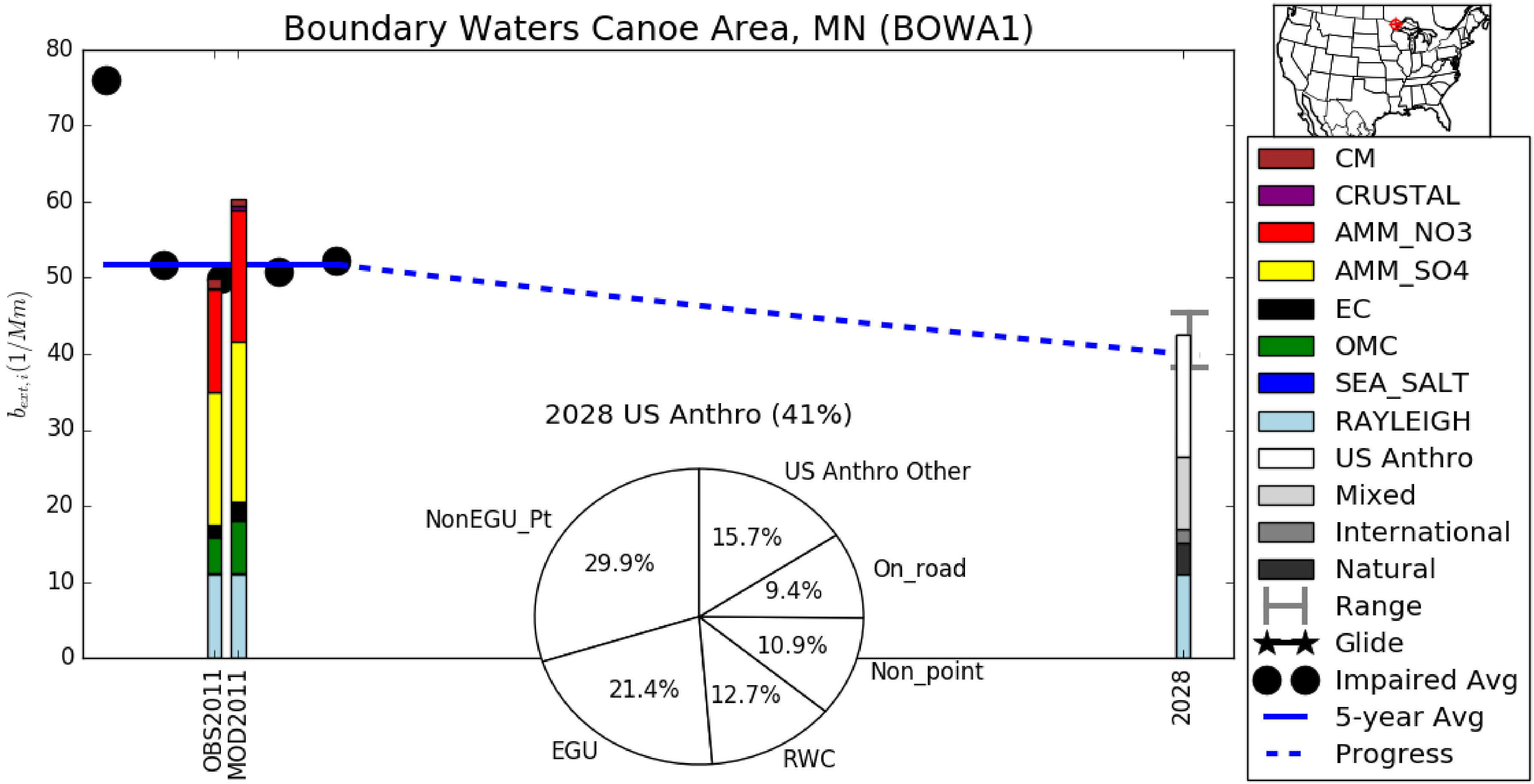


Figure B-81: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Boundary Waters Canoe Area (MN).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

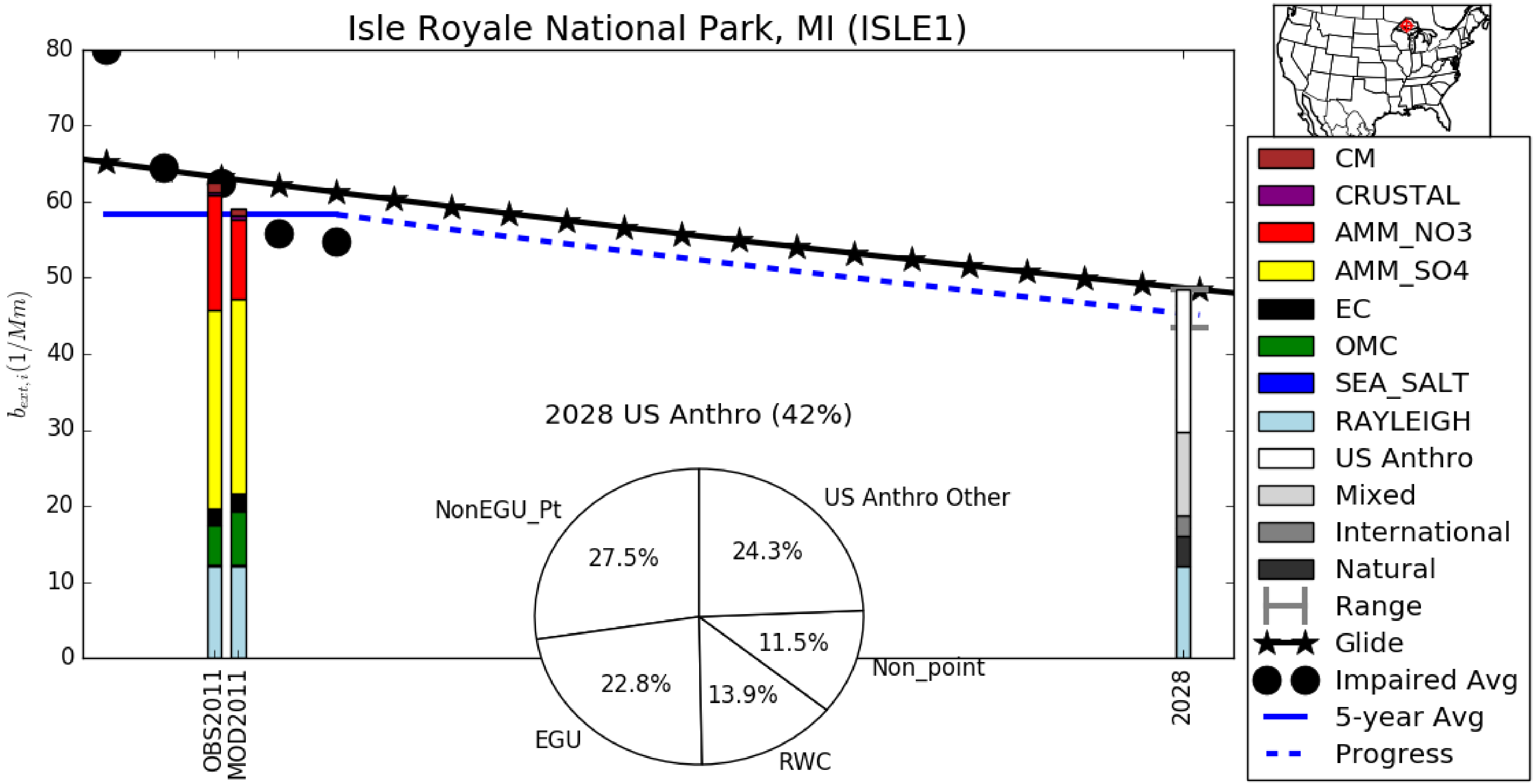


Figure B-82: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Isle Royale National Park (MI).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

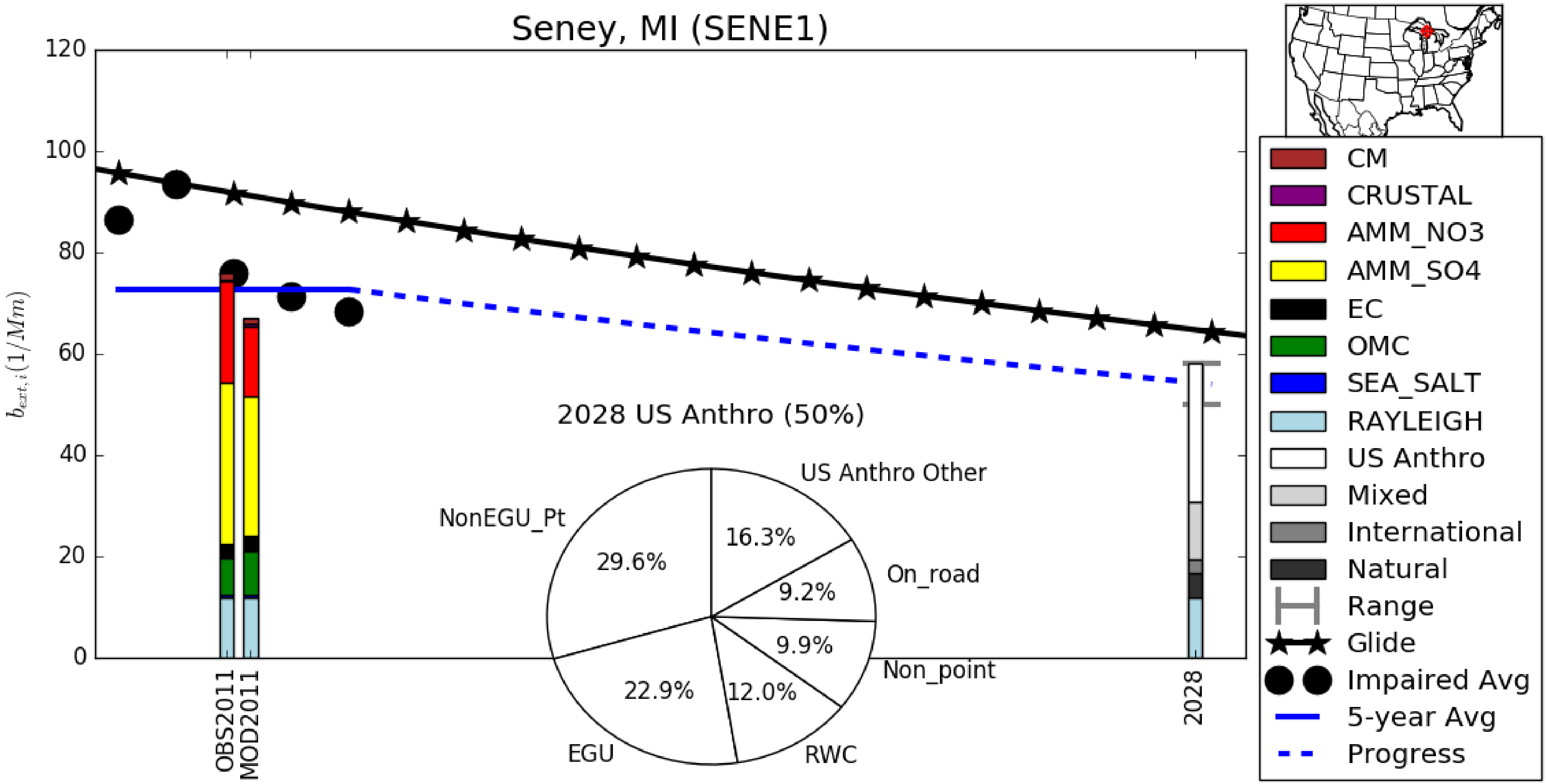


Figure B-83: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Seney (MI).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

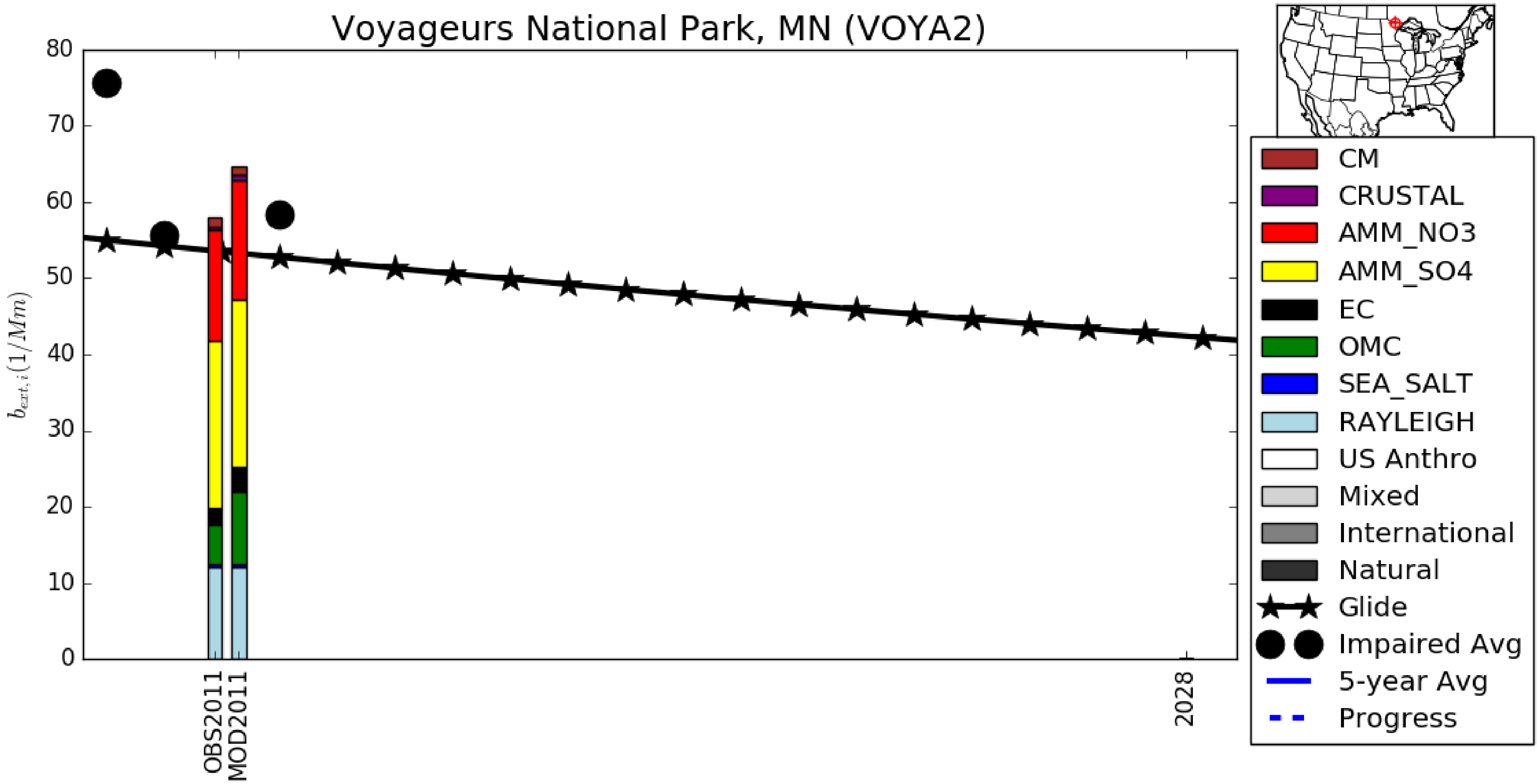


Figure B-84: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Voyageurs National Park (MN).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

Appalachia

- Cohutta Wilderness (GA)(COHU1)
- Dolly Sods Wilderness (WV) and Otter Creek Wilderness (WV)(DOSO1)
- Great Smoky Mountains National Park (TN) and Joyce-Kilmer-Slickrock Wilderness (TN)(GRSM1)
- James River Face Wilderness (VA)(JARI1)
- Linville Gorge Wilderness (NC)(LIGO1)
- Shenandoah National Park (VA)(SHEN1)
- Shining Rock Wilderness (NC)(SHRO1)
- Sipsey Wilderness (AL)(SIPS1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Dominated by sulfate, smaller amount of organic carbon
Model visibility performance summary (on 20% most impaired days)	Performance generally good, but sulfate underpredicted
Uncertainty in sector contributions	Relatively low "mixed" sector contribution percentage (26%-34%).
2028 US anthropogenic percent contribution	42-54%
Largest US anthropogenic sector contributions	EGU and nonEGU point

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

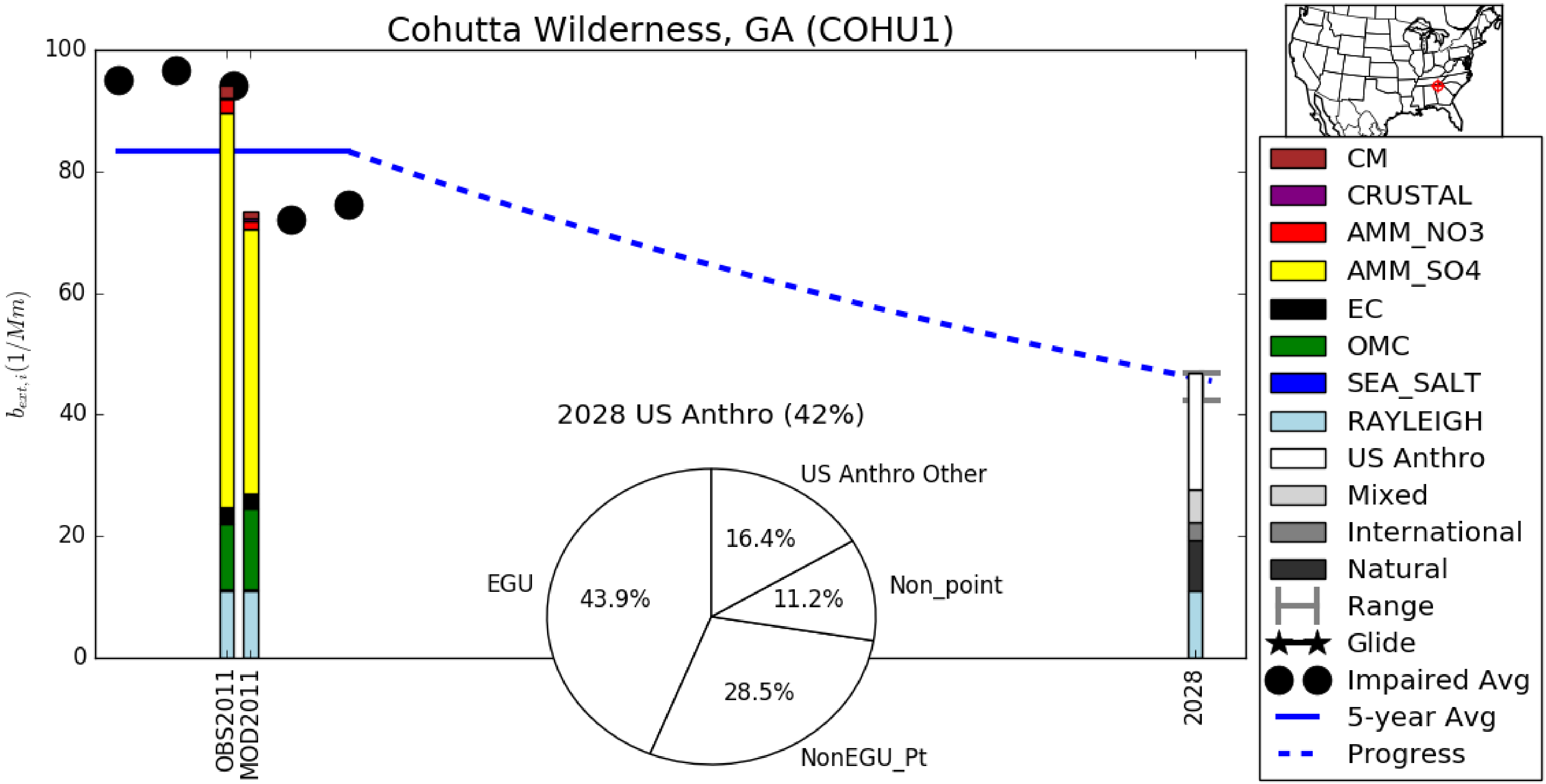


Figure B-85: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Cohutta Wilderness (GA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

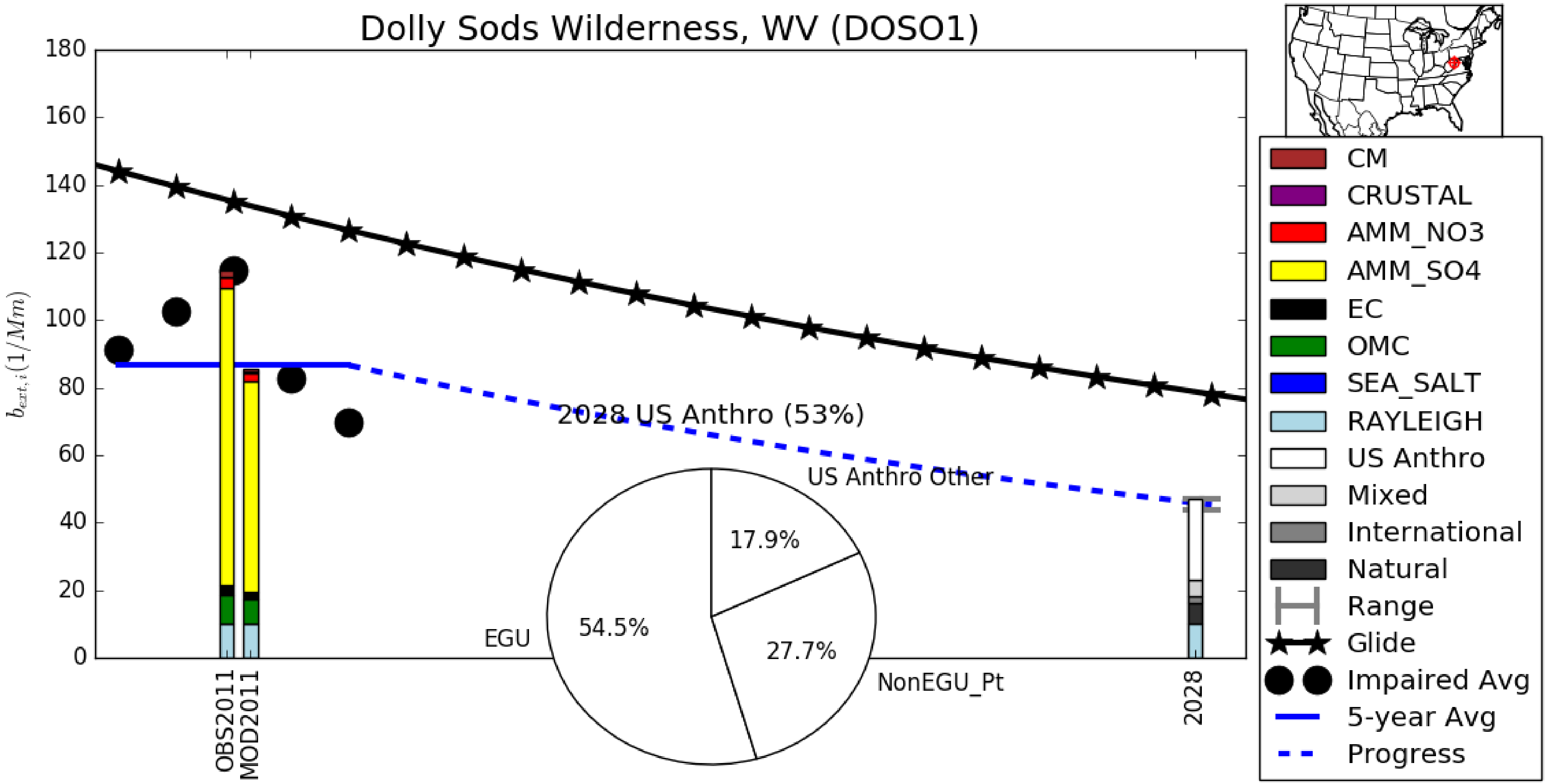


Figure B-86: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Dolly Sods Wilderness (WV) and Otter Creek Wilderness (WV).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

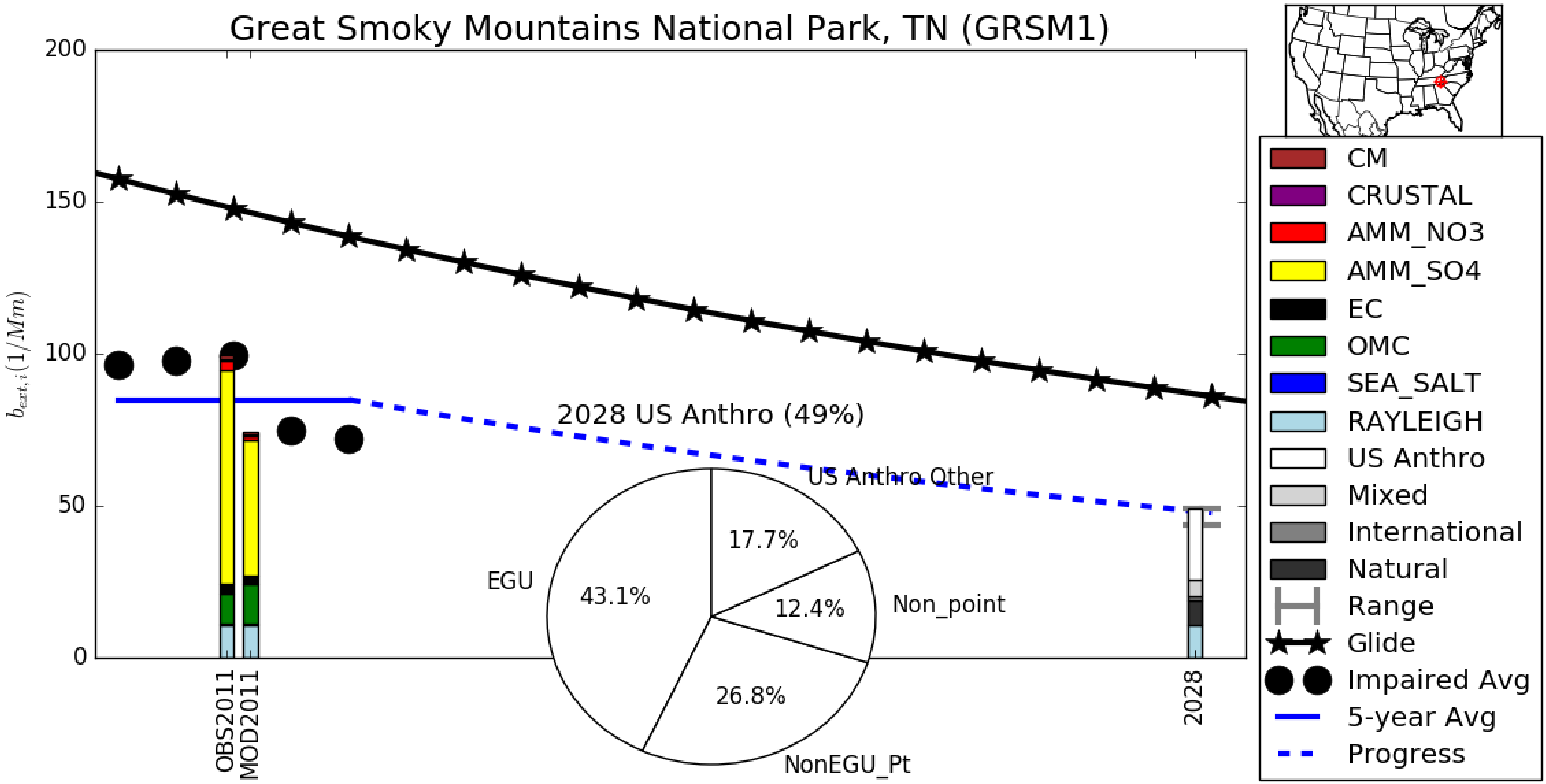


Figure B-87: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Great Smoky Mountains National Park (TN) and Joyce-Kilmer-Slickrock Wilderness (TN).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

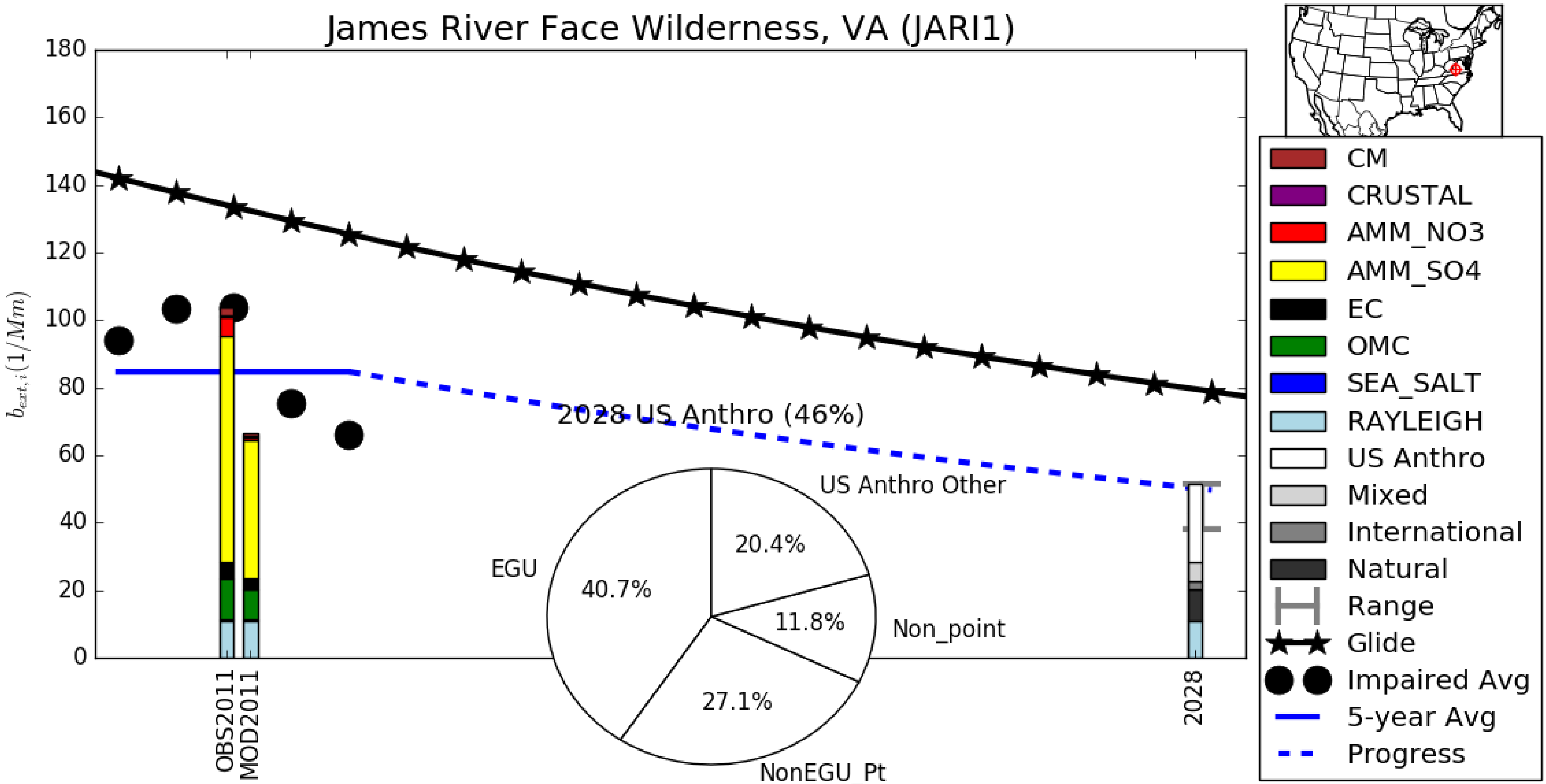


Figure B-88: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at James River Face Wilderness (VA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

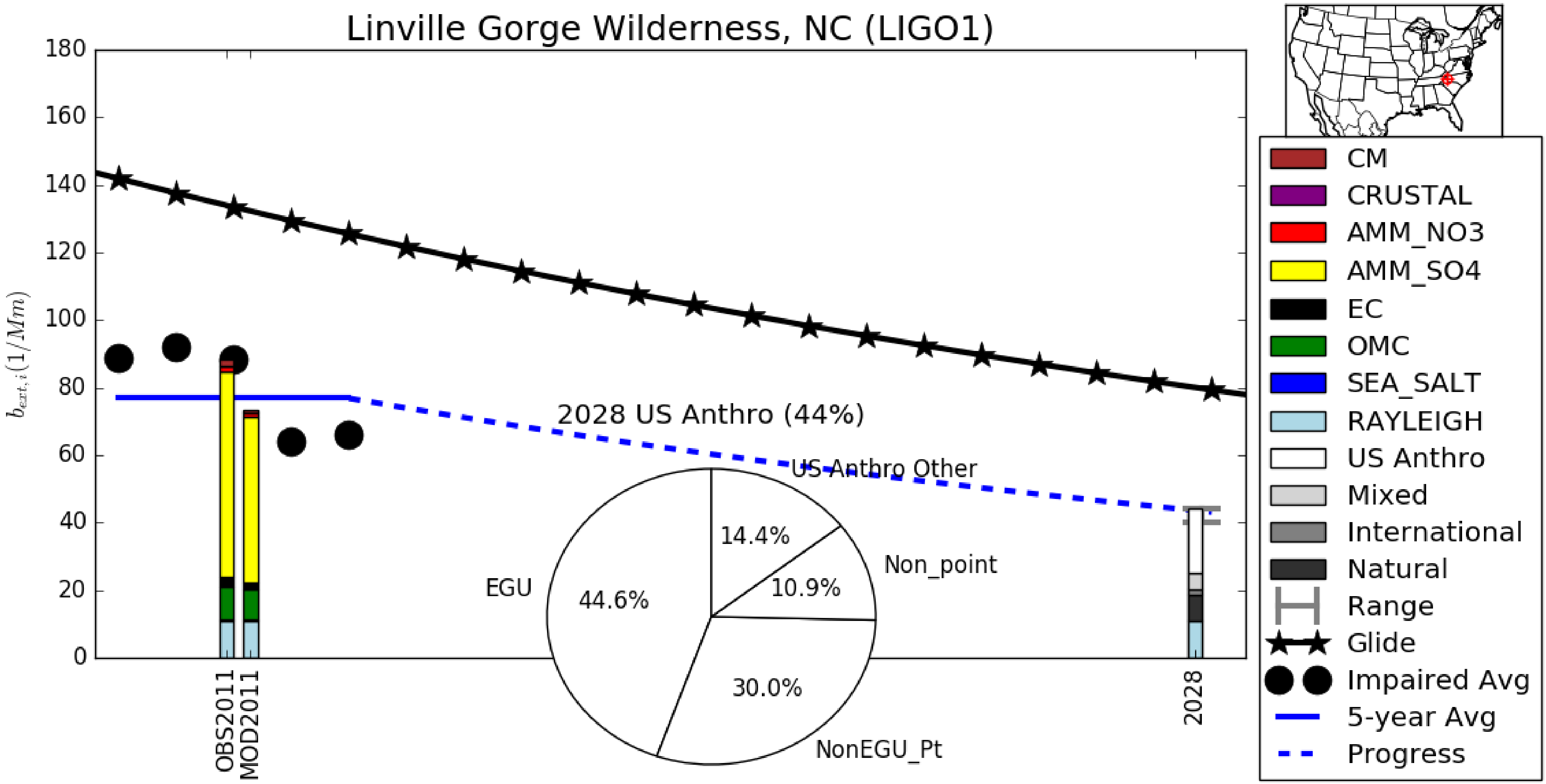


Figure B-89: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Linville Gorge Wilderness (NC).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

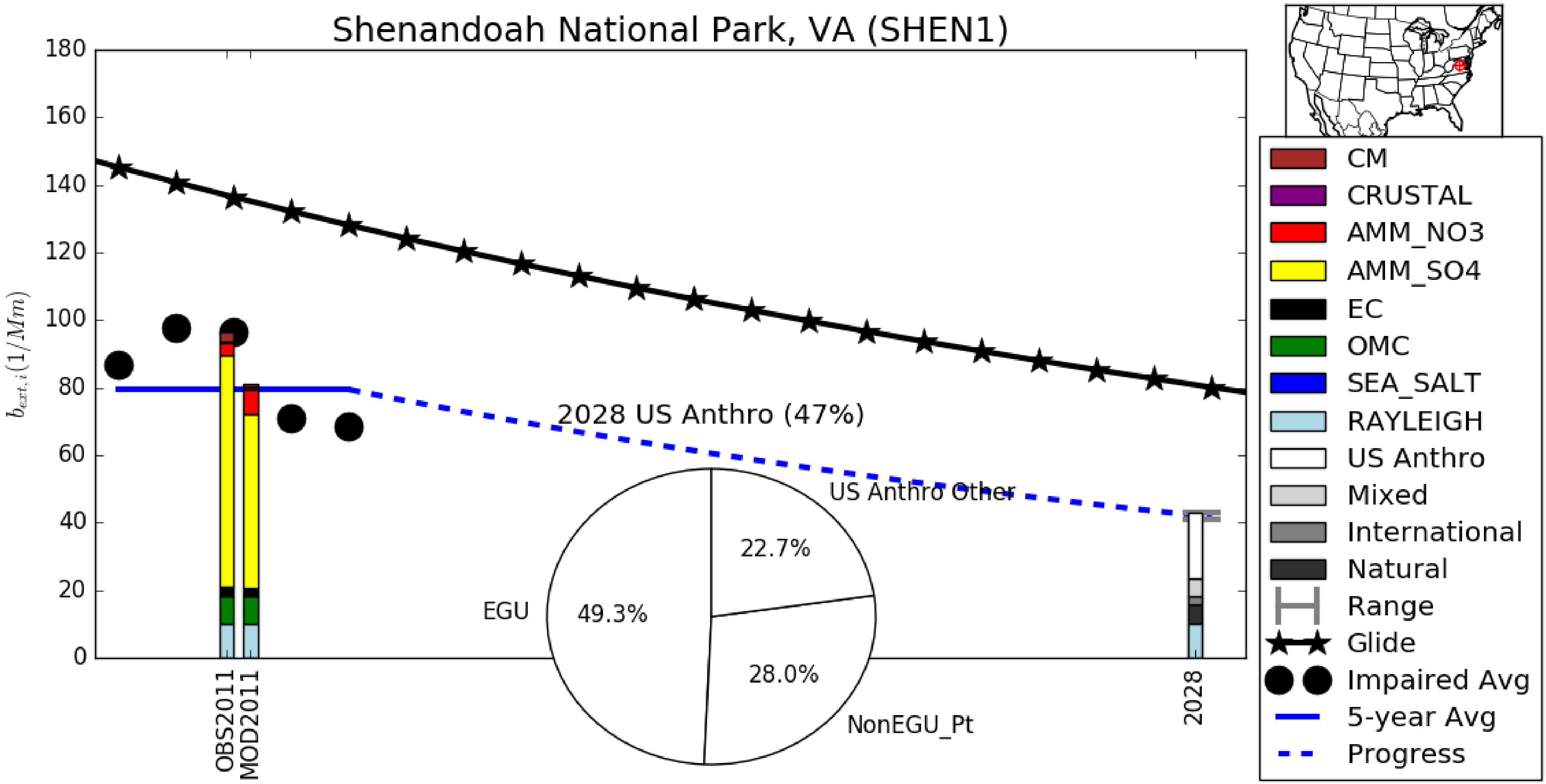


Figure B-90: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Shenandoah National Park (VA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

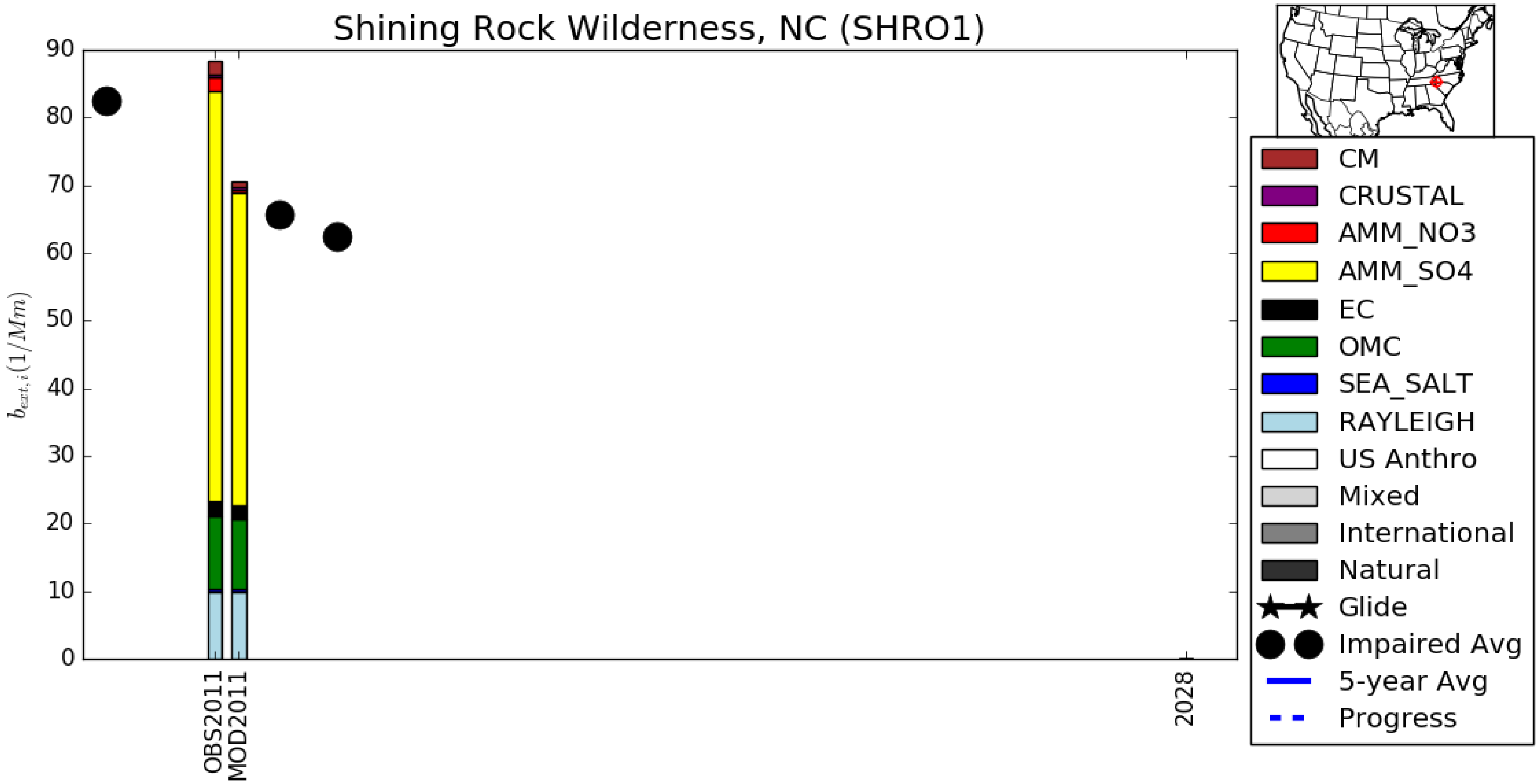


Figure B-91: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Shining Rock Wilderness (NC).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period. A 2028 visibility projection could not be calculated for this site due to incomplete ambient IMPROVE data in 2011.

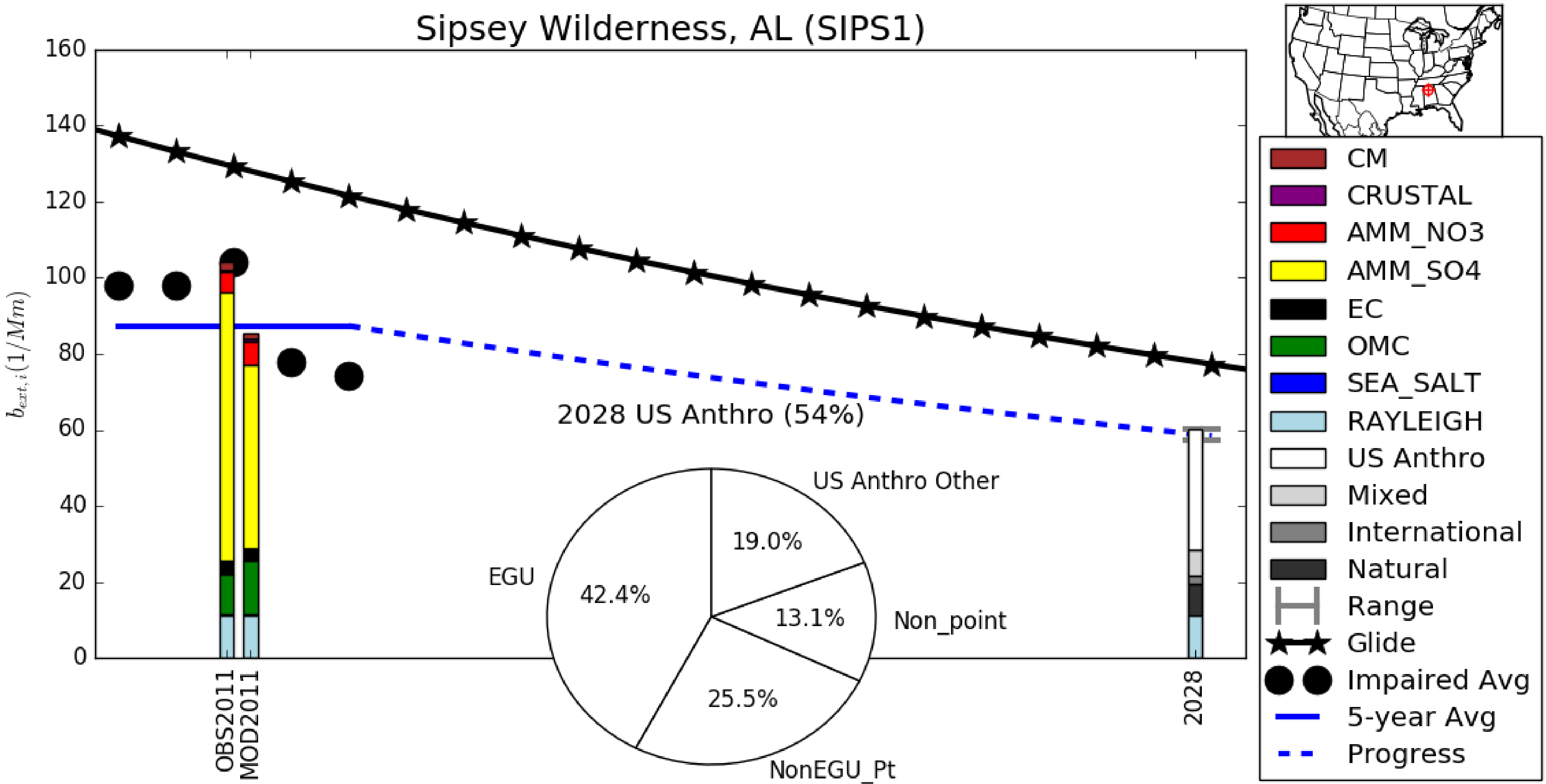


Figure B-92: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Sipsey Wilderness (AL).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Ohio River Valley

- Mammoth Cave National Park (KY)(MACA1)
- Mingo (MO)(MING1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Sulfate, nitrate
Model visibility performance summary (on 20% most impaired days)	Performance generally good, but sulfate underpredicted
Uncertainty in sector contributions	Low “mixed” sector contribution percentage (22%-25%).
2028 US anthropogenic percent contribution	53-61%
Largest US anthropogenic sector contributions	EGU, and nonEGU point

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high “mixed” (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

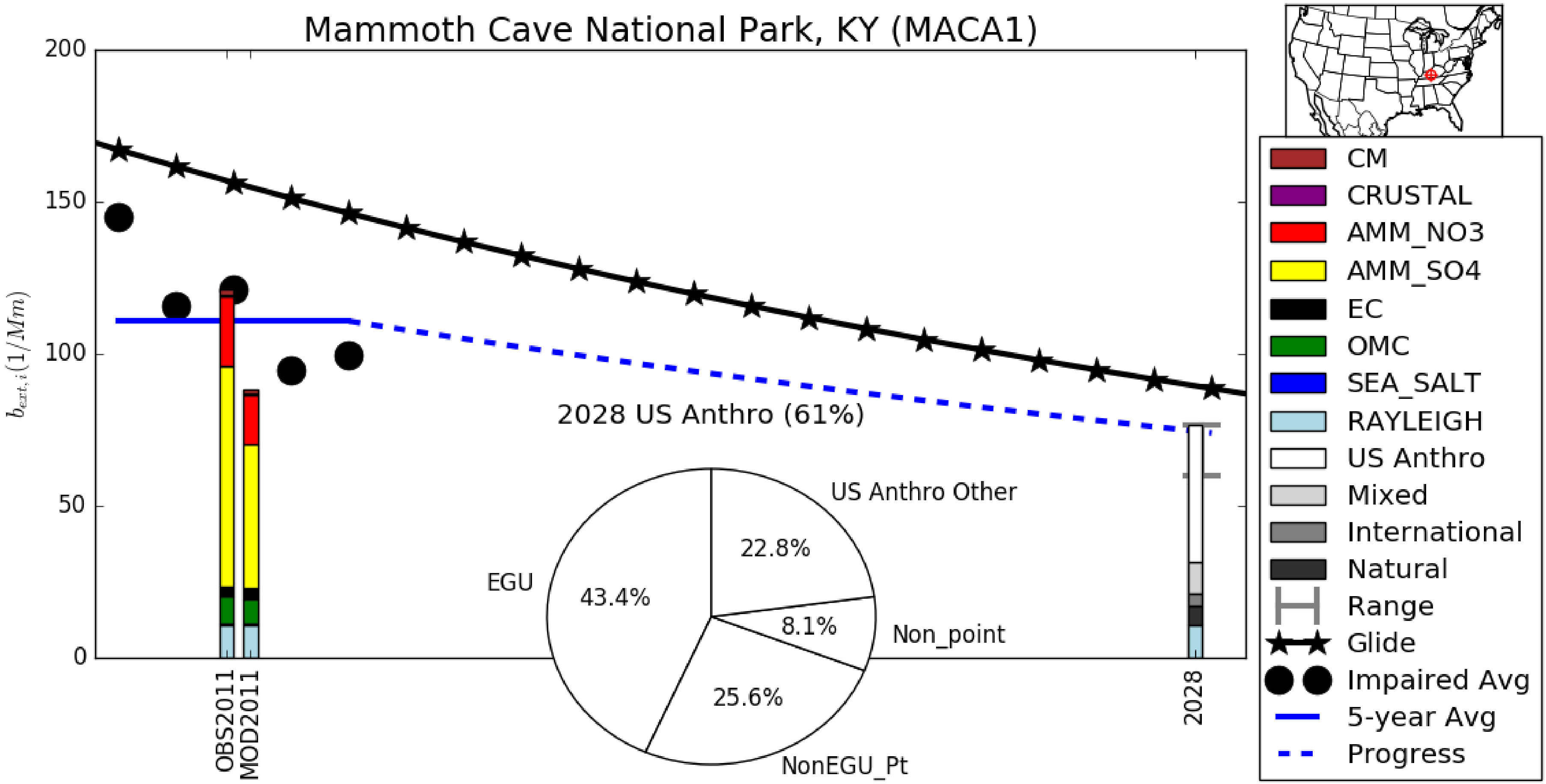


Figure B-93: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Mammoth Cave National Park (KY).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

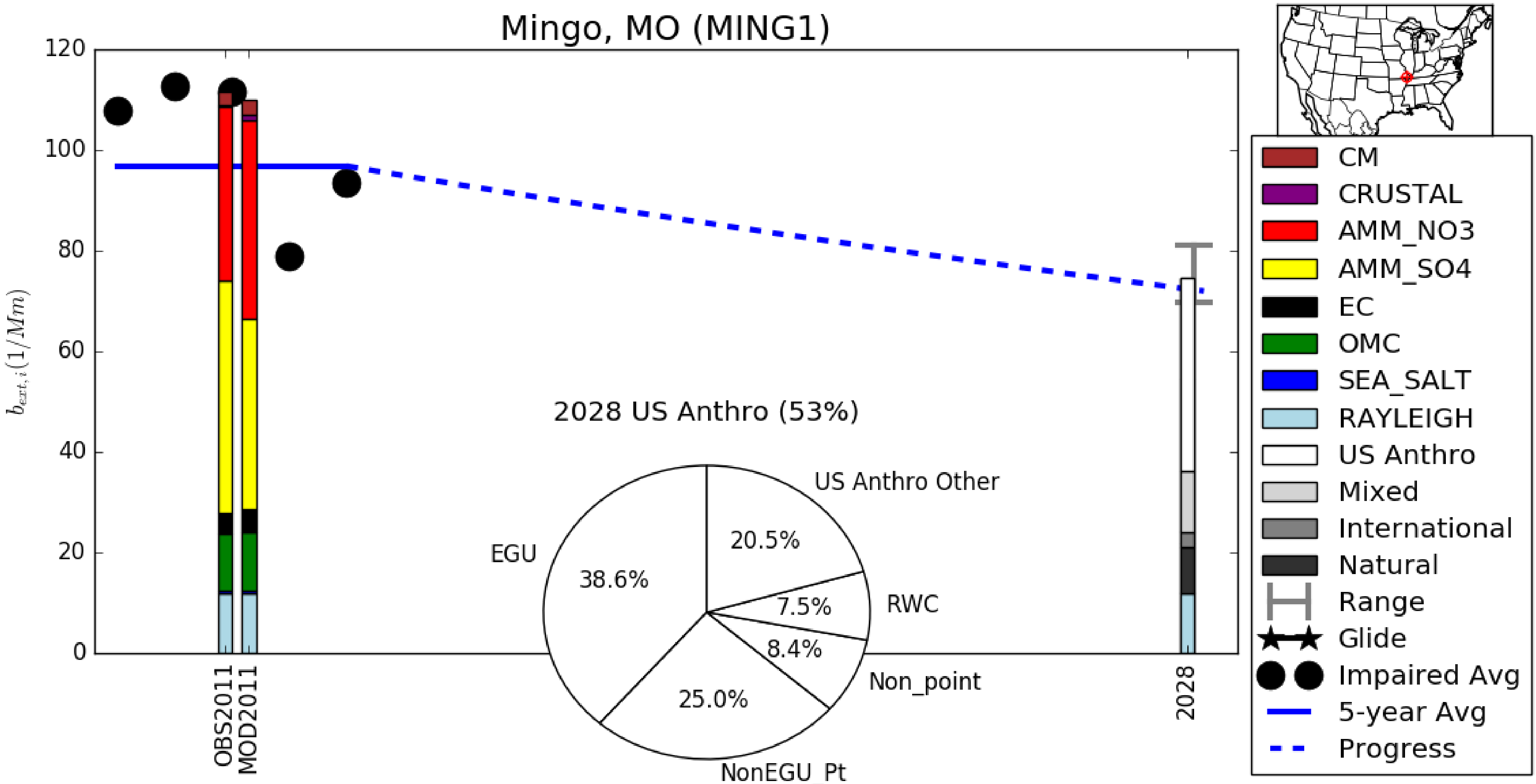


Figure B-94: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Mingo (MO).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

Southeast

- Breton (LA)(BRIS1)
- Chassahowitzka (FL)(CHAS1)
- Everglades National Park (FL)(EVER1)
- Okefenokee (GA) and Wolf Island (GA)(OKEF1)
- Cape Romain (SC)(ROMA1)
- St. Marks (FL)(SAMA1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Dominated by sulfate, smaller amount of organic carbon
Model visibility performance summary (on 20% most impaired days)	Performance generally good, but sulfate underpredicted
Uncertainty in sector contributions	Relatively low "mixed" sector contribution percentage (36%-46%) except *very high* at EVER1 (80%).
2028 US anthropogenic percent contribution	32-43% except 9% at EVER1
Largest US anthropogenic sector contributions	EGU, nonEGU point, nonpoint (at EVER1)

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

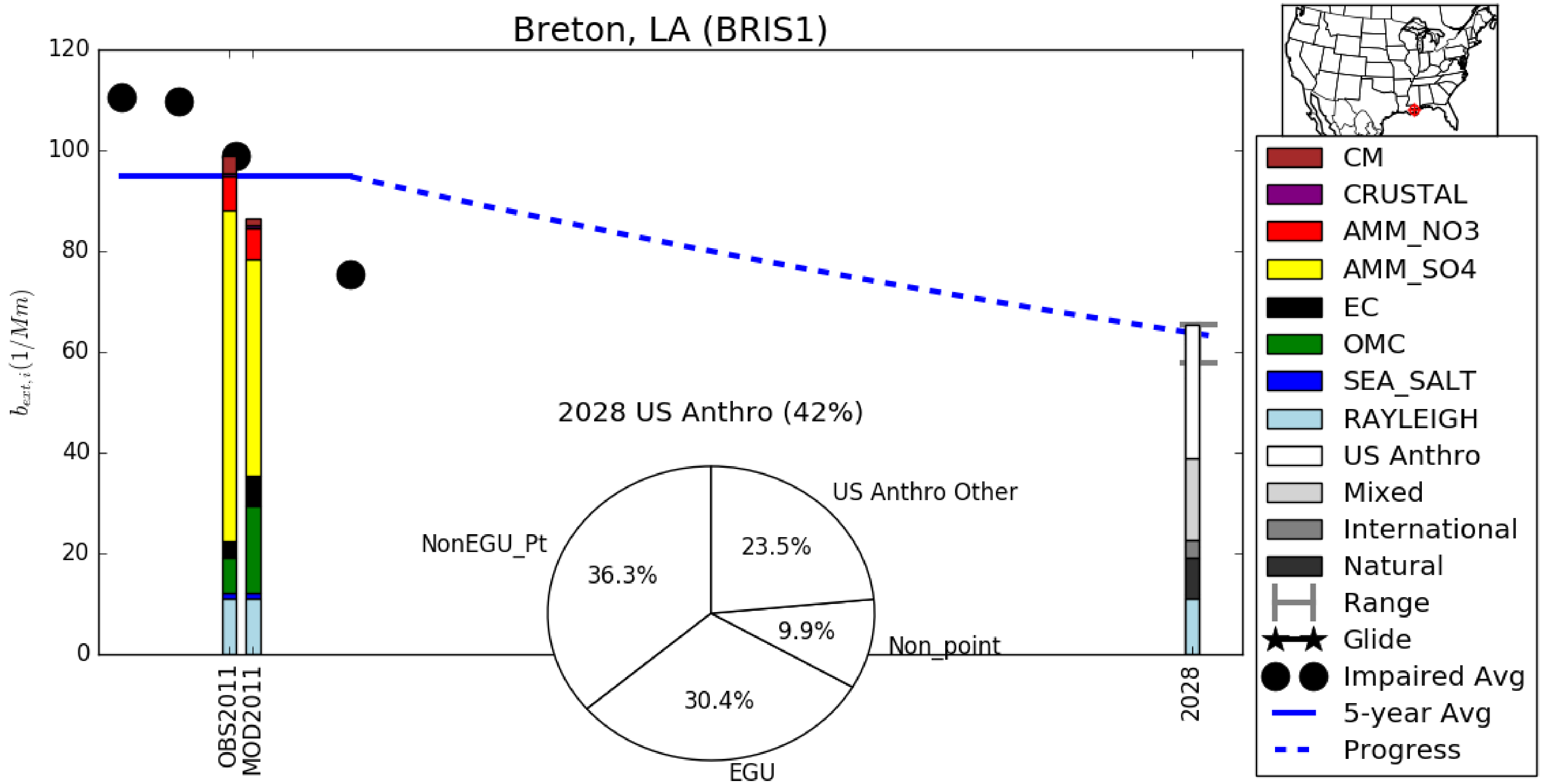


Figure B-95: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Breton (LA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

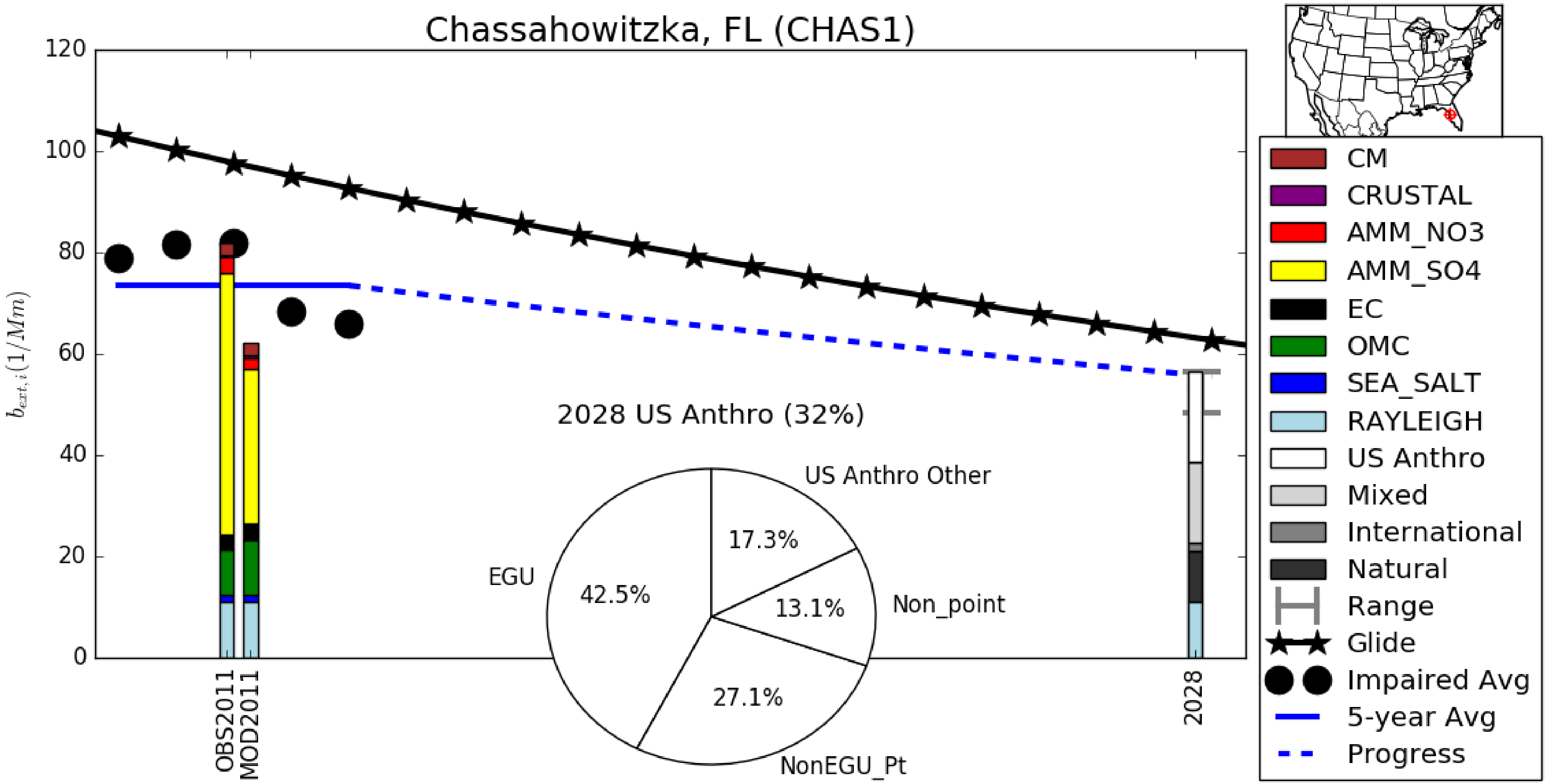


Figure B-96: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Chassahowitzka (FL).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

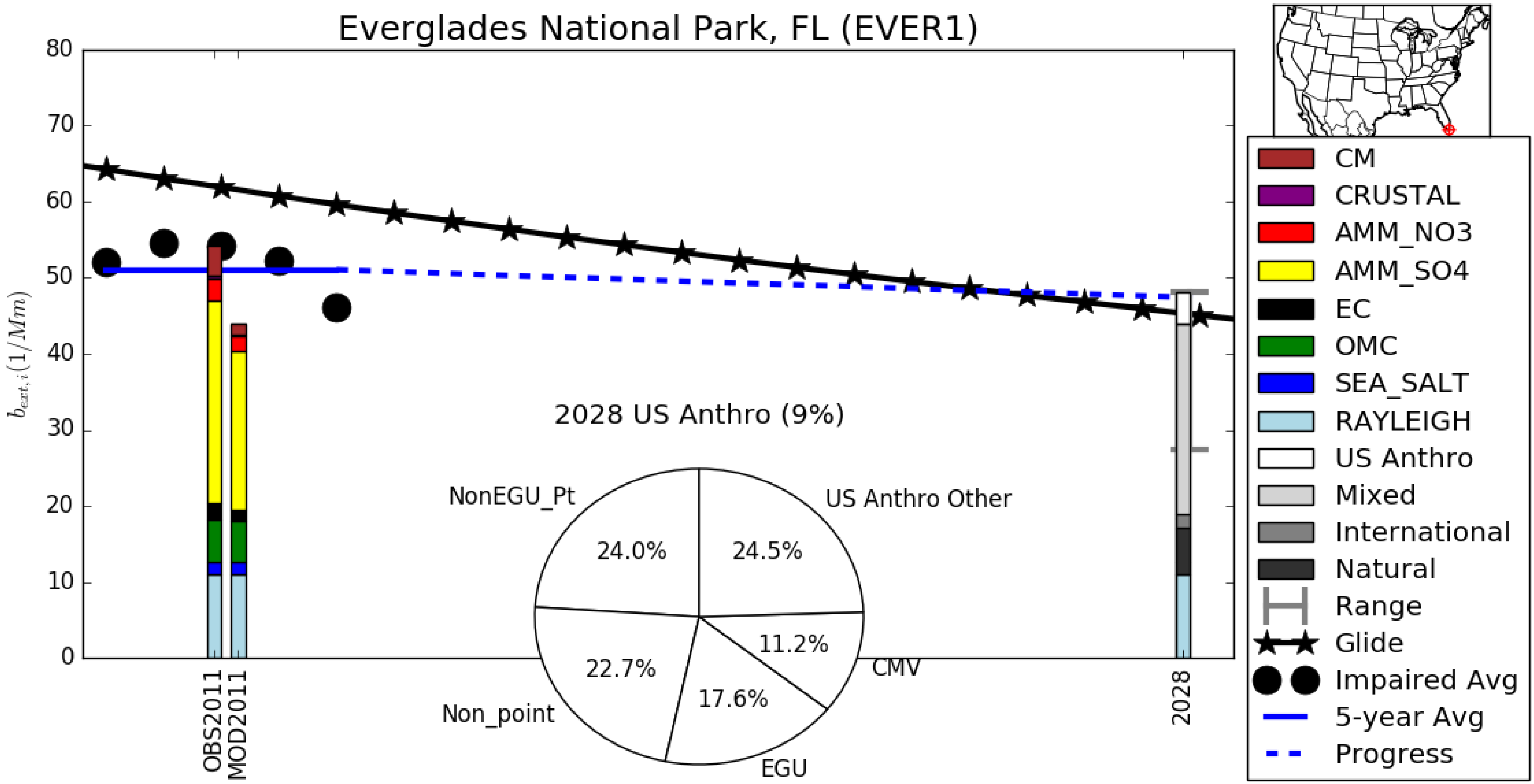


Figure B-97: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Everglades National Park (FL).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

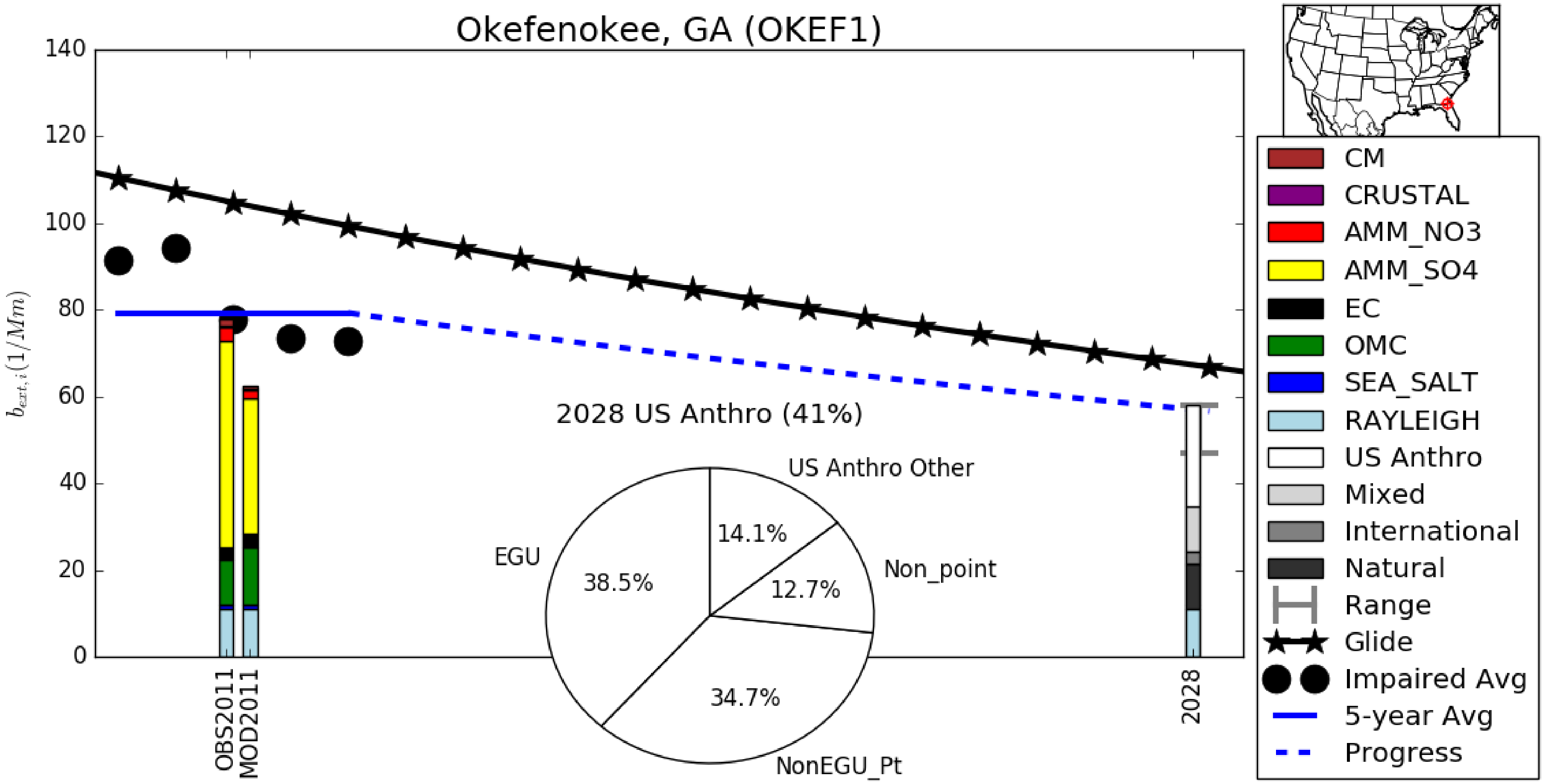


Figure B-98: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Okefenokee (GA) and Wolf Island (GA).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

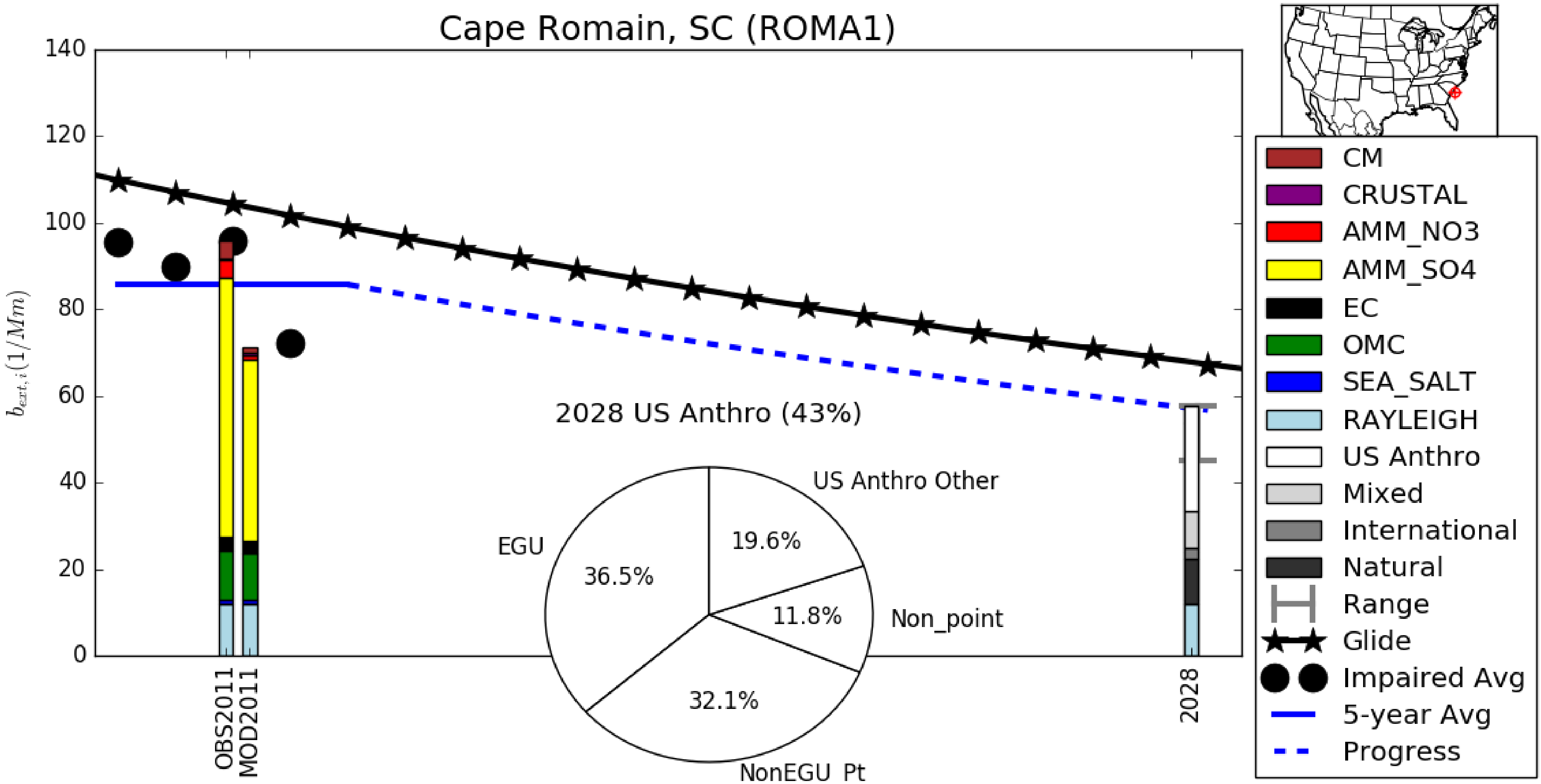


Figure B-99: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Cape Romain (SC).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

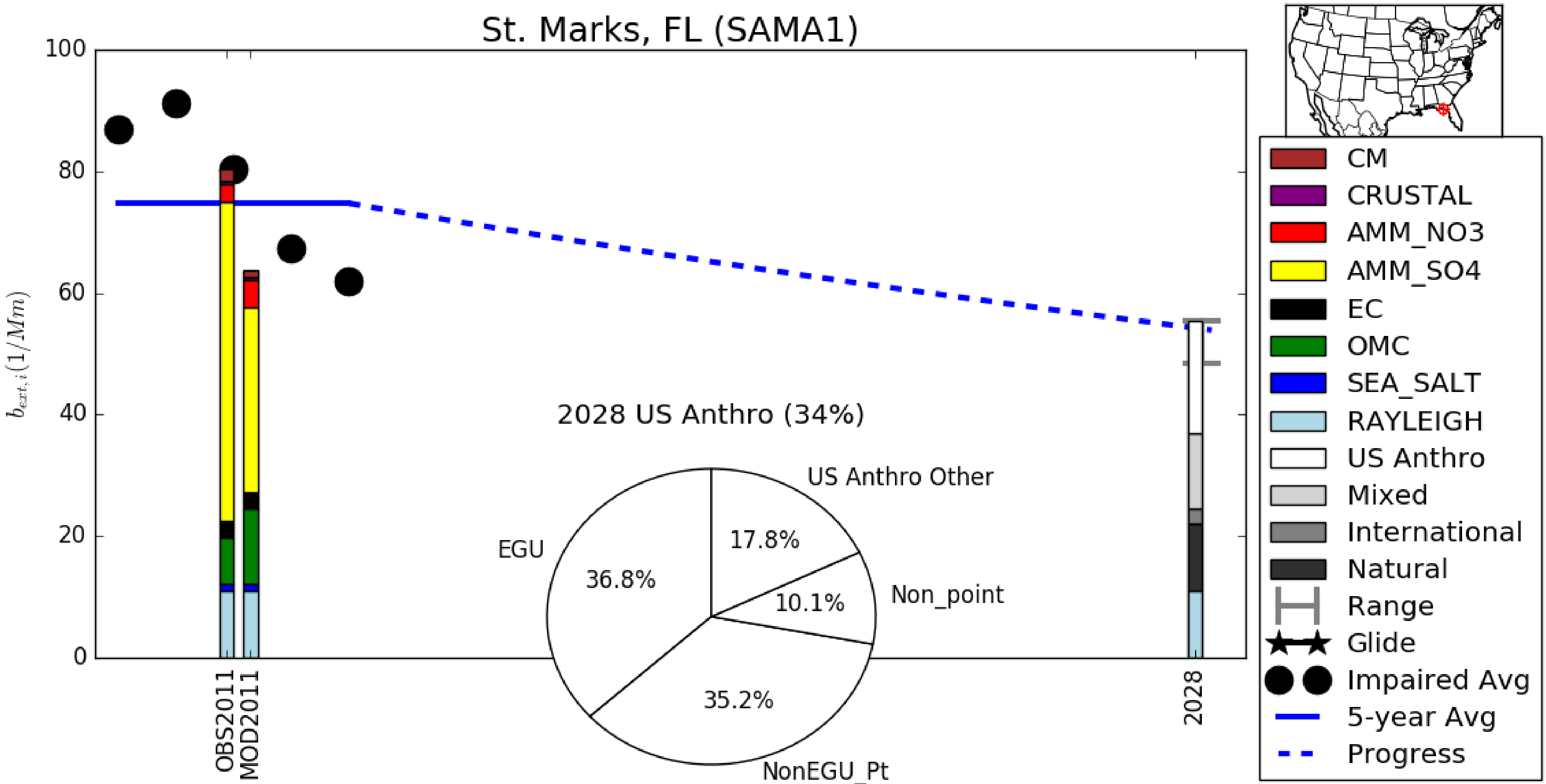


Figure B-100: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at St. Marks (FL).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

East Coast

- Brigantine (NJ)(BRIG1)
- Swanquarter (NC)(SWAN1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Dominated by sulfate, smaller amounts of organic carbon and nitrate
Model visibility performance summary (on 20% most impaired days)	Performance generally good, but sulfate underpredicted
Uncertainty in sector contributions	Relatively low "mixed" sector contribution percentage (29%-38%)
2028 US anthropogenic percent contribution	38-51%
Largest US anthropogenic sector contributions	EGU, nonEGU point, and nonpoint

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high "mixed" (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

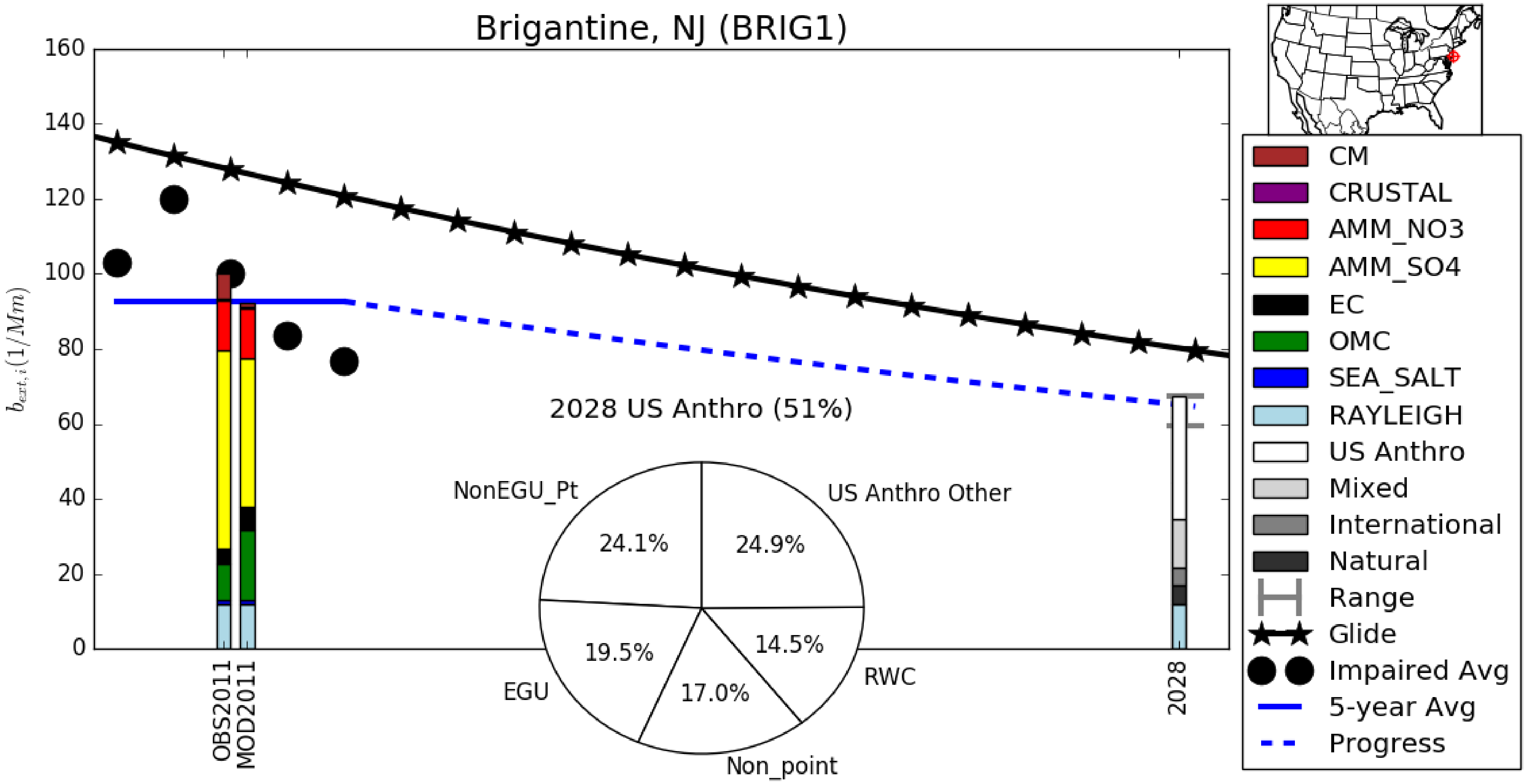


Figure B-101: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Brigantine (NJ).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

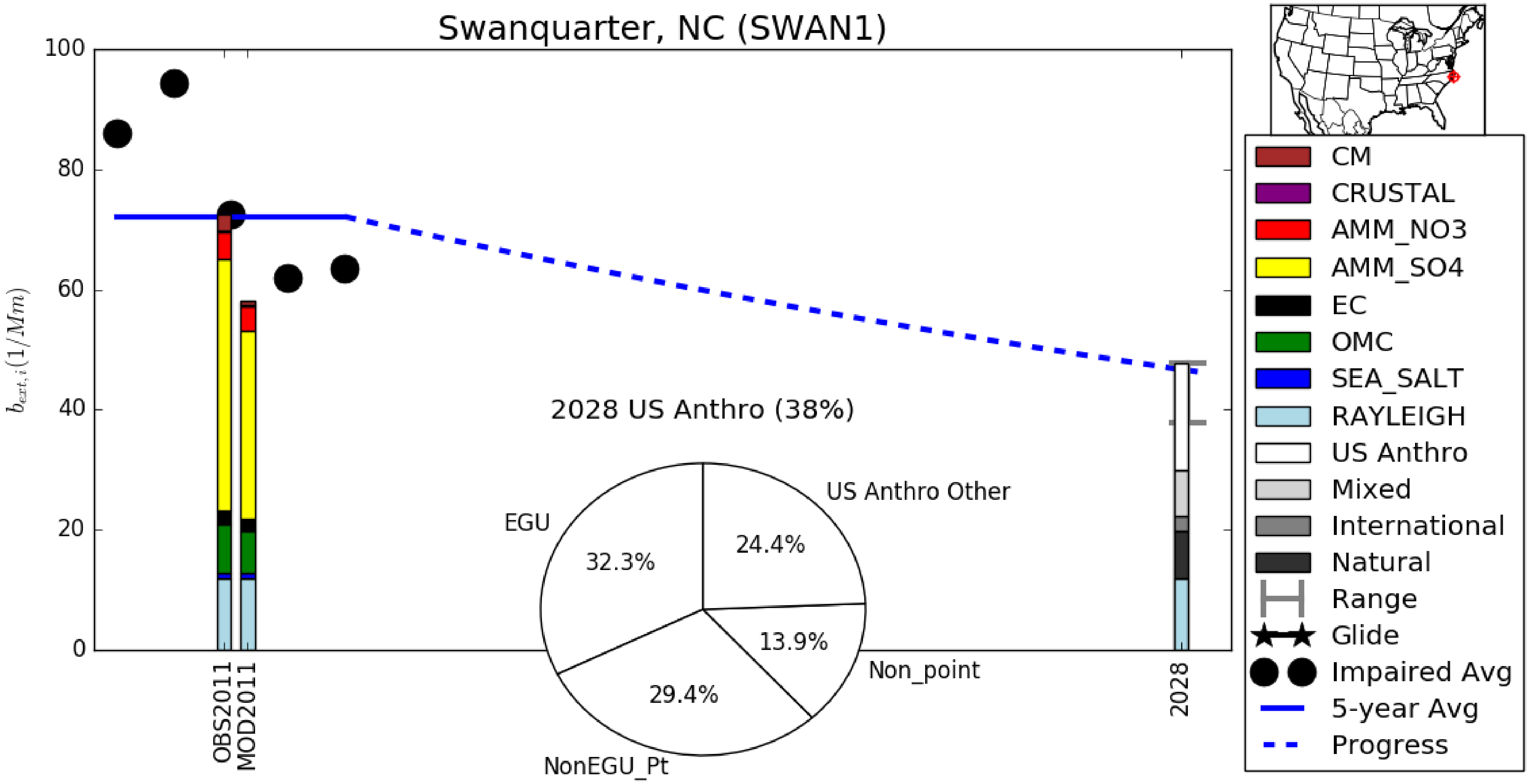


Figure B-102: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Swanquarter (NC).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

A glidepath could not be calculated for this site due to incomplete ambient IMPROVE data in the 2000-2004 baseline period.

Northeast

- Acadia National Park (ME)(ACAD1)
- Great Gulf Wilderness (NH) and Presidential Range-Dry River Wilderness (NH)(GRGU1)
- Lye Brook Wilderness (VT)(LYEB1)
- Moosehorn (ME) and Roosevelt Campobello International Park (ME)(MOOS1)

Regional visibility model performance and contribution summary on the 20% most impaired days

Most important ambient PM species contribution to visibility (on 20% most impaired days)	Dominated by sulfate, smaller amount of organic carbon
Model visibility performance summary (on 20% most impaired days)	Performance generally good, but sulfate underpredicted
Uncertainty in sector contributions	Relatively high “mixed” sector contribution percentage (57%-65%) at ACAD1 and MOOS1, relatively low (30-34%) at GRGU1 and LYEB1.
2028 US anthropogenic percent contribution	16-22% at ACAD1 and MOOS1, 30-40% at GRGU1 and LYEB1
Largest US anthropogenic sector contributions	NonEGU point, EGU, nonpoint, and RWC

Due to uncertainties in the modeling, the 2028 regional haze results should be used with caution. In particular, the modeling results (including the estimated 2028 US anthropogenic contributions) are most uncertain at sites with poor visibility model performance and/or high “mixed” (boundary conditions, fugitive dust, offshore, and secondary organics) contributions.

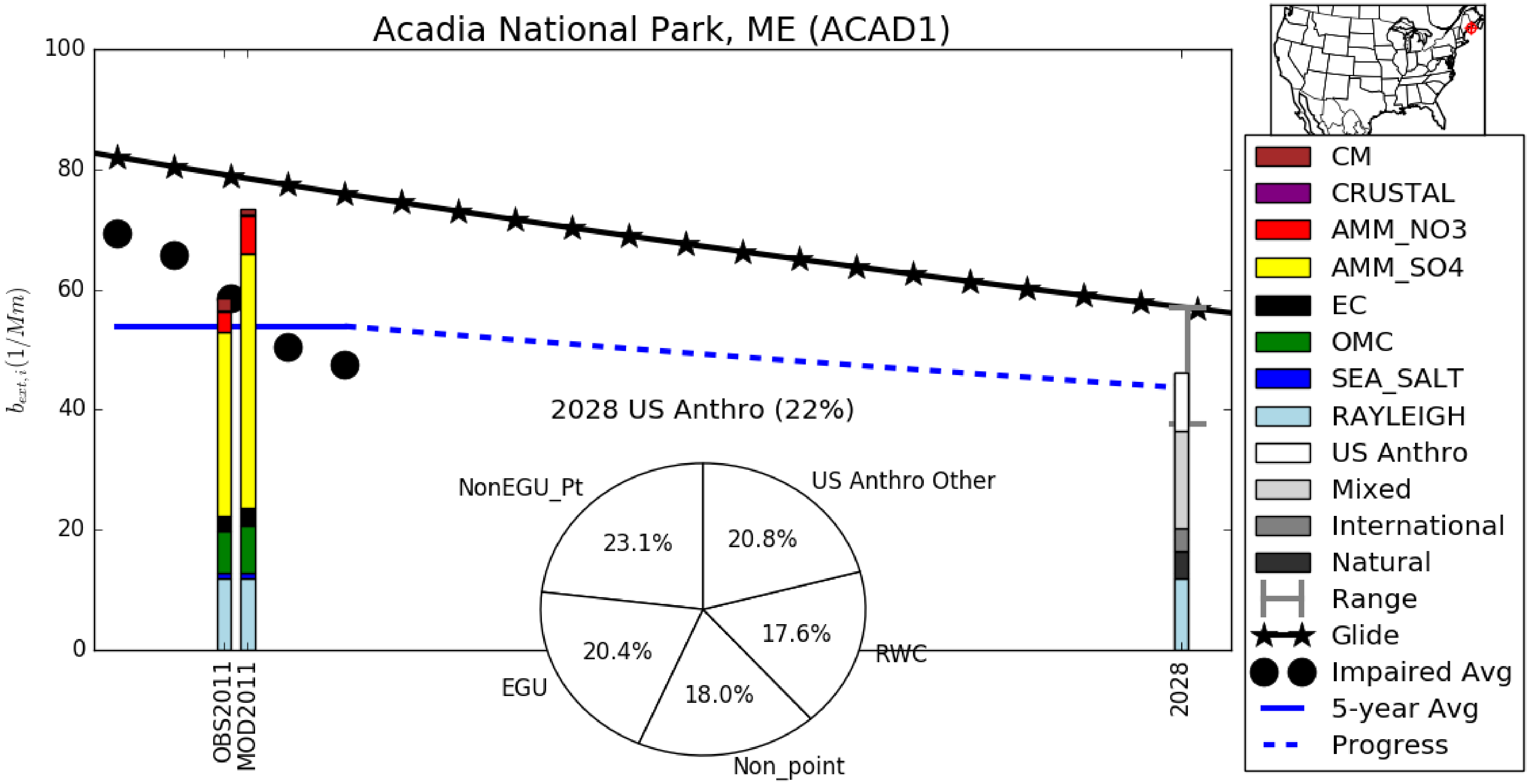


Figure B-103: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Acadia National Park (ME).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

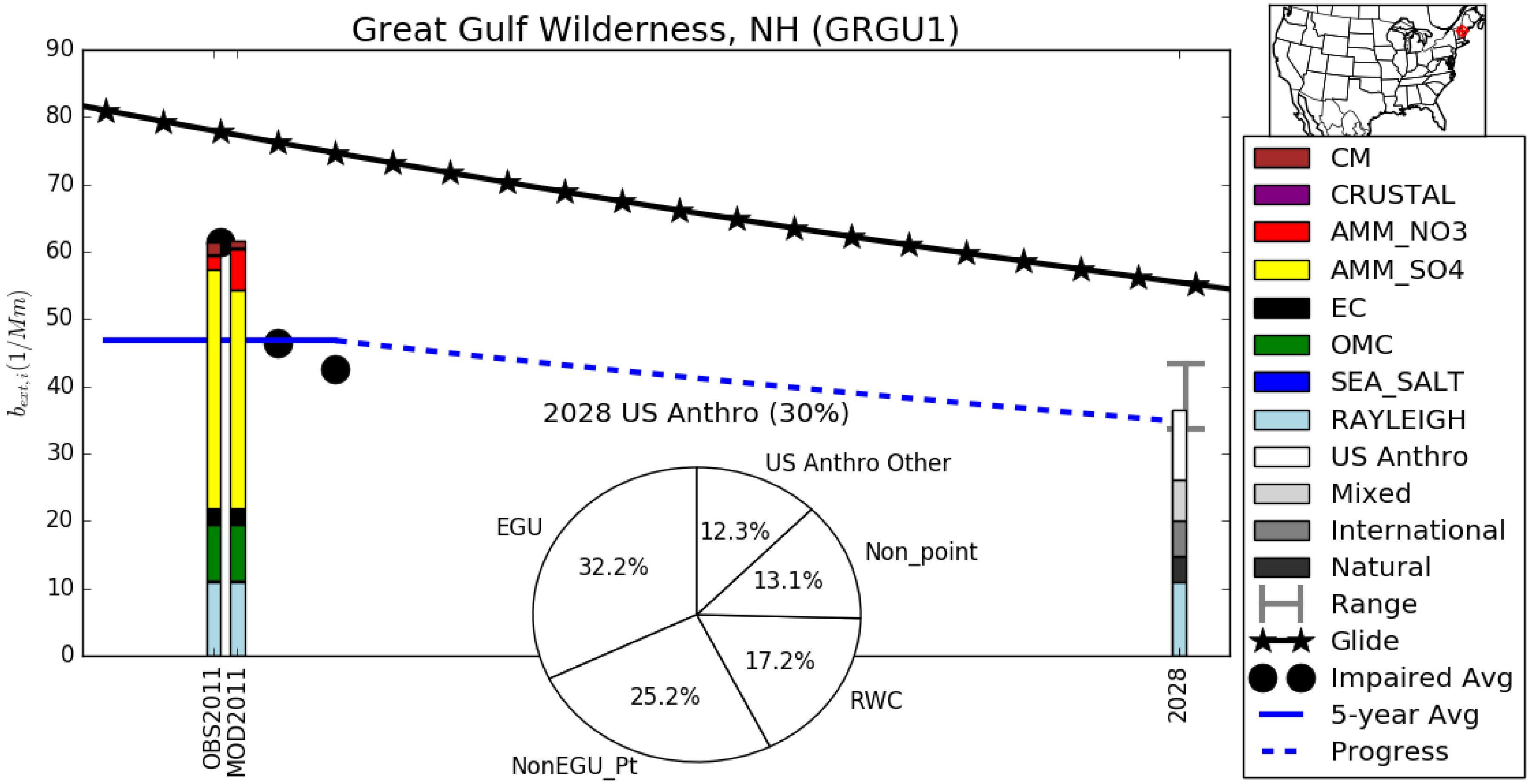


Figure B-104: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Great Gulf Wilderness (NH) and Presidential Range-Dry River Wilderness (NH).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

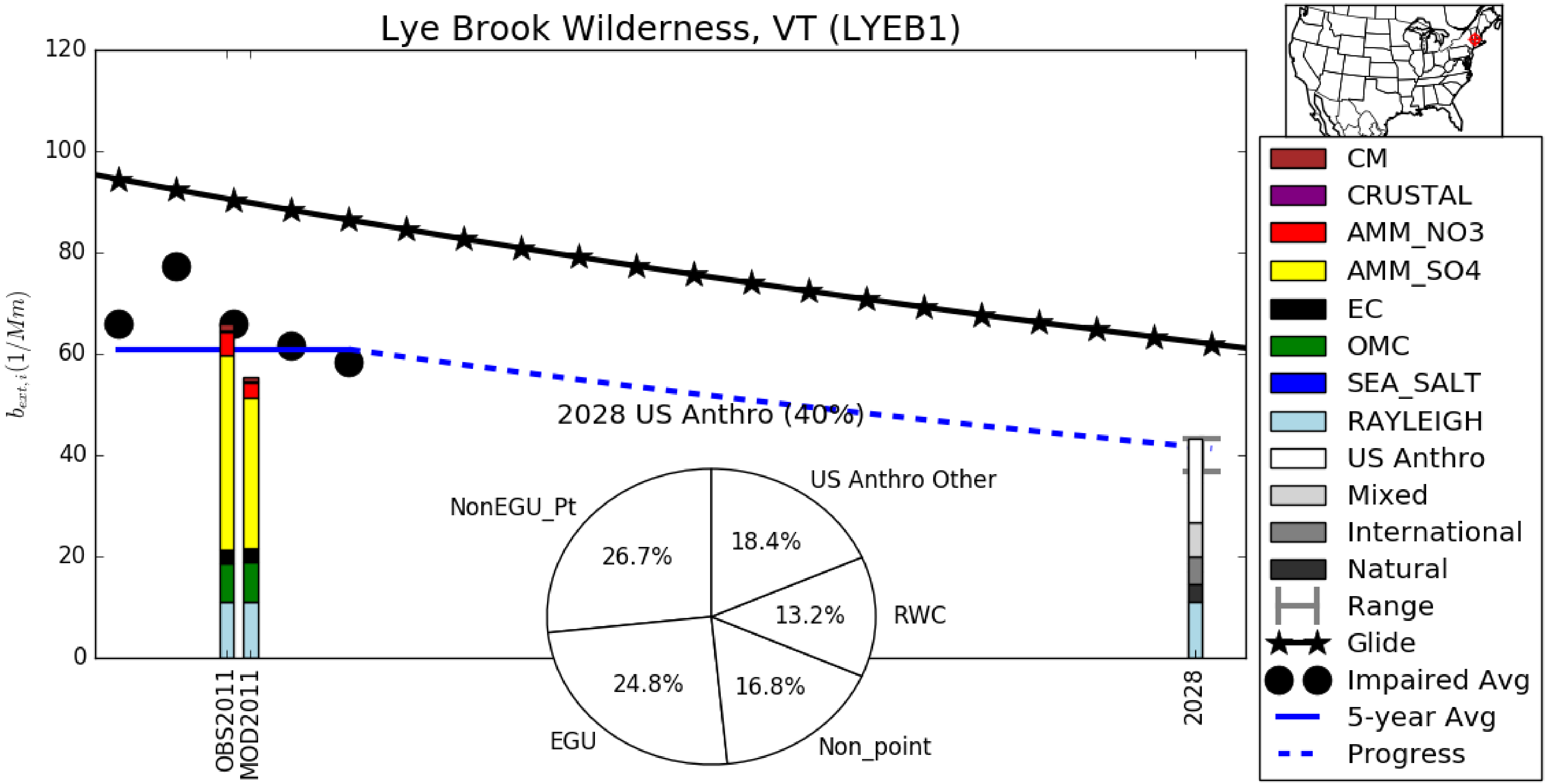


Figure B-105: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Lye Brook Wilderness (VT).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

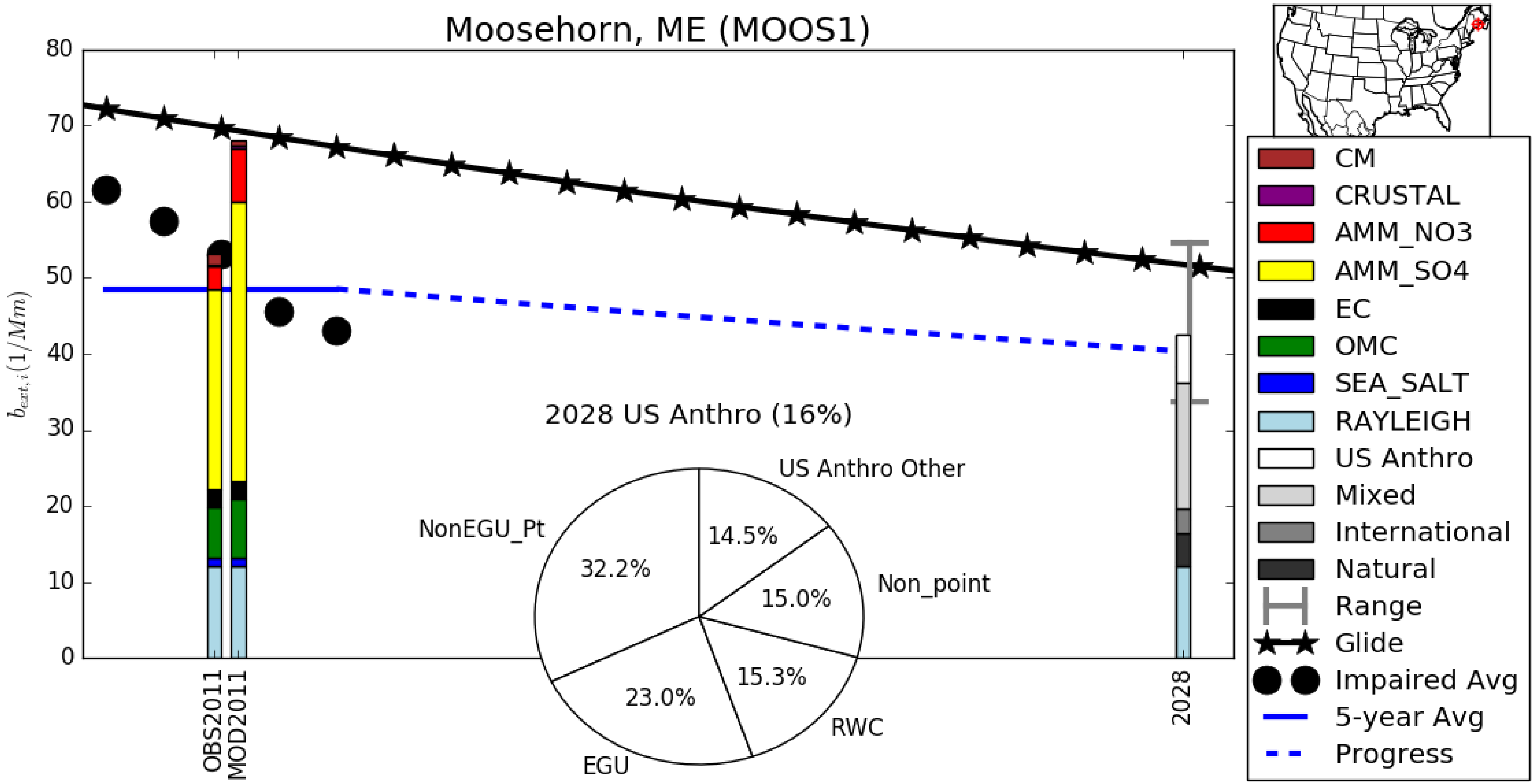


Figure B-106: 2011 IMPROVE observations, 2011 CAMx model predictions, 2028 modeled projection, and 2028 sector contributions at Moosehorn (ME) and Roosevelt Campobello International Park (ME).

This figure reflects EPA's initial 2028 regional haze modeling that contains a number of uncertainties such that the results should be used with caution.

Appendix C

“Range” calculation details

Boundary condition tagged extinction is particularly influential in visibility calculations at IMPROVE sites. IMPROVE sites are remote and have relatively few proximate large anthropogenic sources, so sources like wind-blown dust and boundary conditions can be important. Natural wind-blown dust is missing from the 2011/2028 CAMx modeling platform and modeled boundary conditions were held constant from 2011 to 2028. These, and other modeling artifacts, create uncertainty in the future projection and fractional tags in the future.

The RRF approach and fractional tagging employed here have the effect of extrapolating present day bias correction to future tags. Equation C1-C4 illustrate the steps in this analysis of projection using RRF (Eq C1), conversion to species-specific extinction (Eq C2), concentration proportional source attribution (Eq C3), and its net effect of bias correction in future extinction. Thus, the future tagged extinction effectively assumes that relative bias in the present (O_{Pi}/Y_{Pi}) reflects a proportional underestimation of all sources, and that the future bias is expected to be similar.

$$O_{Fi} = O_{Pi} RRF_i = O_{Pi} \frac{Y_{Fi}}{Y_{Pi}} \qquad \text{Eq C1}$$

$$b_{Fi} = a_i O_{Fi} \qquad \text{Eq C2}$$

$$b_{Fis} = b_{Fi} \left(1 - \frac{Y_{Fi} - Y_{Fis}}{Y_{Fi}}\right) = b_{Fi} \frac{Y_{Fis}}{Y_{Fi}} \qquad \text{Eq C3}$$

$$b_{Fis} = a_i O_{Pi} \frac{Y_{Fi}}{Y_{Pi}} \frac{Y_{Fis}}{Y_{Fi}} = a_i Y_{Fis} \frac{O_{Pi}}{Y_{Pi}} \qquad \text{Eq C4}$$

Where:

- *O* is observed concentration, *Y* is predicted concentration, *b* is extinction
- Subscripts *F* is future, *P* is present, *i* is species, and *s* is source tag, *O, Y* are observations and model predictions
- a_i is the species-specific IMPROVE factor for the future

The proportional bias correction has implications that are specific to artifacts in our modeling. For example, at sites heavily impacted by wind-blown dust, the proportional bias correction could be growing all sources to correct for the missing source. This is because the observed dust is likely from a combination of natural and anthropogenic sources, but the only modeled source of dust is anthropogenic (i.e., the model does not include wind-blown dust). Therefore, the projection methodology “grows” (see Eq. C4) the impacts of anthropogenic dust. Additionally, at all sites, boundary conditions were held constant and so biases in the present are being directly projected to the future. We use two alternative projections to bound the projected future extinction values, assuming that: (1) the present day simulated boundary conditions should not be grown to account for bias or (2) that bias corrected boundary conditions will reduce by 50 percent between 2011 and 2028.

(1) In this scenario, the boundary conditions are set to their future simulated value (Y_{Fis}) (and are not bias corrected). The remaining fraction of extinction ($1-O_{Pi}/Y_{Pi}$) is removed from the future projection. This approximates a case where bias correction of boundary conditions was substituting for a missing controllable source.
(2) In this scenario, the boundary conditions are bias corrected (Eq C4) and then reduced by 50%. Holding the boundary conditions constant between 2011 and 2028 assumes emission sources that influence the boundaries are either constant or their change is not expected to be important. All sources are expected to change (in some way) in the future, but particularly international and off-shore. Trans-continental pollution may be decreasing due to a combination of emission controls (van der A et al. 2017) and transport patterns (Lin et al. 2014). Off-shore marine emissions are expected to decrease due to implementation of the North American Emission Control Area (NA ECA) that has been shown to correlate with observed sulfate decreases at IMPROVE monitors (Kotchenruther et al. 2017). To account for unknown decreases in extra-domain emissions, we use a simple assumption that 50% of the RRF adjusted boundary condition will be removed in the future.

Considering these two alternative cases provides three possible projected extinction values. The range represents all three possible values. There are alternative possible projections and these should be considered.

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Appendix D

Emissions Summary by Sector 2011 and 2028

		2011el Base Case (tons per year)					2028el Future Case (tons per year)				
tag #	tag name	NH3	NOX	PM2.5	SO2	VOC	NH3	NOX	PM2.5	SO2	VOC
1	Biogenics		1,690,559			68,816,532	0	1,690,559	0	0	68,816,532
2	Area source fugitive dust			923,590					1,041,531		
3	Agriculture ammonia*	3,520,078					3,610,183				
4	Commercial Marine-onshore*	232	414,099	18,124	91,209	12,584	237	234,994	6,392	7,649	13,249
5	Non-point *	94,225	719,546	403,887	275,915	3,671,736	94,578	733,131	427,652	95,817	3,452,106
6	Onroad mobile*	120,859	5,708,150	188,925	28,195	2,713,181	82,339	1,294,105	64,138	11,637	733,952
7	Nonroad mobile*	2,615	1,620,441	154,052	4,011	2,049,504	3,426	743,790	66,807	2,487	1,140,497
8	Nonpoint and Point oil and gas*	5,947	1,176,902	30,268	83,814	2,648,051	5,951	1,221,453	45,550	131,672	2,320,496
9	EGUs*	25,066	2,095,119	208,134	4,670,569	38,063	44,033	827,546	127,329	1,116,509	30,866
10	Wildfires	167,331	165,799	850,662	82,691	2,374,690	167,331	165,799	850,662	82,691	2,374,690
11	Fires in Mexico and Canada	161,999	167,599	848,892	83,082	2,313,404	161,999	167,599	848,892	83,082	2,313,404
12	Prescribed fires*	28,280	44,537	167,516	13,608	395,801	28,280	44,537	167,516	13,608	395,801
13	Agricultural fires*	3,315	46,021	101,345	17,752	80,514	3,315	46,021	101,345	17,752	80,514
14	Point non-EGU sources*	65,990	1,213,359	320,737	1,049,287	800,826	66,205	1,211,347	327,466	799,340	805,074
15	Rail*	347	791,380	23,963	7,936	40,851	379	459,501	9,864	367	17,067
16	Residential Wood Combustion*	19,745	34,508	381,914	8,964	443,014	18,089	34,814	352,453	7,526	403,145
17	Canada and Mexico	532,125	1,851,236	370,048	1,102,930	1,805,184	529,151	1,599,819	387,451	980,958	1,790,593
18	Offshore	189	1,096,992	39,667	259,586	88,628	189	950,907	15,892	60,756	114,454
	* US anthropogenic		2011 to 2028 US Anthropogenic Emissions Change				+1.7%	-50.1%	-11.3%	-64.0%	-23.6%

Appendix E
Example Sector Tag Spatial Maps

The following plots show examples of the “raw” modeled CAMx PSAT sector tag outputs. Two example maps are presented for each sector tag. The plots represent modeled monthly average PM species concentrations for a single month and a single PM species. The month and species were chosen to represent the time of the year (either January or July) and species (sulfate, nitrate, organic carbon, or coarse mass) when each respective sector has a relatively large contribution to PM. There may be other months of the year and/or species which have larger (or at least sizable) contributions.

Tag 1- Biogenics

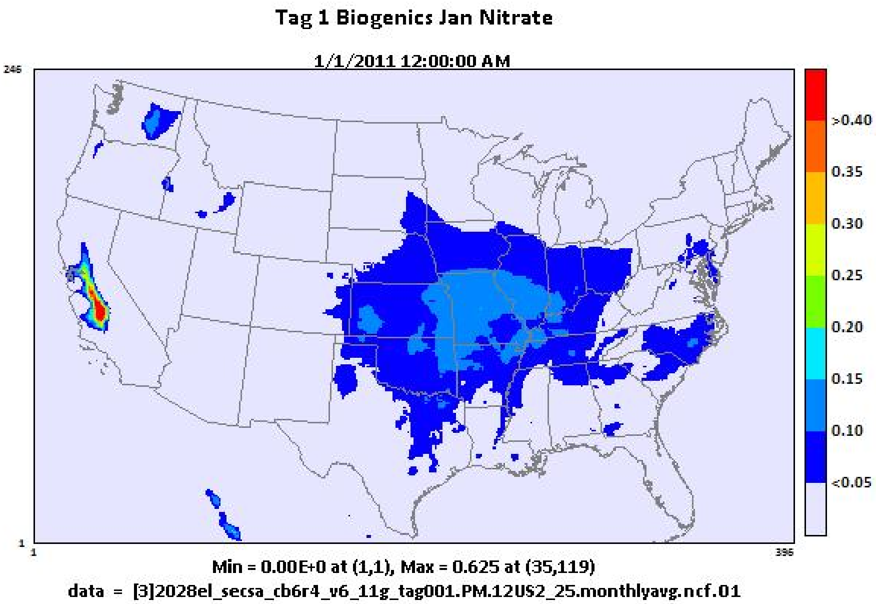

Figure E-1 January 2028 monthly average nitrate contribution (in ug/m3) from biogenics.

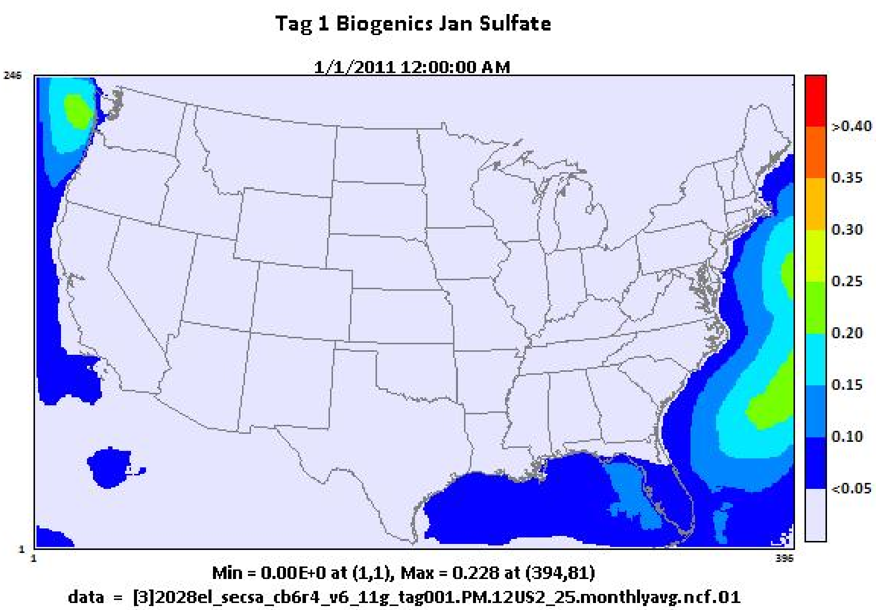

Figure E-2 January 2028 monthly average sulfate contribution (in ug/m3) from biogenics.

Tag 2- Fugitive Dust

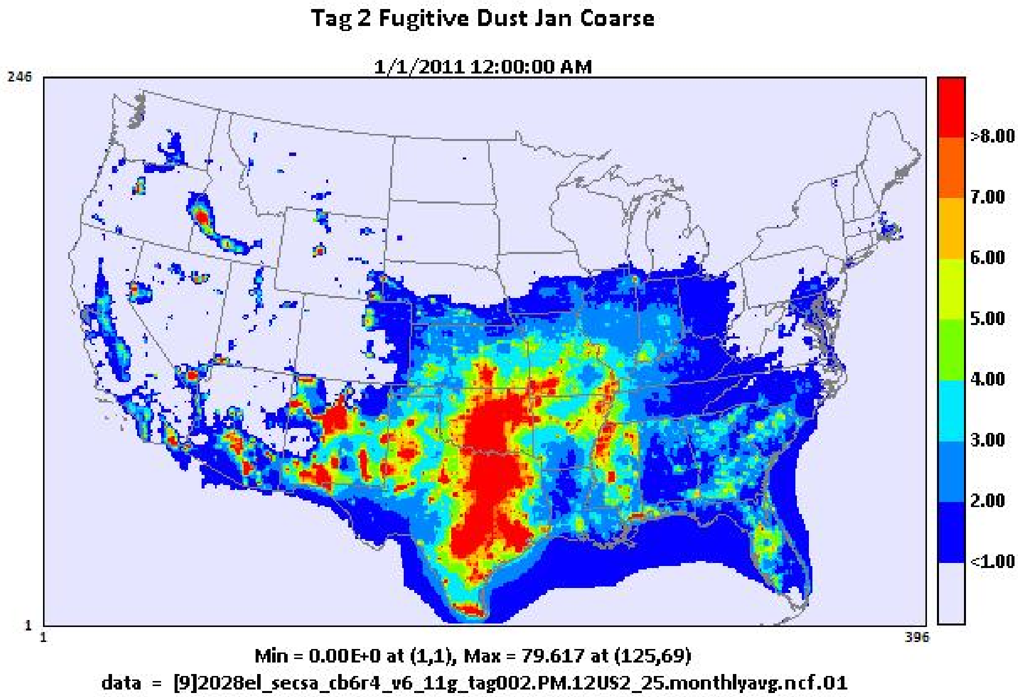

Figure E-3 January 2028 monthly average coarse mass contribution (in ug/m3) from fugtive dust.

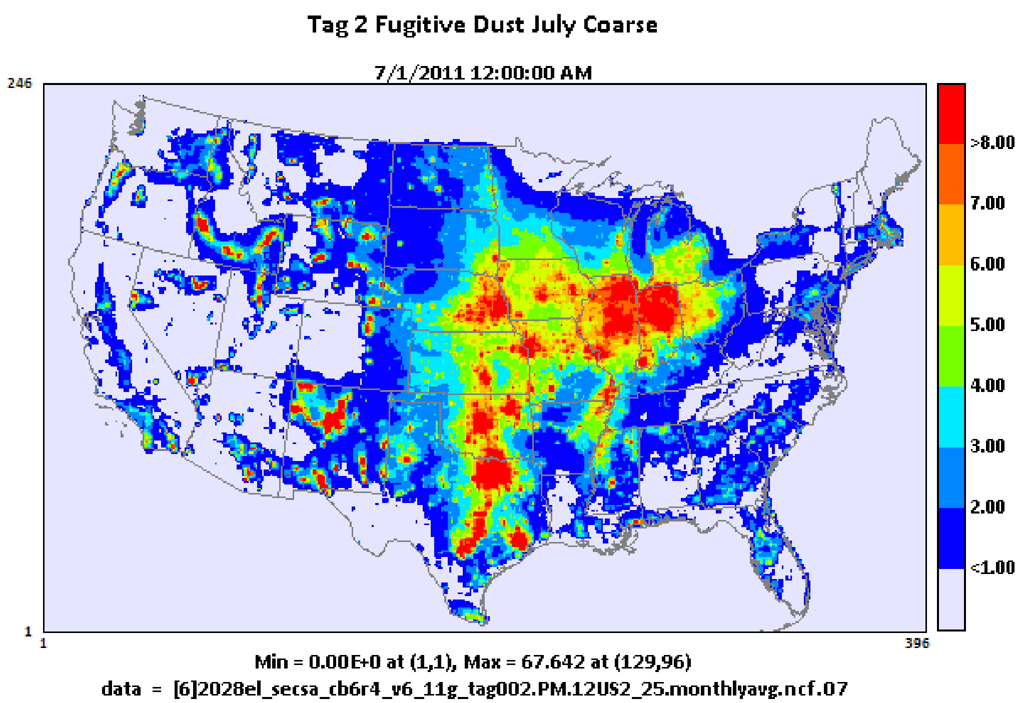

Figure E-4 July 2028 monthly average coarse mass contribution (in ug/m3) from fugitive dust.

Tag 3- Agricultural ammonia

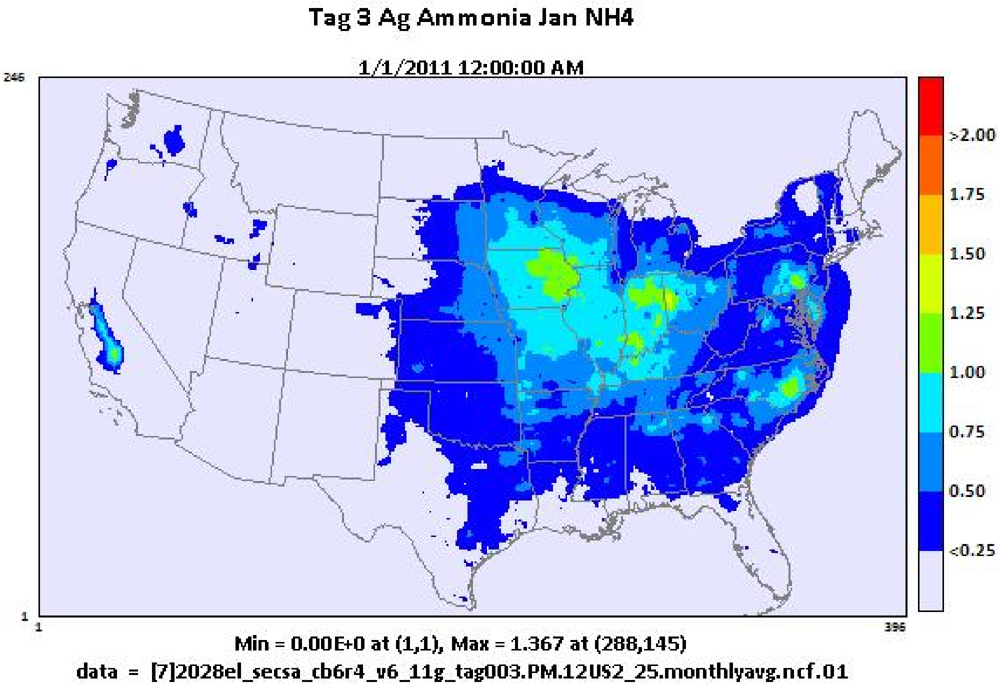

Figure E-5 January 2028 monthly average ammonium contribution (in ug/m3) from ag ammonia.

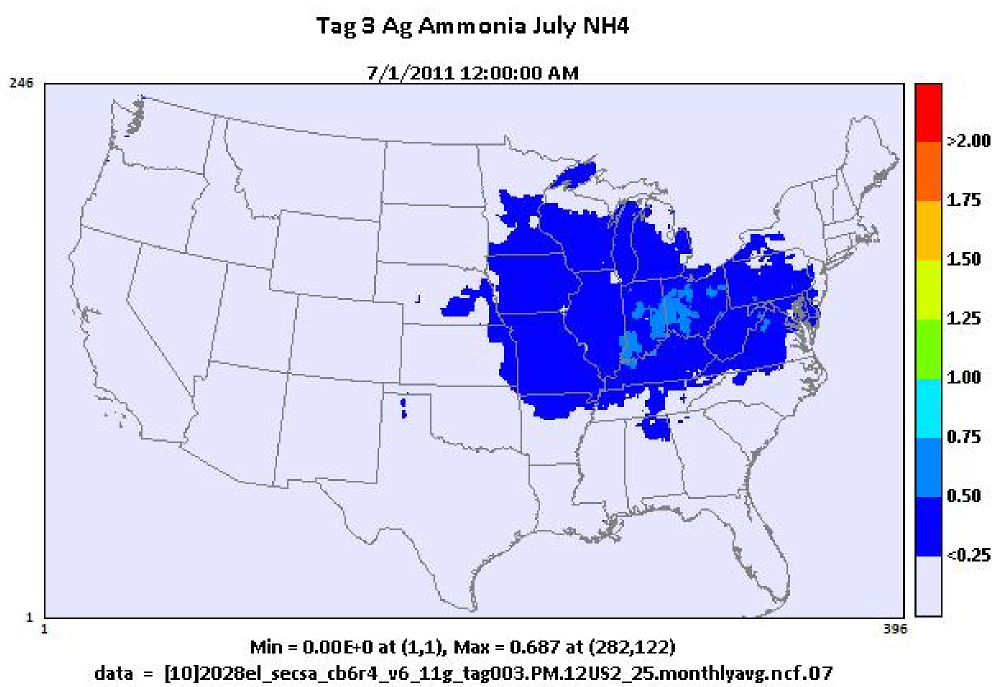

Figure E-6 July 2028 monthly average ammonium contribution (in ug/m3) from ag ammonia.

Tag 4- Commercial marine vessels (CMV)- onshore

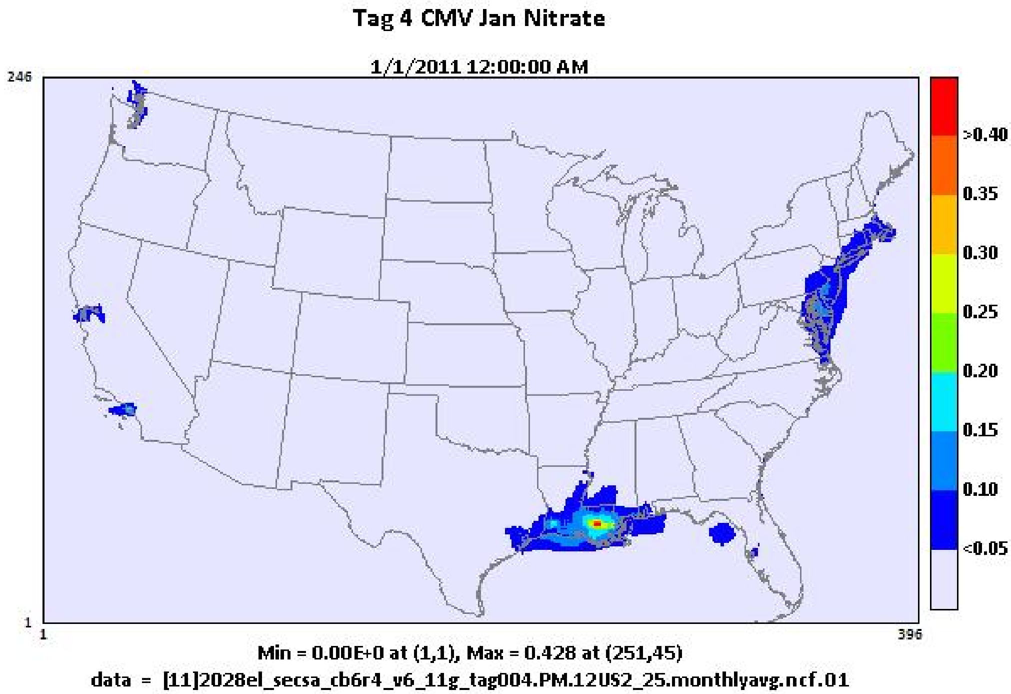

Figure E-7 Januay 2028 monthly average nitrate contribution (in ug/m3) from CMV.

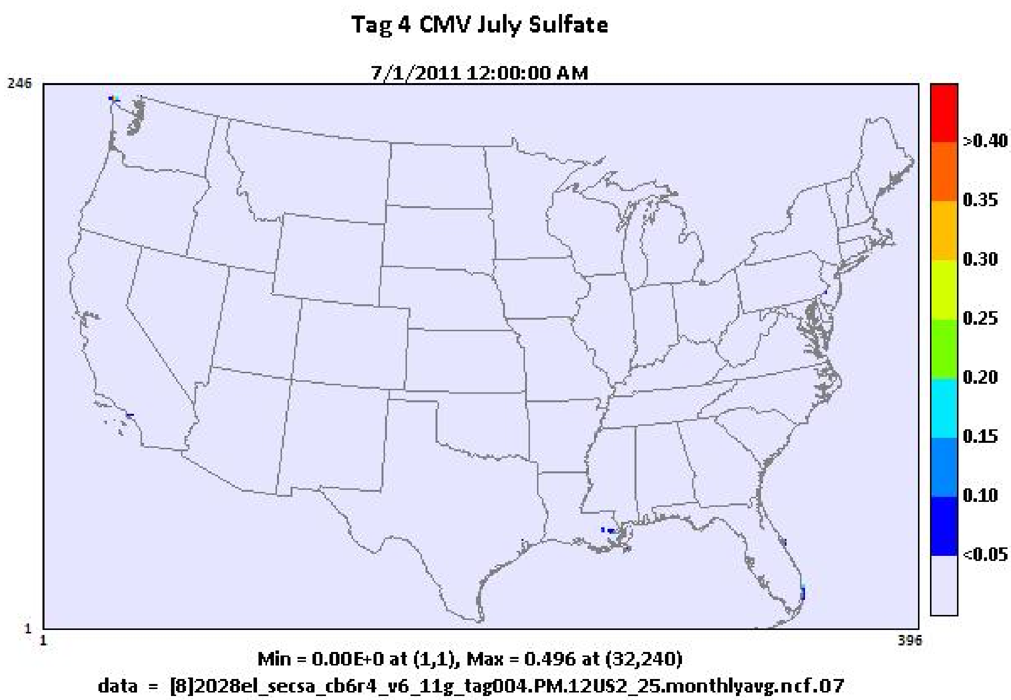

Figure E-8 July 2028 monthly average sulfate contribution (in ug/m3) from CMV.

Tag 5- Non-point

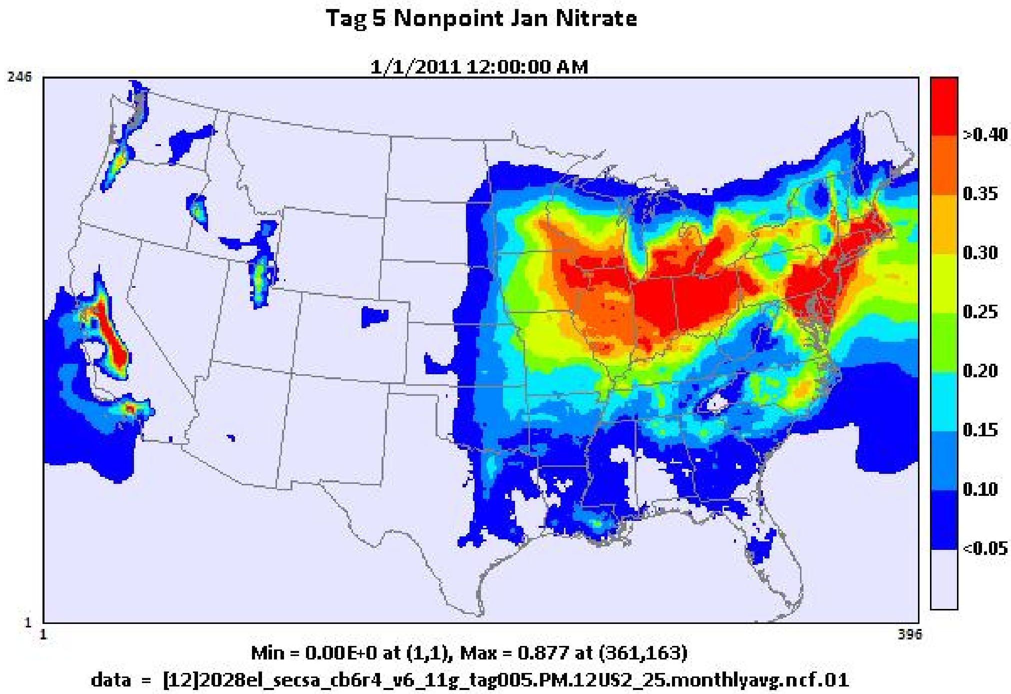

Figure E-9 January 2028 monthly average nitrate contribution (in ug/m3) from non-point.

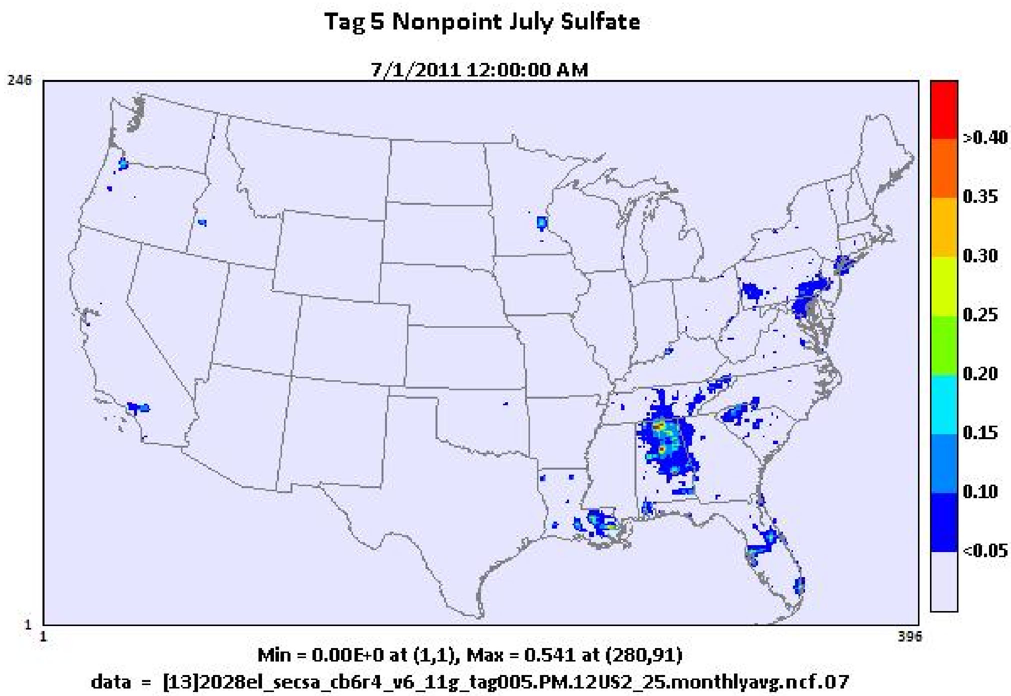

Figure E-10 July 2028 monthly average sulfate contribution (in ug/m3) from non-point.

Tag 6- On-road mobile

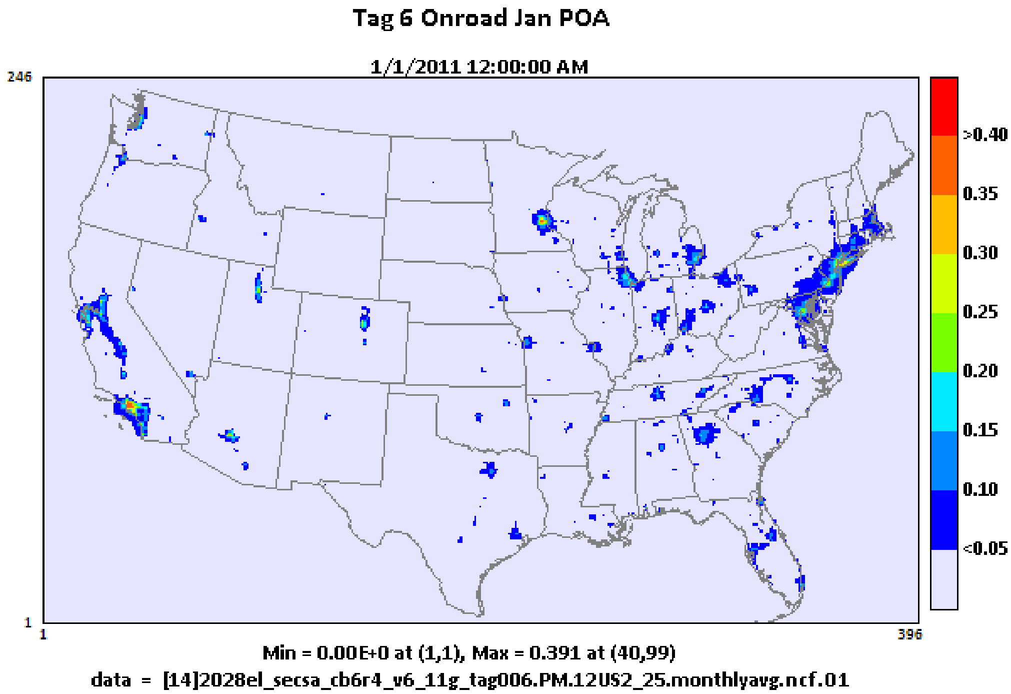

Figure E-11 January 2028 monthly average primary organic carbon contribution (in ug/m3) from on-road mobile.

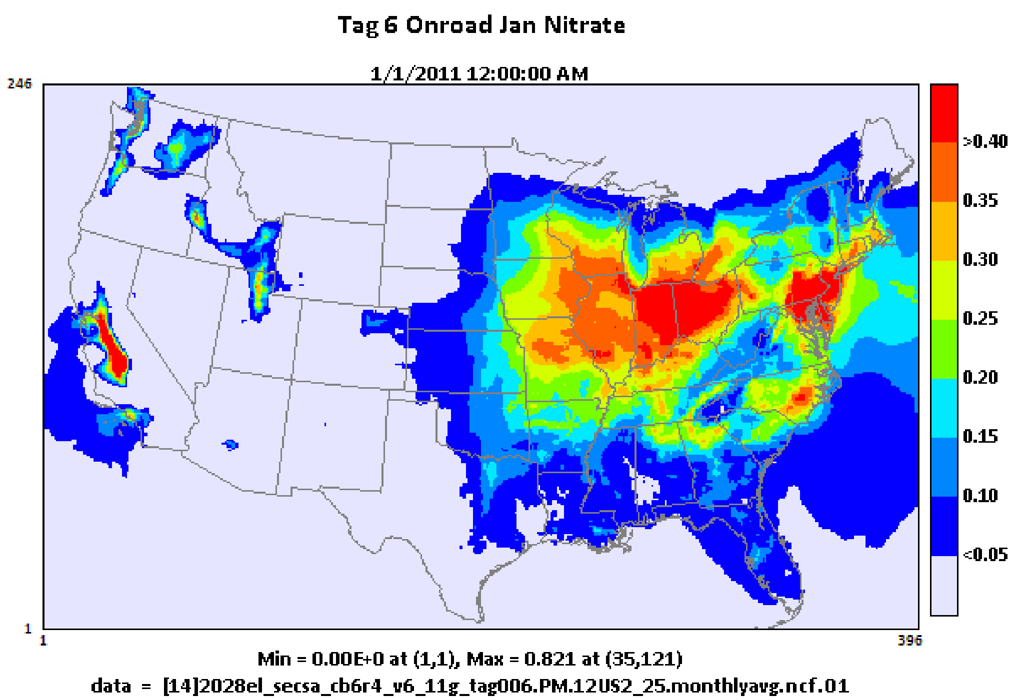

Figure E-12 January 2028 monthly average nitrate contribution (in ug/m3) from on-road mobile.

Tag 7- Non-road mobile

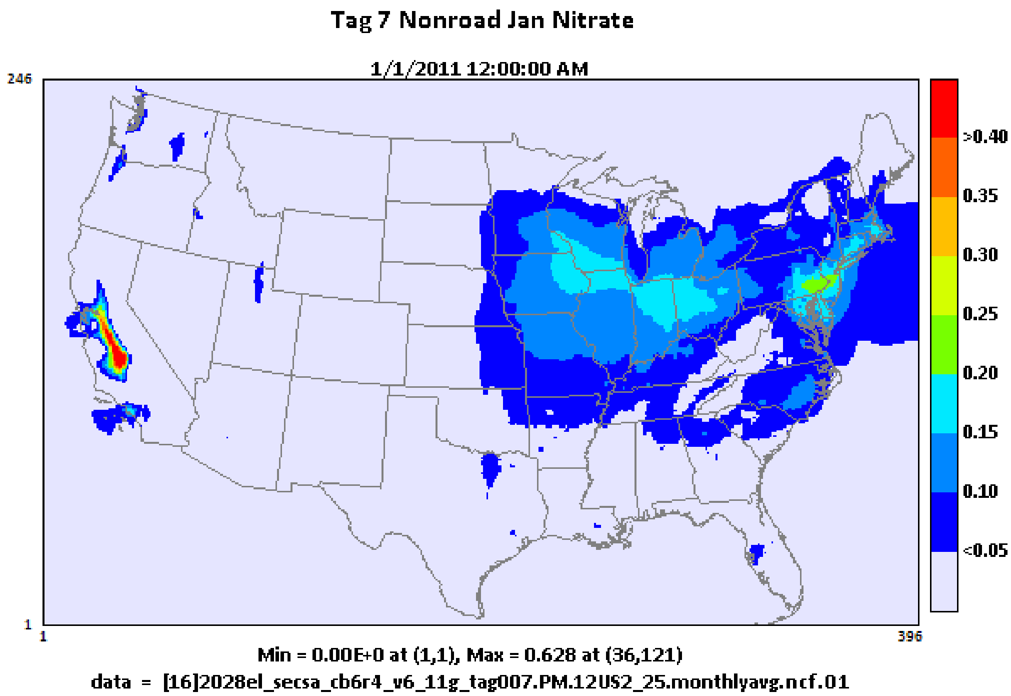

Figure E-13 January 2028 monthly average nitrate contribution (in ug/m3) from non-road mobile.

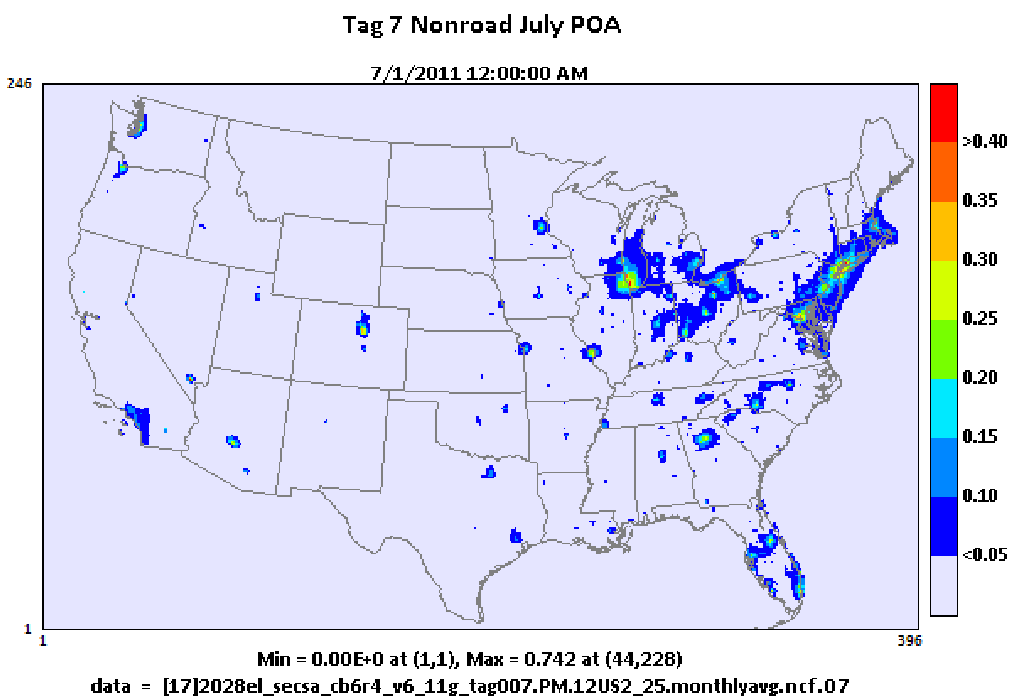

Figure E-14 July 2028 monthly average primary organic carbon contribution (in ug/m3) from non-road mobile.

Tag 8 Nonpoint and point oil & gas

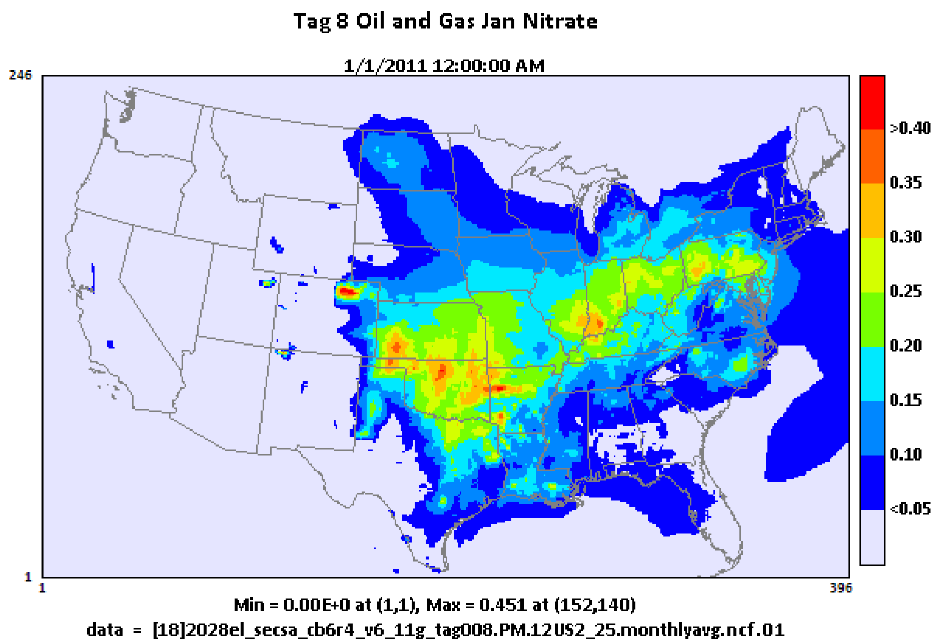

Figure E-15 January 2028 monthly average nitrate contribution (in ug/m3) from oil and gas point and nonpoint.

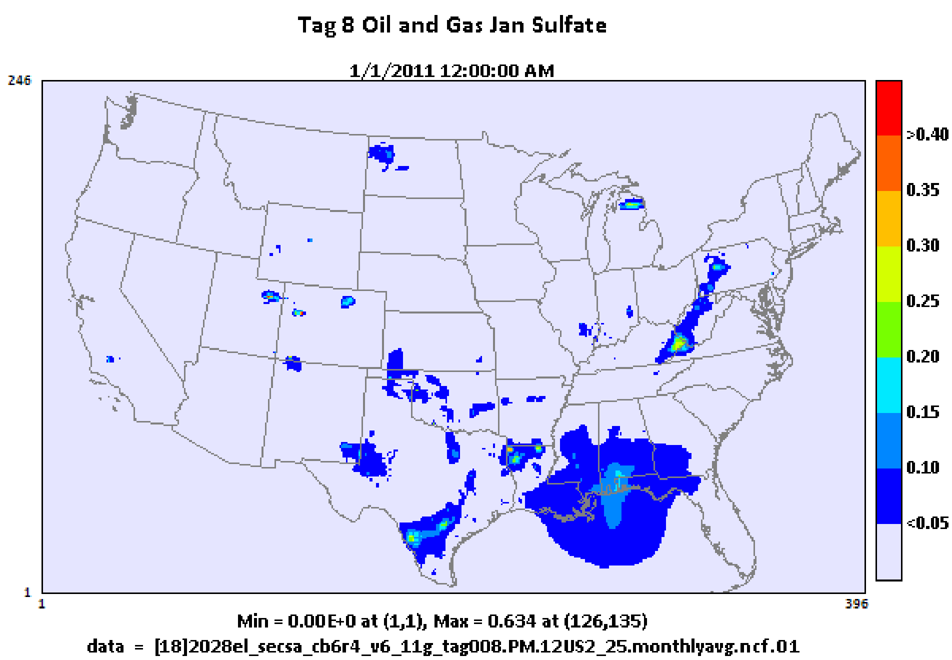

Figure E-16 January 2028 monthly average sulfate contribution (in ug/m3) from oil and gas point and nonpoint.

Tag 9 Electric generating units (EGU)

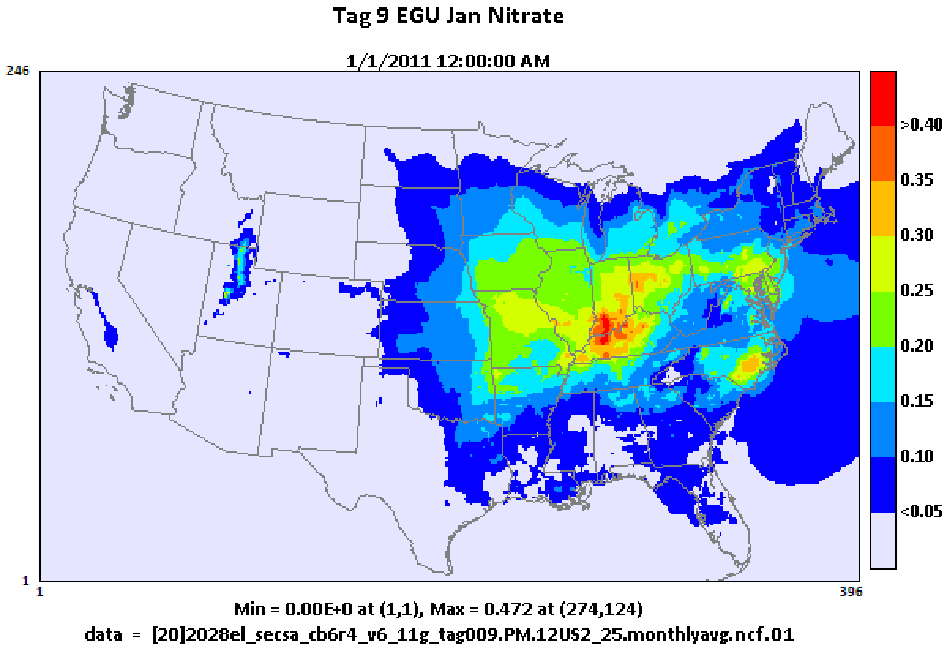

Figure E-17 January 2028 monthly average nitrate contribution (in ug/m3) from electric generating units.

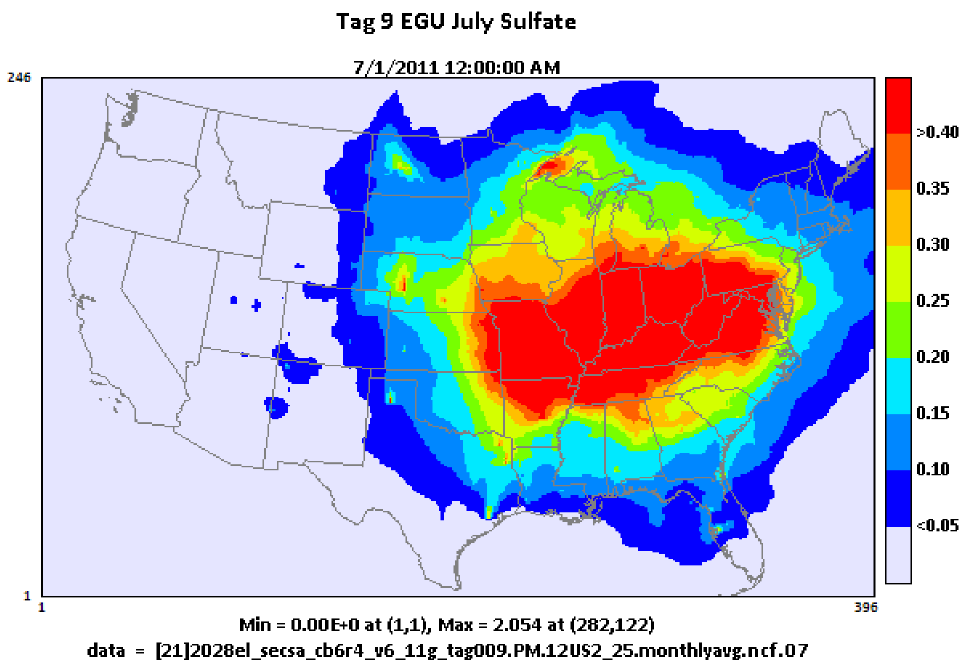

Figure E-18 July 2028 monthly average sulfate contribution (in ug/m3) from electric generating units.

Tag 10 U.S Wildfires

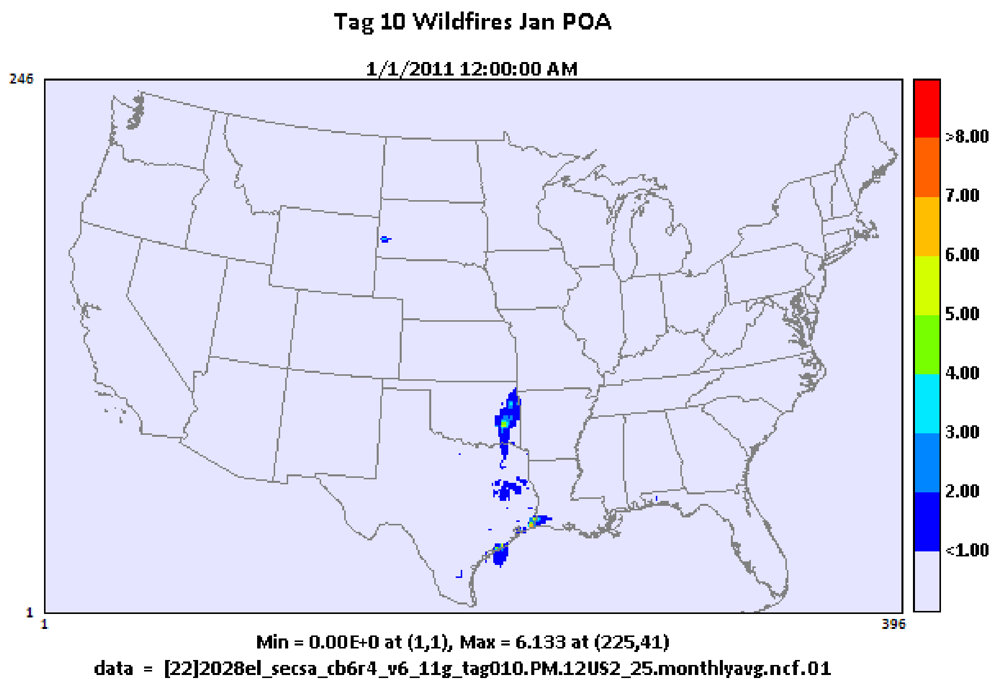

Figure E-19 January 2028 monthly average primary organic carbon contribution (in ug/m3) from U.S. wildfires.

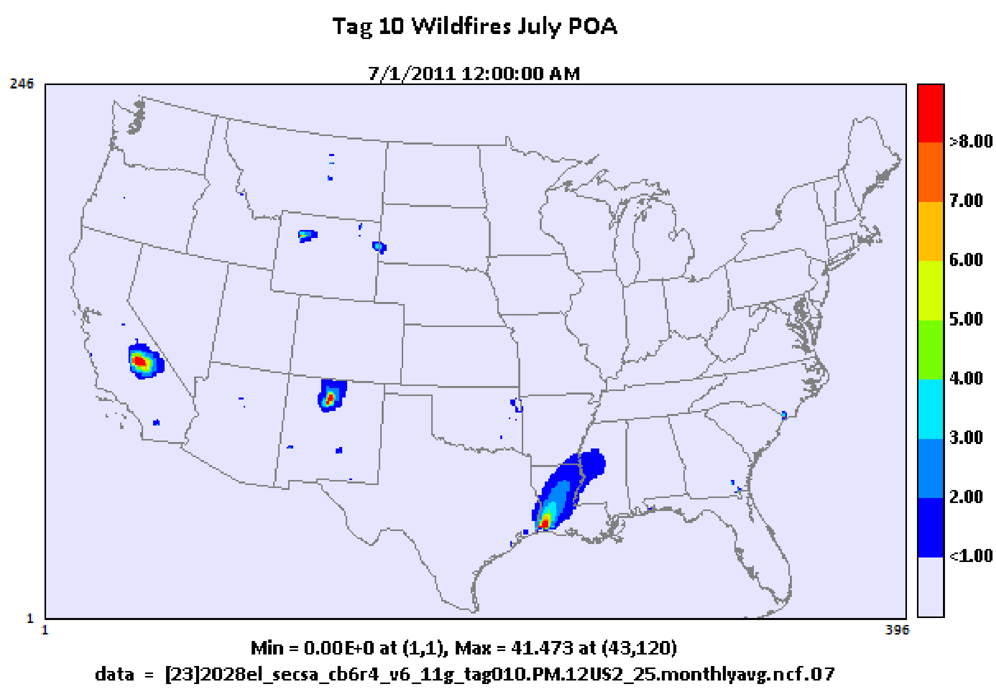

Figure E-20 July 2028 monthly average primary organic carbon contribution (in ug/m3) from U.S. wildfires.

Tag 11 Prescribed Fires

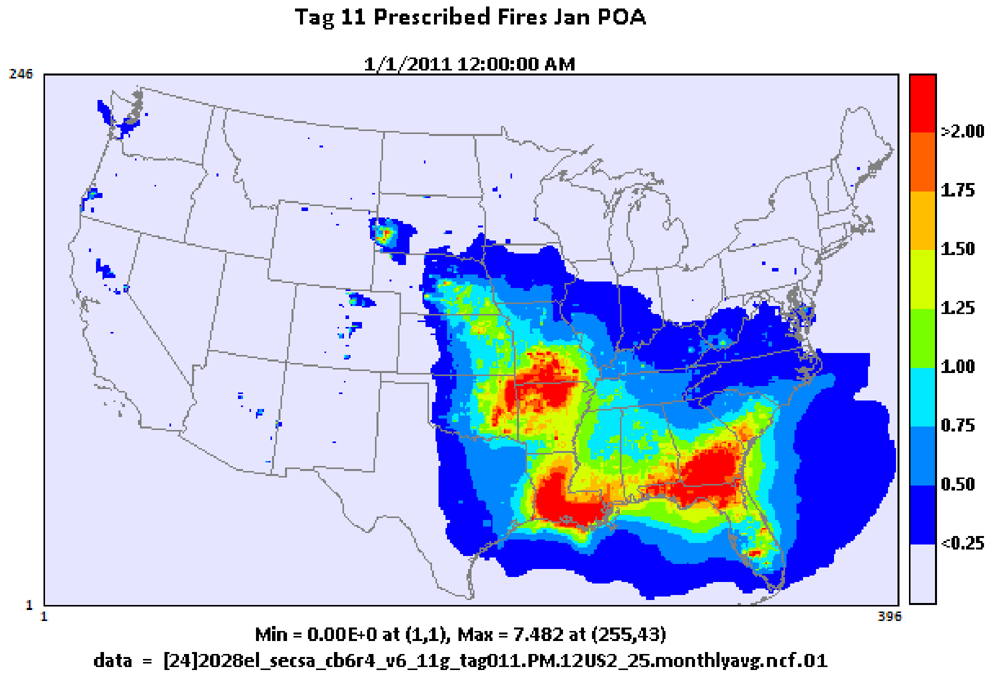

Figure E-21 January 2028 monthly average primary organic carbon contribution (in ug/m3) from U.S. prescribed fires.

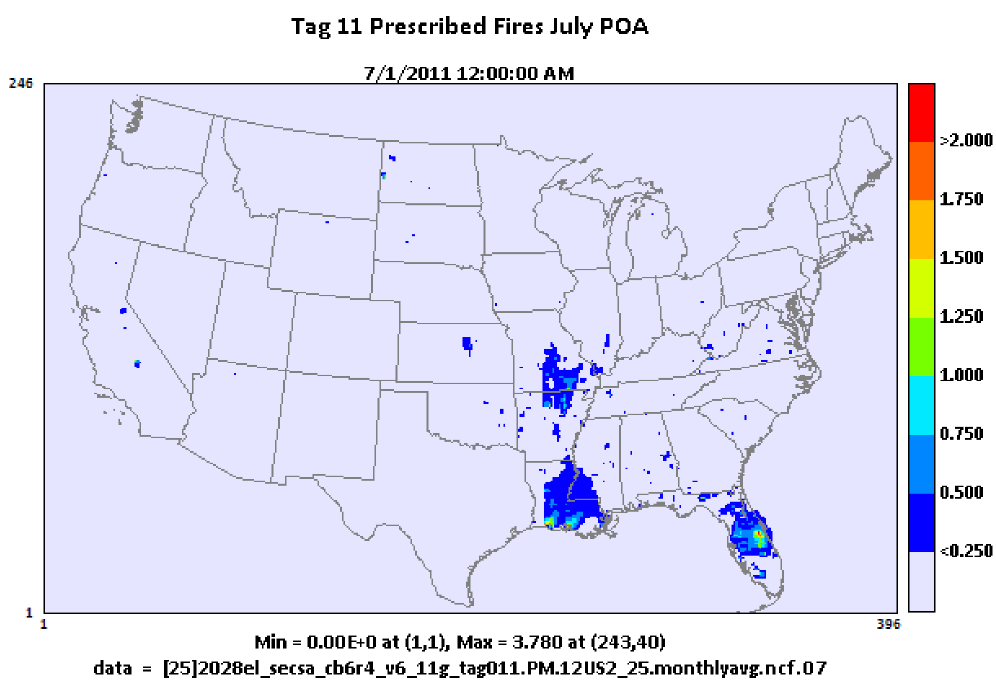

Figure E-22 July 2028 monthly average primary organic carbon contribution (in ug/m3) from U.S. prescribed fires.

Tag 12 Wildfires- Mexico and Canada

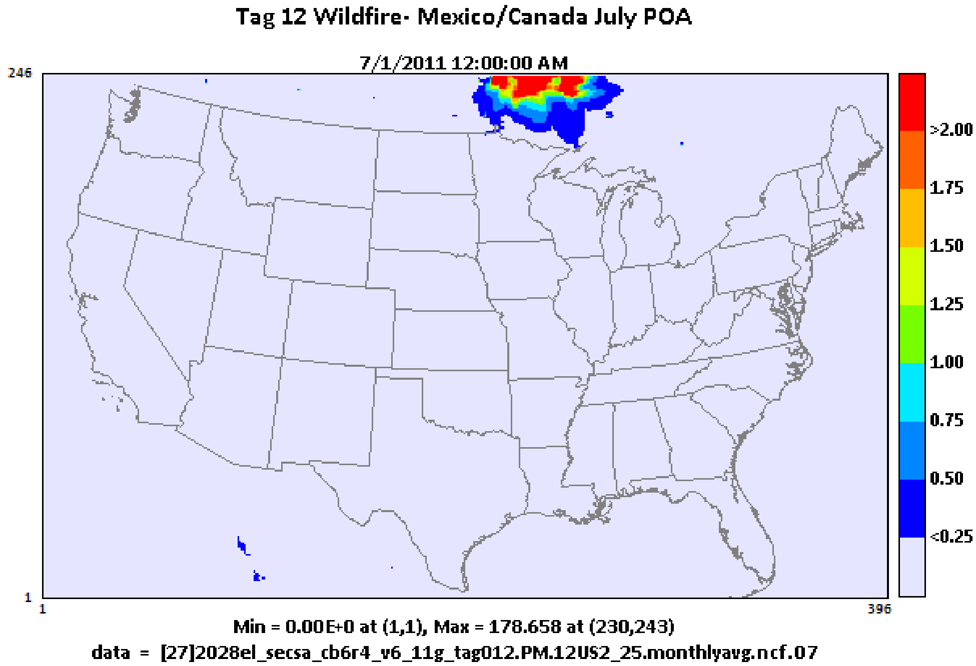

Figure E-23 July 2028 monthly average primary organic carbon contribution (in ug/m3) from wildfires in Mexico and Canada.

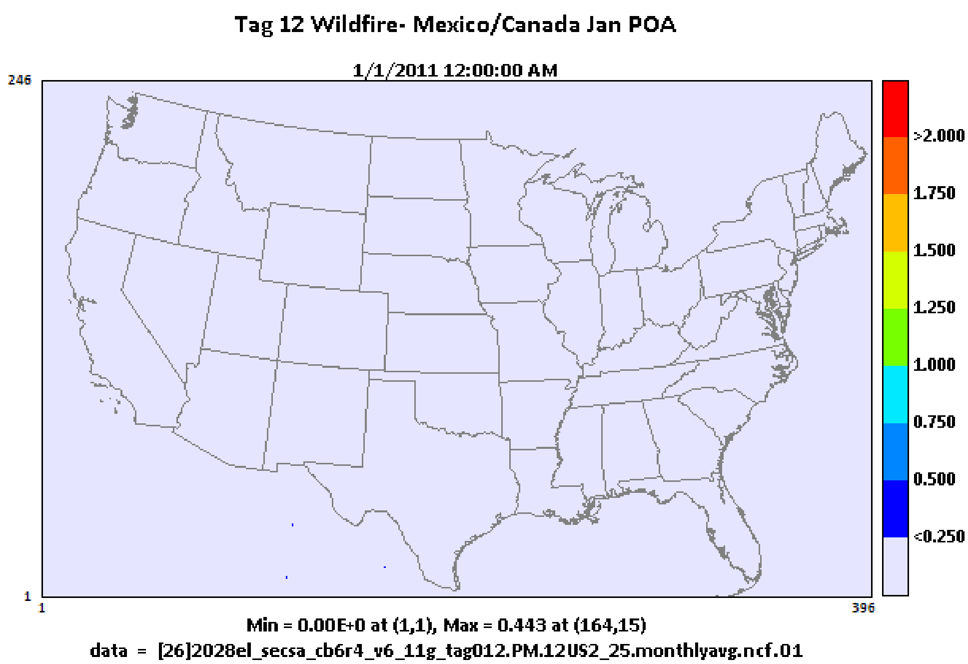

Figure E-24 January 2028 monthly average primary organic carbon contribution (in ug/m3) from wildfires in Mexico and Canada.

Tag 13 Agricultural Fires

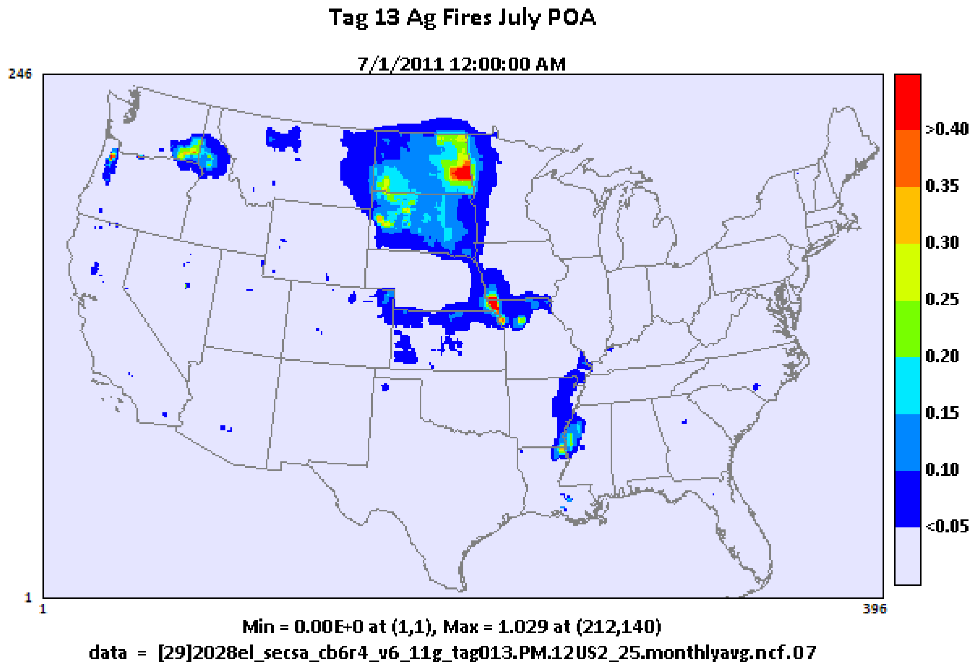

Figure E-25 July 2028 monthly average primary organic carbon contribution (in ug/m3) from U.S. agricultural fires.

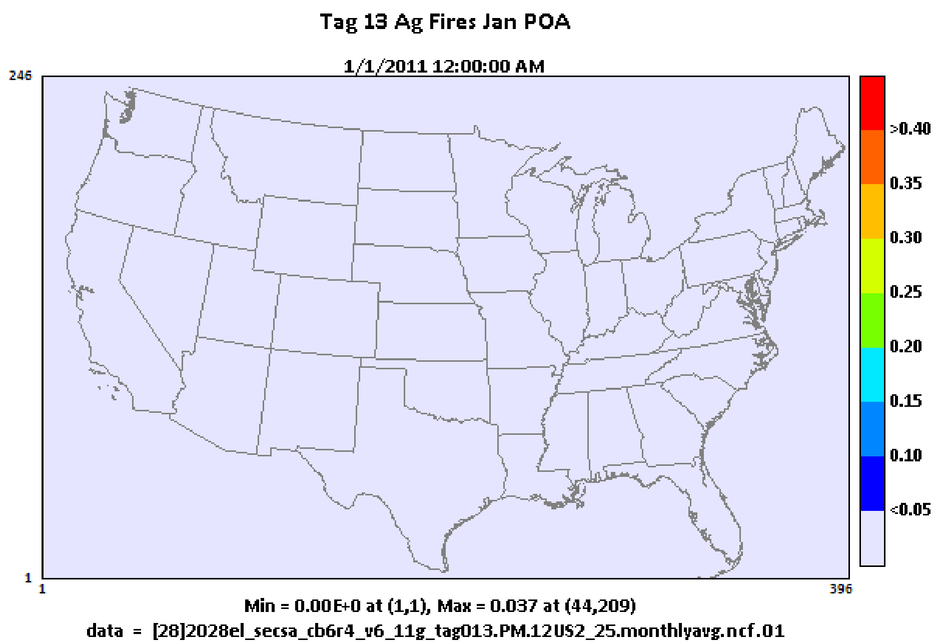

Figure E-26 January 2028 monthly average primary organic carbon contribution (in ug/m3) from U.S. agricultural fires.

Tag 14 NonEGU Point

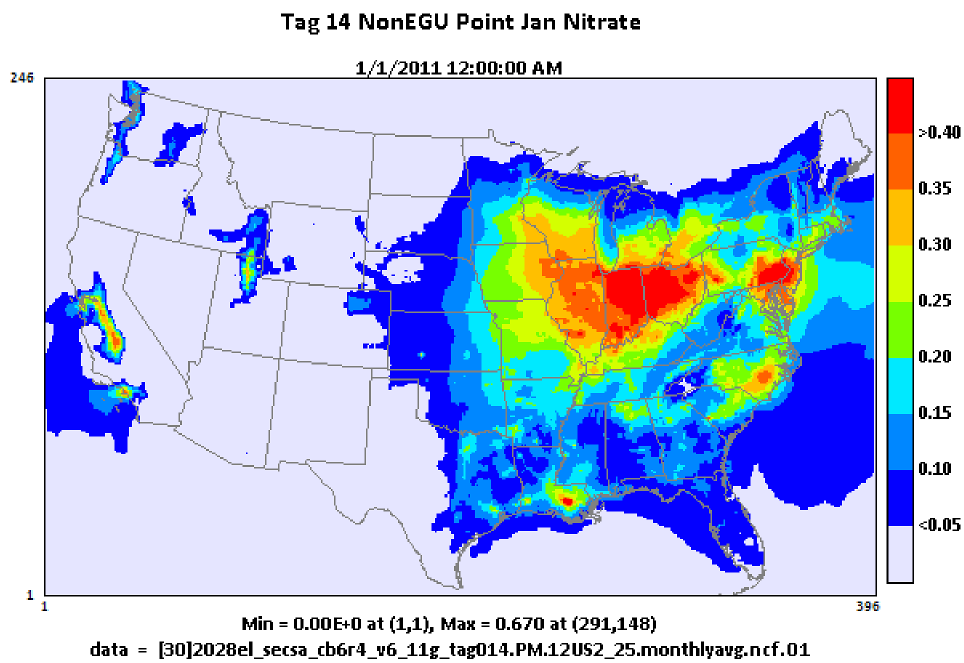

Figure E-27 January 2028 monthly average nitrate contribution (in ug/m3) from nonEGU point sources.

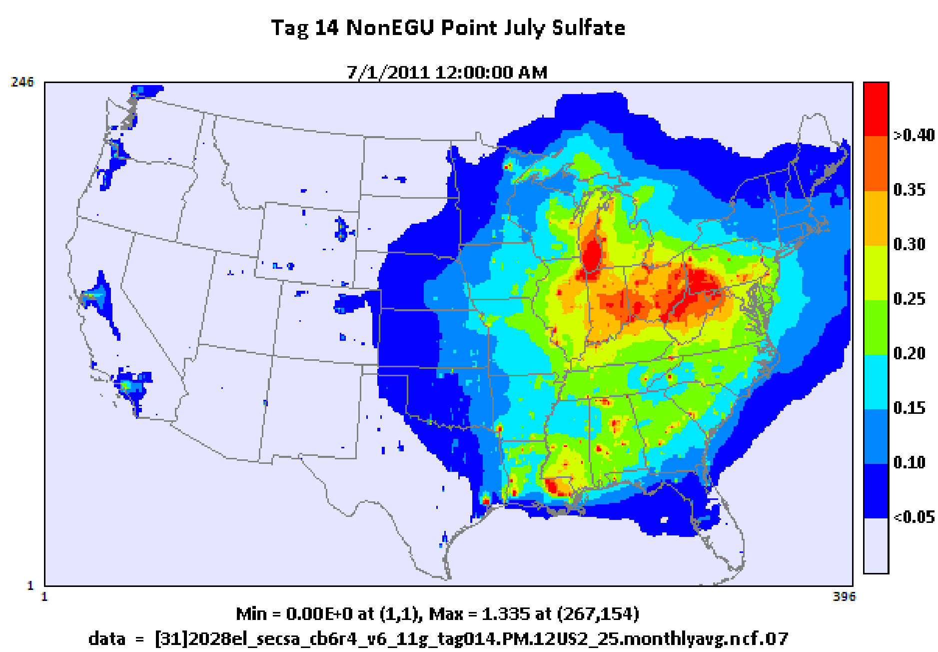

Figure E-28 July 2028 monthly average sulfate contribution (in ug/m3) from nonEGU point sources.

Tag 15 Rail

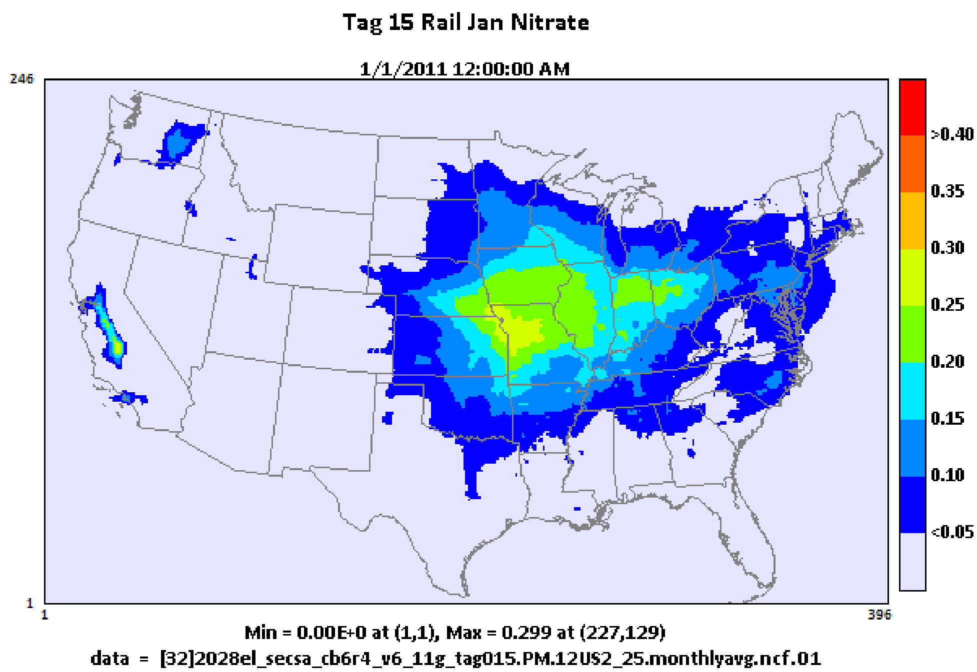

Figure E-29 January 2028 monthly average nitrate contribution (in ug/m3) from rail.

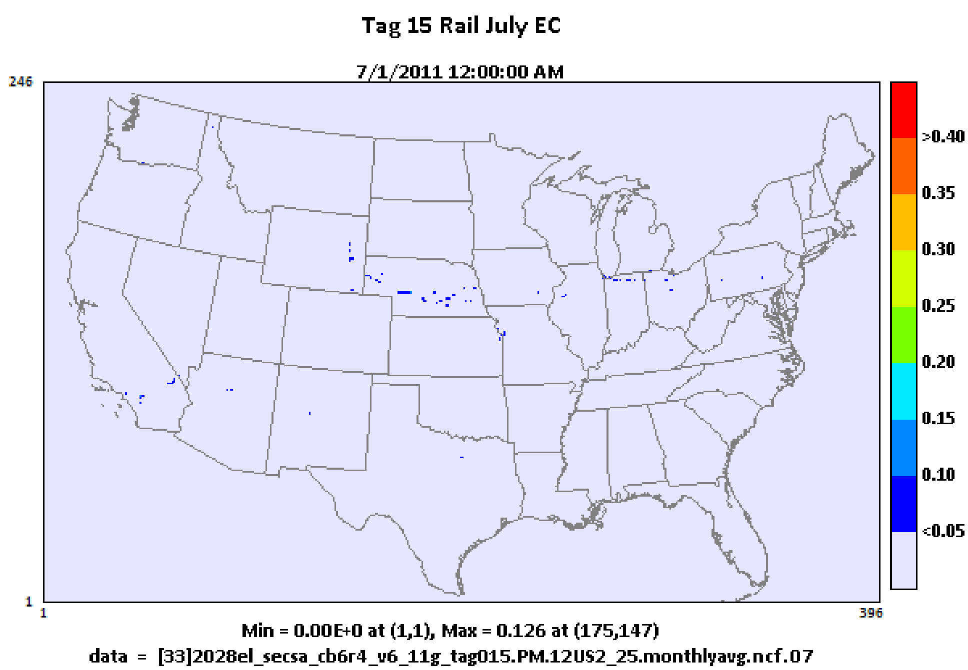

Figure E-30 July 2028 monthly average elemental carbon contribution (in ug/m3) from rail.

Tag 16 Residential wood combustion

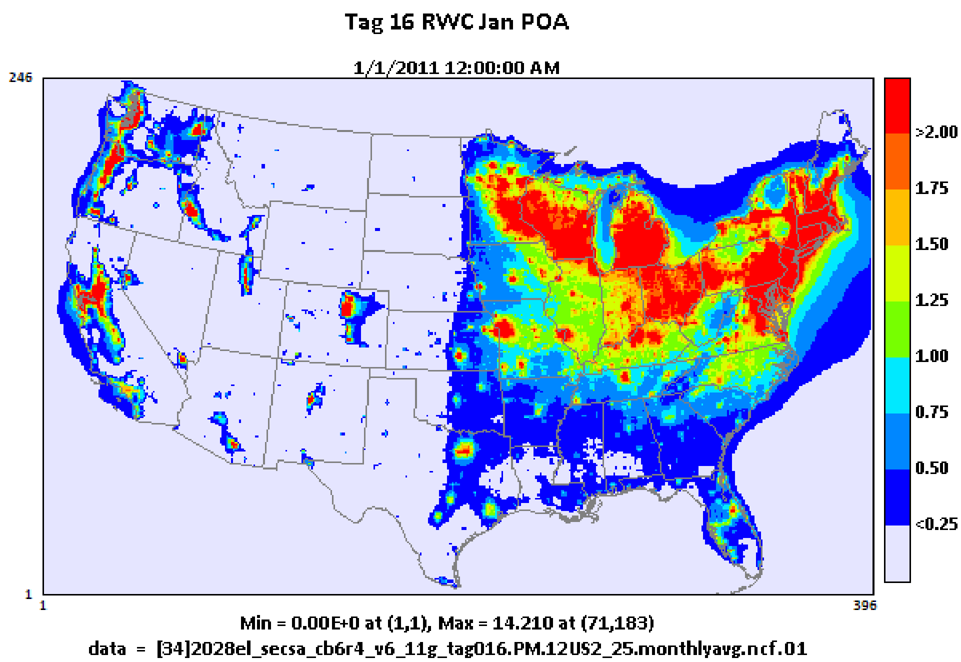

Figure E-31 January 2028 monthly average primary organic carbon contribution (in ug/m3) from residential wood combustion.

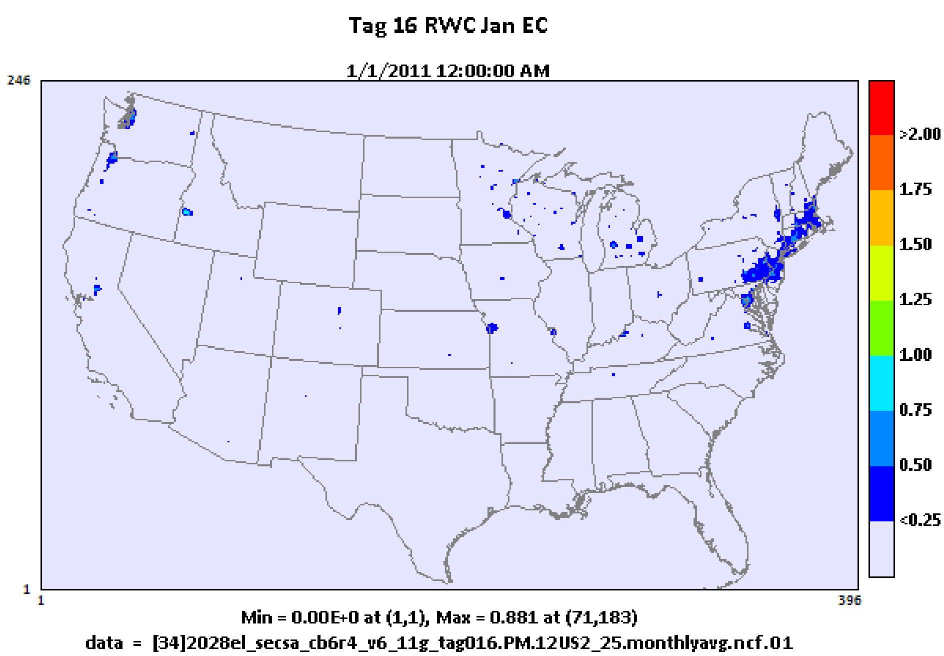

Figure E-32 January 2028 monthly average elemental carbon contribution (in ug/m3) from residential wood combustion.

Tag 17 Canada and Mexico (anthropogenic)

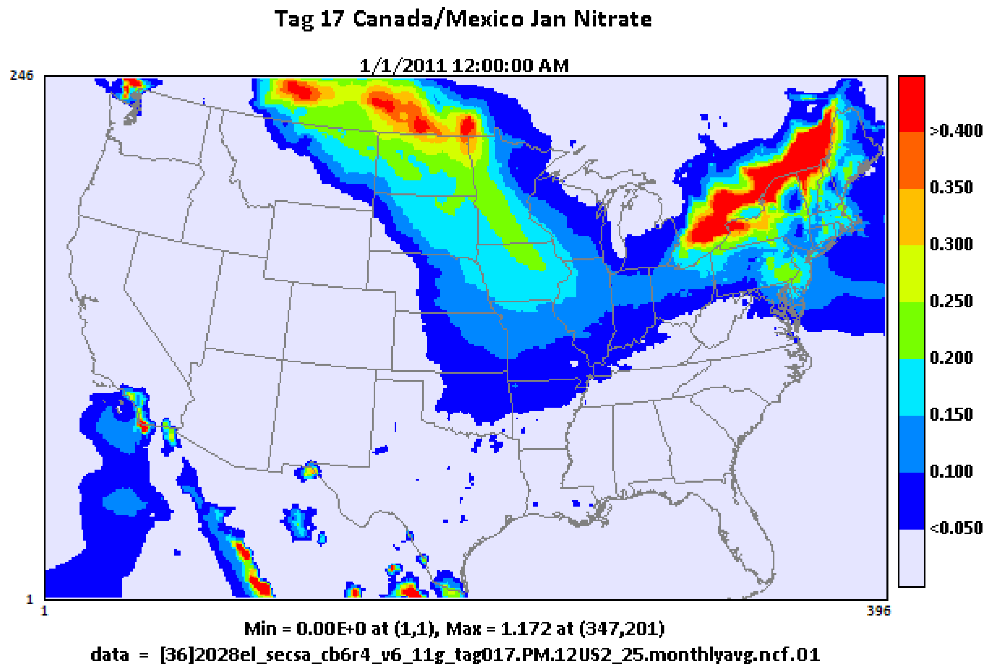

Figure E-33 January 2028 monthly average nitrate contribution (in ug/m3) from Mexico and Canada.

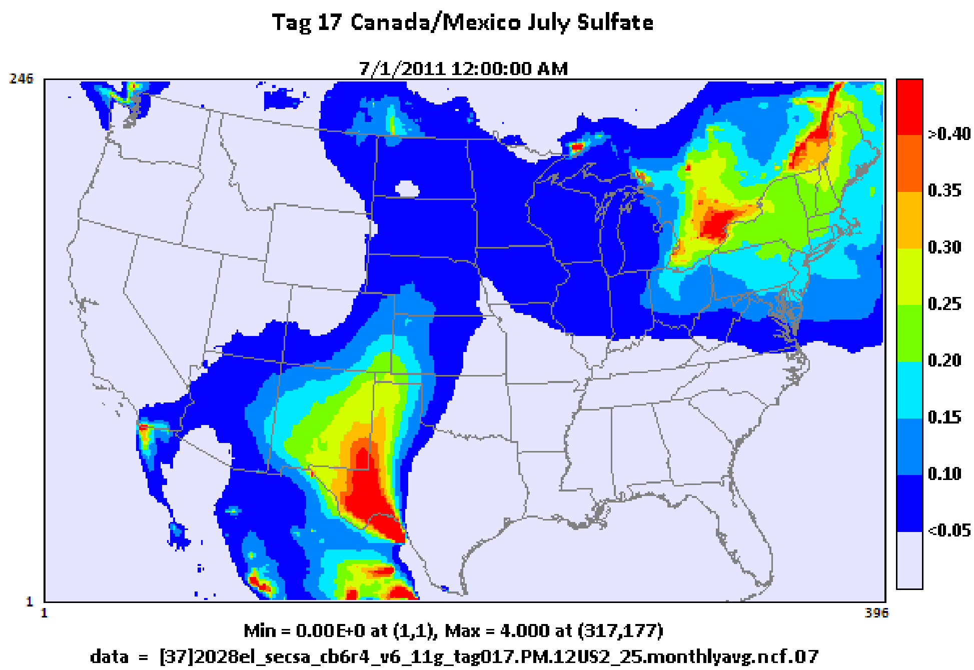

Figure E-34 July 2028 monthly average sulfate contribution (in ug/m3) from Mexico and Canada.

Tag 18 Offshore (commercial marine and offshore oil and gas)

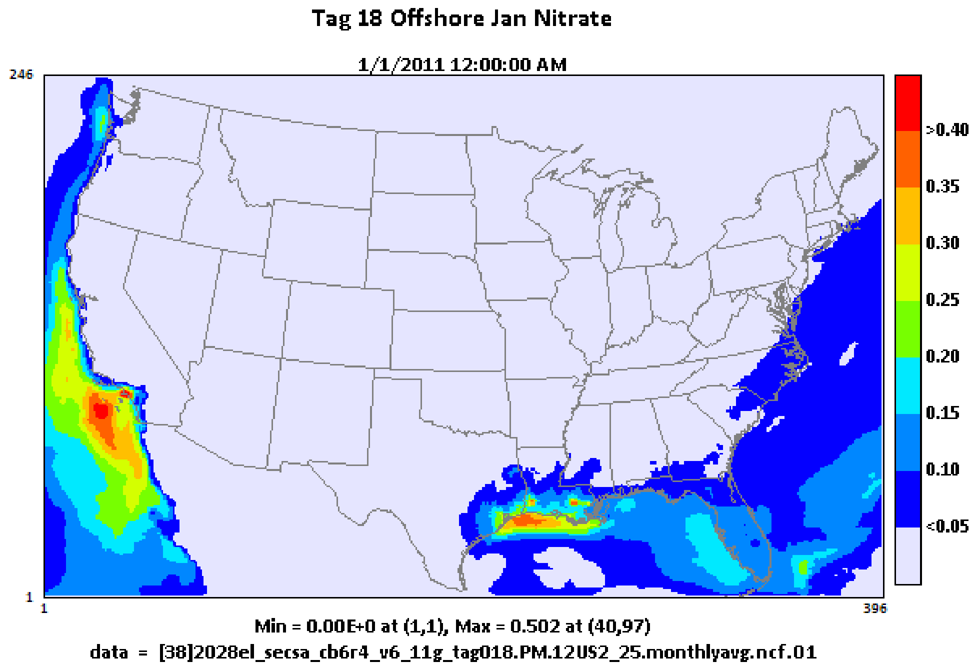

Figure E-35 January 2028 monthly average nitrate contribution (in ug/m3) from offshore emissions.

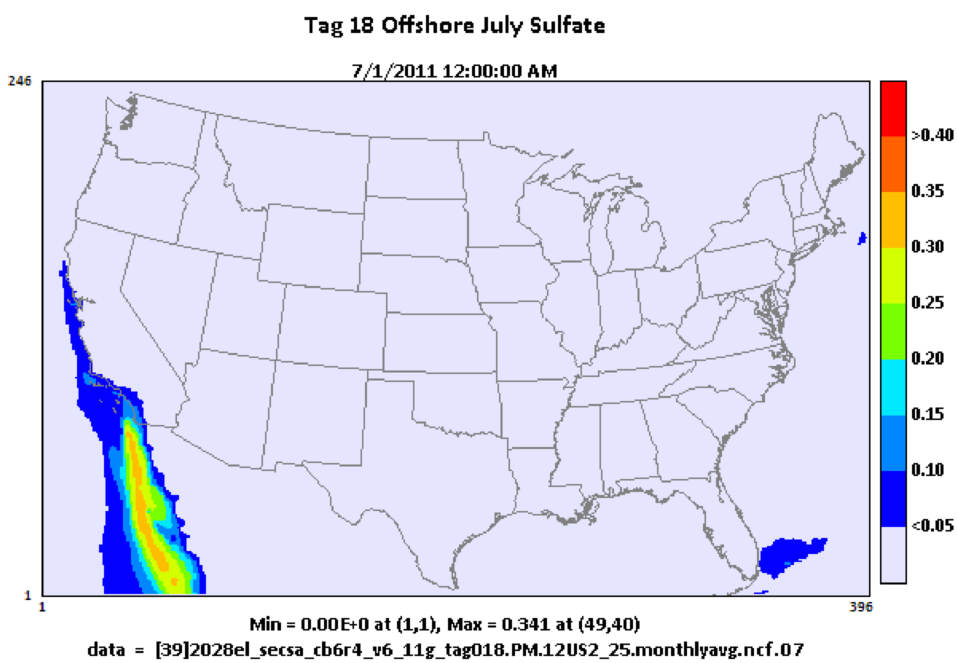

Figure E-36 July 2028 monthly average sulfate contribution (in ug/m3) from offshore emissions.

Tag 19 Initial and Boundary Conditions

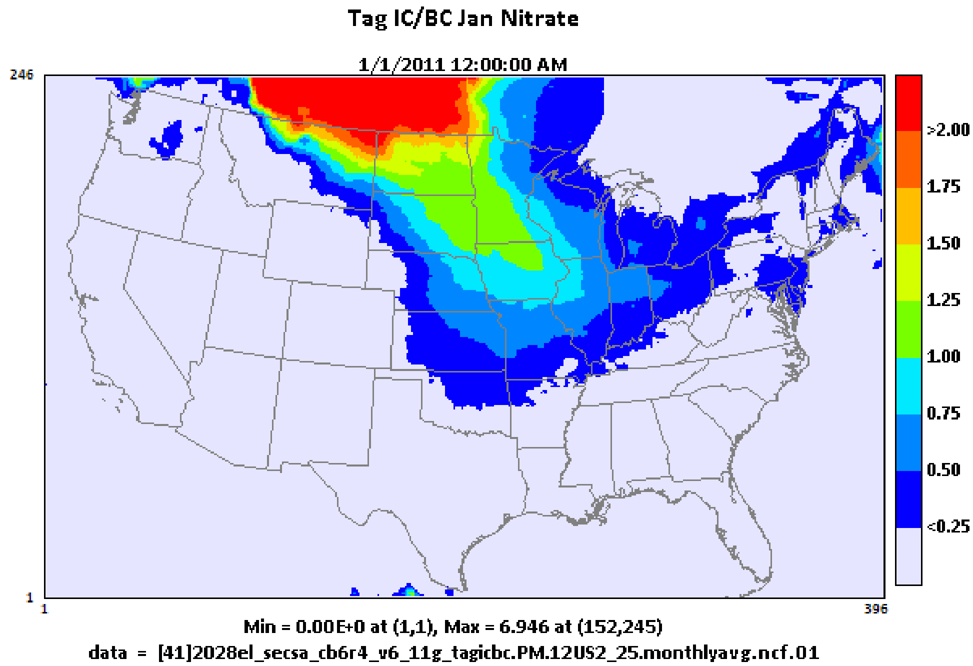

Figure E-37 January 2028 monthly average nitrate contribution (in ug/m3) from initial and boundary conditions.

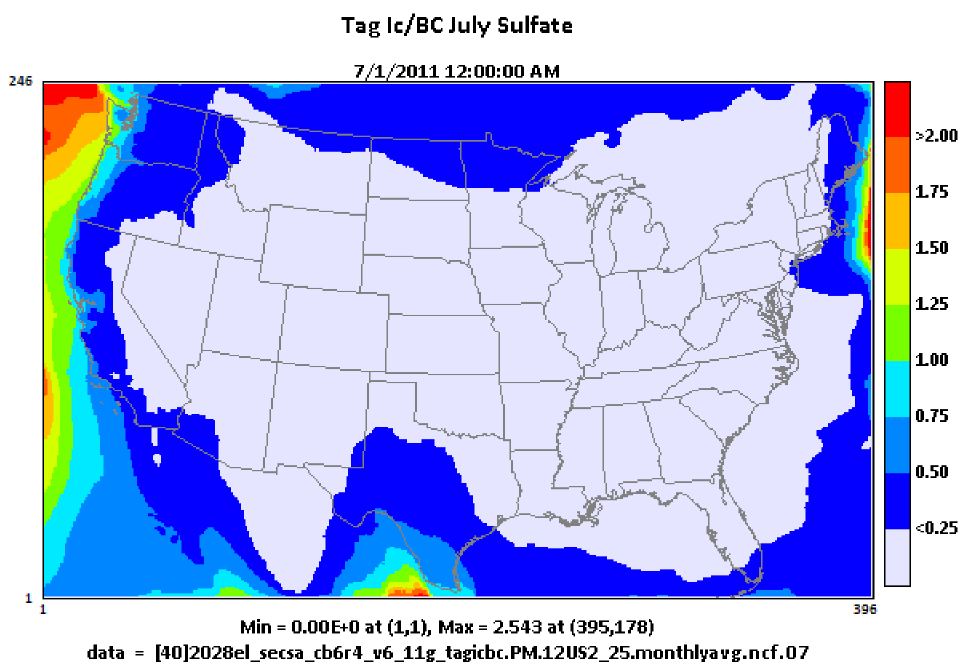

Figure E-38 July 2028 monthly average sulfate contribution (in ug/m3) from initial and boundary conditions.