Technical Support Document for EPA's Updated 2028 Regional Haze Modeling for Hawaii, Virgin Islands, and Alaska

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Technical Support Document for EPA's Updated 2028 Regional Haze Modeling for Hawaii, Virgin Islands, and Alaska

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1.0 Background

The Regional Haze Rule (RHR) requires states to develop and submit state implementation plans (SIP) that evaluate 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.[1] The EPA conducted visibility modeling for 2028 with the intention of informing the regional haze SIP development process.

This modeling provides a number of outputs and metrics that may be helpful in the state regional haze SIP planning process. These include:

1) Projected 2028 visibility impairment on the 20% most anthropogenically impaired and 20% clearest days at each Class I area in Hawaii, Alaska, and the U.S. Virgin Islands.
2) Estimated contribution of U.S. anthropogenic emissions to visibility impairment at each Class I area.

Our goal is that this information, along with future collaborative work, will improve the technical foundation of modeling used in regional haze SIP development. States should consult with their EPA Regional Office to determine the usefulness of these model results for any particular Class I area. Information about EPA's modeling for Class I areas in the contiguous U.S. is provided elsewhere (U.S. Environmental Protection Agency, 2019c).

1.1 Introduction

In this technical support document (TSD) we describe the air quality modeling performed to examine regional haze in 2028 at Class I areas in Alaska, Hawaii, and the Virgin Islands. For this assessment, air quality modeling is used to project visibility levels at individual Class I areas (represented by IMPROVE monitoring sites) to 2028 and to estimate U.S. anthropogenic contribution 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 in 2028. Hemispheric CMAQ modeling provides an estimate of international anthropogenic contribution and a zero-out of U.S. anthropogenic emissions for

[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.

each area provides an estimate of more local contribution. This information allows for a better understanding and accounting of sources of future visibility impairment.

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, with comparisons to both the "unadjusted" and "unadjusted" glidepath.

2.0 Air Quality Modeling Platform

The EPA used a 2016-based air quality modeling platform which includes emissions, meteorology, and other inputs for 2016 as the base year for the modeling described in this TSD. The 2016 base year emissions were projected to a future year base case scenario, 2028. The emissions, meteorological modeling, and photochemical modeling used for this regional haze assessment are further described below.

2.1 Air Quality Model Configuration

The photochemical model simulations performed for this Regional Haze assessment used the Community Multiscale Air Quality Modeling (CMAQ) system version 5.3 (https://www.epa.gov/cmaq). CMAQ 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. 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.

Figures 2-1 and 2-2 show the geographic extent of the modeling domains that were used for air quality modeling in this analysis. The three domains will subsequently be referred to as the AK, HI and PR & VI domains, respectively. Domain specifications are provided in Table 2-1. All domains are Lambert Conic projections with centers and true latitudes noted in Table 2-1. Each nested simulation used initial and lateral boundary inflow from the coarser domain. The 27 km domains were initialized using a hemispheric scale model simulation. The modeling domain contains 35 vertical layers with a top at about 17,550 meters, or 50 millibars (mb). The model simulations produce hourly air quality concentrations for each cell across the modeling domain.

Table 2-1. Domain specifications used for each area.

Domain	Cell size (km)	X and Y origin (km)	NX	NY	Lambert center	Lambert true latitudes
27AK1	27	-1,971,000.0, -1,701,000.0	146	126	-115, 63	60, 70
9AK1	9	-1,107,000.0, -1,134,000.0	312	252	-115, 63	60, 70
27HI1	27	-1,012,500.0, -1,012,500.0	75	75	-157, 21	19, 22
9HI1	9	-517,500.0, -490,500.0	100	100	-157, 21	19, 22
3HI1	3	-391,500.0, -346,500.0	225	201	-157, 21	19, 22
27PR1	27	-1,012,500.0, -1,012,500.0	75	75	-66, 18	17, 19
9PR1	9	-517,500.0, -436,500.0	100	100	-66, 18	17, 19
3PR1	3	-274,500.0, -202,500.0	150	150	-66, 18	17, 19

CMAQ requires a variety of input files that contain information pertaining to the modeling domain and simulation period. These include gridded hourly emissions estimates, meteorological data, and boundary concentrations. Separate emissions inventories were prepared for the 2016 base year and the 2028 base case. All other inputs (i.e., meteorological fields, initial concentrations, and boundary concentrations) were specified for the 2016 base year model application and remained unchanged for the future-year model simulations. The CMAQ modeling scenarios were each performed using a single time segment with a 10-day ramp-up period at the end of December 2015.

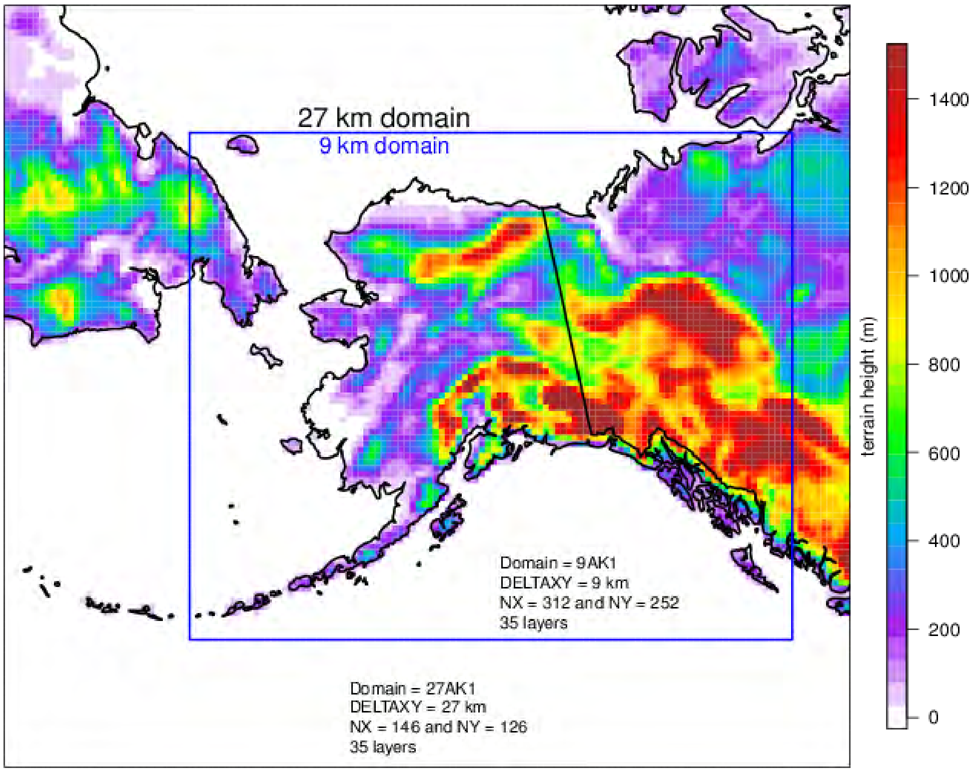

Figure 2-1. *Maps of the 27km and 9km (insert) WRF and CMAQ modeling domains used for regional haze modeling covering Alaska.*

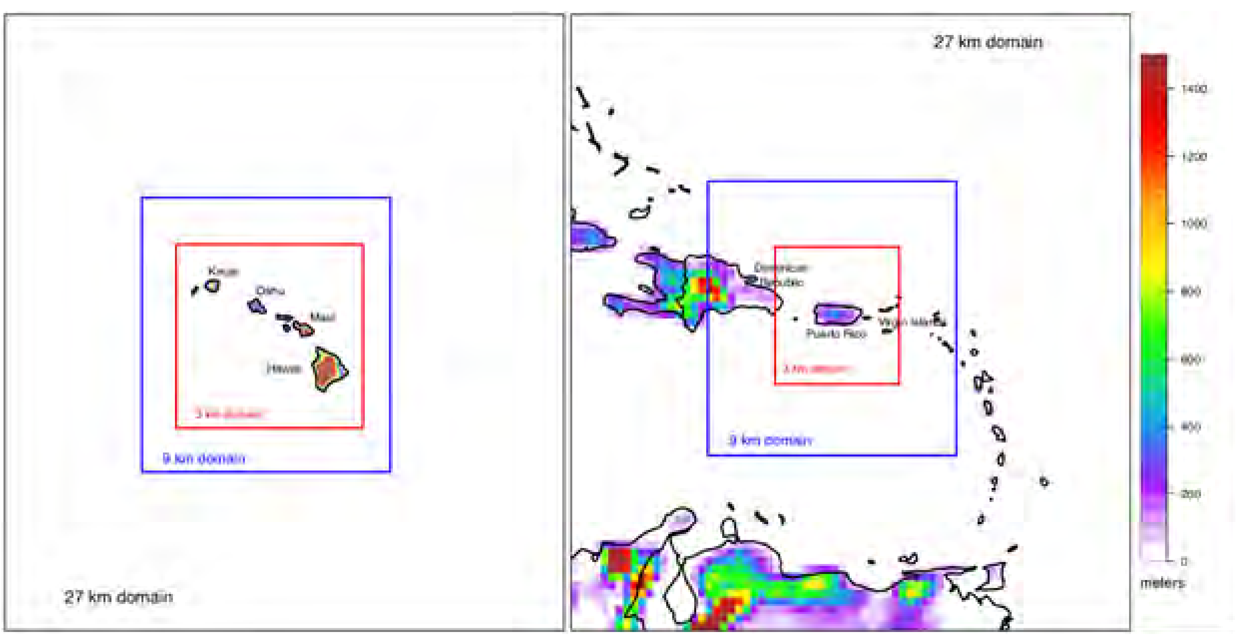

Figure 2-2. *Maps of the WRF and CMAQ modeling domains used for regional haze modeling covering Hawaii, Puerto Rico and the Virgin Islands*

Table 2-2 shows each of the CMAQ model runs performed for this analysis. For each of the three modeling domains there are three model simulations: a 2016 base case, a 2028 future base case, and a 2028 U.S. anthropogenic emissions zero-out model run.

Table 2-2. CMAQ model simulations for Alaska, Hawaii, and Puerto Rico/Virgin Islands.

Scenario Name	Description
2016fh_16j	Historical 2016 base case
2028fh_16j	Future year 2028 “on the books” scenario
2028fh_16j_zeroanth	Future year 2028 “on the books” scenario, with U.S. anthropogenic emissions zeroed out.

2.2 Meteorological Data for 2016

Meteorological inputs for the photochemical and emissions models were generated with version 3.9.1.1 of the Weather Research and Forecasting (WRF) model (www2.mmm.ucar.edu/wrf/users). WRF was applied for the entire year of 2016 using 35 layers between the surface and 50 mb with thinner layers closer to the surface to better resolve diurnal variation in the planetary boundary layer. The Hawaii and Puerto Rico domains were modeled using grid cells sized at 27, 9, and 3 km horizontal resolutions (Figure 2-2), the Alaska domain was modeled at 27 and 9 km. The 27 km model domain was initialized with the National Centers for Environmental Protection (NCEP) 0.25 degree Global Forecast System (GFS) 0 hour analysis and 3 hour forecast (National Centers for Environmental Prediction, 2015). The 9 and 3 km model domains, where applicable, were initialized using the coarser WRF domain output. WRF was applied with the settings and inputs as described in Table 2-3 and briefly summarized here. Unless otherwise noted in Table 2-3, WRF was applied with Morrison microphysics, RRTMG radiation, Kain-Fritsch cumulus at 29 and 9 km (none at 3 km domains), MODIS landcover, NOAH land surface model, revised MM5 Monin-Obukhov surface layer scheme, and YSU planetary boundary layer option. Analysis nudging was applied for each model domain using default nudging coefficients. WRF output was processed for input to CMAQ using MCIP version 4.5 (Otte and Pleim, 2010). The MODIS landcover dataset was adjusted to change incorrect landcover assignments of lakes to barren for Hawaii and Puerto Rico.

Table 2-3. **WRF Options - 27, 9, and 3 km Hawaii, Puerto Rico, and Alaska domains**

Option	Hawaii	Puerto Rico	Alaska
WRF version	3.9.1.1	3.9.1.1	3.9.1.1
Boundary layer (bl_pbl_physics)	YSU	YSU	MYNN Level 2.5
Surface layer (sf_sfclay_physics)	Revised MM5 Monin-Obukhov scheme	Revised MM5 Monin-Obukhov scheme	MYNN
Land surface model (sf_surface_physics)	Noah	Noah	Noah
Cumulus scheme	Kain Fritsch – 27 and 9 km (cu_rad_feedback = .true.) none – 3 km	Kain Fritsch – 27 and 9 km (cu_rad_feedback = .true.) none – 3 km	Kain Fritsch – 27 and 9 km (cu_rad_feedback = .true.)
Microphysics	Morrison	Morrison	Morrison
Longwave radiation	RRTMG	RRTMG	RRTMG
Shortwave radiation	RRTMG	RRTMG	RRTMG
Initialization data	GFS 0.25-degree (0h analysis and 3h forecast)	GFS 0.25-degree (0h analysis and 3h forecast)	GFS 0.25-degree (0h analysis and 3h forecast)
Horizontal grid resolution	27, 9, and 3 km	27, 9, and 3 km	27 and 9 km
Model top	50 mb	50 mb	50 mb
Number of vertical layers	35	35	35
Sea surface temperature data	GFS- 27 and 9km/ NLCD-3km	GFS- 27 and 9km/ NLCD-3km	GFS- 27 and 9km
Analysis nudging	yes	yes	yes
MCIP version	4.5	4.5	4.5
Land cover data	Modis	Modis	Modis

Details of the annual 2016 meteorological model simulation and evaluation for the AK domain are provided in a separate technical support document (U.S. Environmental Protection Agency, 2020a). Additional evaluation for the Hawaii and Puerto Rico/Virgin Islands domain are also available elsewhere (Baker et al., 2020).

2.3 Initial and Boundary Concentrations

The lateral boundary and initial species concentrations are based on a hemispheric modeling platform. The standard hemispheric simulation is described in detail in the Hemispheric CMAQ 2016 Simulation TSD (U.S. Environmental Protection Agency, 2019a). The hemispheric simulation is summarized in Section 2.3.1 and processing to boundary conditions is summarized in Section 2.3.2.

2.3.1 Hemispheric Simulation

The hemispheric modeling platform uses the Weather Research and Forecasting model (WRF v3.8) meteorological model, the Sparse Matrix Operating Kernel for Emissions (SMOKE v4.5) emissions model, and the Community Multiscale Air Quality model (CMAQ) version 5.2.1 with the Carbon Bond mechanism (CB6r3) and the non-volatile aerosol option (AE6).

The hemispheric scale model uses a polar stereographic projection at 108 kilometer (km) resolution to completely and continuously cover the Northern Hemisphere. The hemispheric scale allows for long-range free tropospheric transport with 44 layers between the surface and 50 hPa (~20 km asl). The hemispheric modeling system was initiated on May 1st 2015 and run continuously through December 31st, 2016.

The regional inventories over North America are based on the Inventory Collaborative 2016 emissions modeling platform (http://views.cira.colostate.edu/wiki/wiki/9169), which was developed through the summer of 2019. The hemispheric modeling analysis used the 2016 "alpha release" (specifically the modeling case abbreviated 2016fe) that is publicly available from https://www.epa.gov/air-emissions-modeling/2016-alpha-platform.

For the hemispheric emissions modeling platform, there are thirty anthropogenic sectors of emissions including nine sectors based on the Hemispheric Transport of Air Pollution Version 2 inventory (EDGAR-HTAPv2) inventory and 15 sectors that represent emissions in China which together comprise the anthropogenic emissions outside of North America. The international emission inventories are synthesized from the EDGAR-HTAP v2 harmonized emission inventory and country specific databases where updates were likely to be influential.

The EDGAR-HTAP v2 inventories were projected to represent the year 2014. Projection factors were calculated from the Community Emissions Data System (CEDS) inventory at a country-sector level. This allowed our inventory to evolve without the risks associated with transitioning to a new inventory system. Especially because EDGAR-HTAP v2 is superseded for critical counties, this was the optimal approach. Details of scaling factor development are described in Section 2.1.5 of the 2016v7.1 Hemispheric Modeling Platform Technical Support Document (U.S. Environmental Protection Agency, 2019a).

The China emission inventory was developed at Tsinghua University (THU) (Zhao et al., 2018). This inventory was extensively compared to the EDGAR-HTAP v2 and EDGAR v4.3 inventories before use. The largest differences for NO_X in 2016 occurred in individual emissions sectors rather than inventory totals. The SO_2 emissions were more different than NOx emissions between the two inventories because the THU inventory applies controls to the metal industry that have been adopted by China.

More details on the 2016 hemispheric CMAQ modeling are available in (U.S. Environmental Protection Agency, 2019a) and more details on the hemispheric emissions inventories are available elsewhere (U.S. Environmental Protection Agency, 2019b).

2.3.2 Processing Boundaries from the Hemispheric Simulation

The 108 km resolution hemispheric CMAQ predictions were used to provide one-way dynamic boundary concentrations at one-hour intervals and an initial concentration field for the CMAQ simulations. The hemispheric CMAQ results are spatially interpolated to lateral boundary and initial boundary conditions.

Boundary conditions for the regional CMAQ domain require mapping hemispheric results from the polar stereographic grid and the vertical layer structure. Both lateral and initial conditions use nearest neighbor horizontal interpolation and vertical mass conserving interpolation. The lateral boundaries perform the interpolation along the perimeter for each hour, while the initial boundaries perform the interpolation for the entire domain at only specific hours. The initial boundaries were created for 2015-12-22 at 00:00:00 UTC. These results are directly usable for CMAQ.

2.4 Emissions Inventories

CMAQ 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 2016 and 2028 were preprocessed into CMAQ-ready inputs using the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system (https://www.cmascenter.org/smoke/).[2]

Biogenic emissions of volatile organic compounds (VOC) and nitrogen oxide (NO) were generated using the Model of Emissions for Gases in Nature (MEGAN) version 2.0 (Guenther et al., 2006) at 0.5 degree scale and allocated to the finer scales using relevant MODIS landcover categories. Day-specific wildland fire emissions were based on FINN (Wiedinmyer et al., 2011) for Puerto Rico and SmartFire2/BlueSky framework (Baker et al., 2016) for Alaska and Hawaii. Agricultural burning emissions for Hawaii were developed from the 2016 Hazard Mapping System (HMS) fire activity over agricultural land. Crop-specific emission factors were applied to each daily fire to calculate emissions (Pouliot et al., 2017). Sea-salt (Gantt et al., 2015) and

[2] The SMOKE output emissions case name for the 2016 base year is “2016fh_16j” and the emissions case name for the 2028 base case is “2028fh_16j”.

halogen (Sarwar et al., 2015) emissions from the ocean were included. Lightning, wind-blown dust, and volcanic emissions were not included.

Electric generating unit (EGU) emissions were based on state submitted data to the 2016 emissions modeling platform. Fuel use data provided by the Energy Information Administration (EIA) was used to allocate annual EGU emissions to month when available or a state profile based on total monthly fuel use otherwise. Monthly emissions were allocated to week and hour of the day using default EGU temporal profiles reflective of typical energy use and load patterns. Annual total EGU emissions in Puerto Rico were allocated to month, week, and hour of the day based on regional fuel profiles (south Florida) from the Continuous Emissions Modeling System (CEMS). The EGU emissions were based on 2016 values that were submitted to the 2016 NEI. Values from the 2014 NEI were used for smaller sources that were not submitted for 2016. Alaska provided comments on the EGU emissions from the beta platform that were incorporated into the 2016v1 inventories used for this case. The EGU inventories were held constant at 2016 levels in the 2028 inventories.

The primary data source for non-EGU point sources is the 2016 point source National Emissions Inventory (NEI). For point sources not updated for the 2016 point source NEI, 2014NEIv2 emissions were carried forward with additional updates provided by the States. Industrial emissions were grown to 2028 according to factors derived from the 2019 Annual Energy Outlook. Controls were applied to reflect relevant New Source Performance Standards (NSPS) rules (e.g., reciprocating internal combustion engines (RICE), natural gas turbines, and process heaters). Airport emissions for 2016 were derived from the 2017 draft National Emissions Inventory (NEI) airport inventory, back projected to 2016 using Federal Aviation Administration (FAA) data. Airport emissions were projected to 2028 using the FAA's Terminal Area Forecast (TAF) data. Alaska rail emissions were developed from data maintained by the Federal Railroad Administration (FRA) and tier fleet mix information from the Association of American Railroads (AAR).

The onroad mobile source emissions were generated using the released version of the Motor Vehicle Emissions Simulator (MOVES2014b). The activity data were temporally allocated based on regional average temporal profiles from the Coordinating Research Council (CRC) A-100 data. The CRC A-100 data were available for the continental United States and did not include AK / HI / PR / VI specifically. The A-100 data included regional average profiles, and those were used in AK/HI (West region average) and PR/VI (South region average). Onroad and nonroad mobile source emissions were created for 2028 using emission factors based on MOVES2014b run for 2028, combined with activity data projected from 2016 to 2028 based on data from the Annual Energy Outlook (AEO) 2018 and state/local-provided data, where available.

Meteorological data from the year 2016 were used to compute the emissions for both 2016 and 2028.

Commercial Marine Vessel (CMV) emissions for ships with Category 1 and Category 2 (i.e., small to medium-sized) engines, as well as ships with Category 3 (i.e., large) engines, were modeled as point sources. All CMV emissions were based on AIS hourly ship data for the year 2017, mapped to 2016 dates and adjusted to represent the year 2016 based on national adjustment factors. CMV emissions were projected to 2028 using region-specific factors for NOx, SO2, and other pollutants. More details are available in the 2016 v1 platform specification sheets (National Emissions Inventory Collaborative, 2020) and the 2017 NEI TSD (U.S. Environmental Protection Agency, 2020b).

The majority of nonpoint source emissions for the year 2016 were used as-is from the 2014NEIv2, except for emissions estimated using census data. Historical population data for 2016 from the US Census were used to project these emissions from the 2014NEIv2 to 2016. Puerto Rico and Hawaii nonpoint emissions were held constant from 2014NEIv2 to 2016. Alaska and Puerto Rico industrial emissions were grown to 2028 according to factors derived from the 2019 Annual Energy Outlook. Portions of the nonpoint sector were grown using factors based on expected grown in human population. Controls were applied to reflect relevant New Source Performance Standards (NSPS) rules (i.e., reciprocating internal combustion engines (RICE), natural gas turbines, and process heaters). Nonpoint agricultural emissions, which includes ammonia (NH_3) and VOC emissions from livestock and fertilizer sources, were not included in this assessment due to a lack of available data for 2016.

The nonpoint area fugitive dust sector consists of fugitive dust particulate matter (PM) emissions from the 2014NEIv2 nonpoint source category. Emissions from paved roads were projected from 2014 to 2016 based on county total vehicle miles traveled (VMT), but emissions from all other sources, including unpaved roads, were held constant. After SMOKE processing, road dust emissions were reduced using a gridded transport fraction file that considers the impact of the roughness of the landscape on the emissions and further reduced at specific hours based on snow cover and precipitation. Paved road dust was grown to 2028 levels based on the growth in VMT from 2016 to 2028. The remainder of the sector including building construction, road construction, agricultural dust, and road dust was held constant. The projected emissions are reduced during modeling according to a transport fraction (newly computed for the beta platform) and a year 2016 meteorology-based (precipitation and snow/ice cover) adjustment as they are for the base year.

Residential wood combustion (RWC) emissions were projected from the 2014NEIv2 values to represent 2016 and 2028 using factors based on EPA's 2011v6.3 emissions modeling platform and implemented into spreadsheet tools by MARAMA. Day-of-year temporalization of these sources for Alaska is based on daily minimum temperature by county and calculated by the SMOKE program GenTPRO, with more general profiles used for Hawaii and Puerto Rico. RWC emissions were projected from 2014 to 2028 using the same spreadsheet tools used to create 2016 emissions. The projected emissions account for growth, retirements, and NSPS.

Point oil and gas emissions were based on the 2016 point source emissions modeling platform. Any sources from the 2014 NEI which were not submitted for 2016 were included for Alaska at their 2014 levels unless they were marked as shut down. Nonpoint oil and gas emissions were estimated from the 2016 Nonpoint Oil and Gas Emission Estimation Tool developed by EPA. State air agencies provided the 2016 oil and gas activity data to EPA. When state data is not supplied, EPA populates the inventory with the best available data. Oil and gas emissions were not projected to year 2028 for Alaska, Hawaii or Puerto Rico.

Annual total emissions are provided by major sector in Appendix D for each of the areas and major pollutants relevant for regional haze.

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 modeling system to simulate 2016 measured concentrations. Model performance results are provided in Appendix A.

The model evaluation was focused on the ability of the model to predict visibility related PM components at Class I areas (represented by IMPROVE monitoring sites). The analysis looked at PM species component performance at IMPROVE and other PM monitoring networks, and performance on the 20% most impaired (and 20% clearest) days[3] at individual IMPROVE sites. This provides a comprehensive assessment of the components that make up visibility performance.

[3] 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.

The measured concentrations of PM components such as sulfate and nitrate on the 20% most impaired days at many Class I areas are extremely small. Some 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 sometimes difficult (without further sensitivity modeling and analysis) to determine if the model is getting the right answer for the right reasons.

Overall, the visibility performance for 2016 was generally good, with some regional exceptions. In different parts of the country, varying PM components contribute to visibility impairment, which also varies by season.

Appendix A contains tables and figures, including individual IMPROVE site PM species component performance information for the 20% most impaired days. Performance issues seen in the 2016 operational performance evaluation indicate uncertainty in the model results at some Class I areas. However, visibility performance at most Class I areas is quite good, adding to confidence in the future year contribution analyses and calculations. Further improvements in emissions inputs, boundary conditions, and model chemistry may help improve model performance in specific regions. More details about how the model compared to measurements of chemically speciated $PM_{2.5}$ and precursors are available in a separate document for Hawaii and Puerto Rico/Virgin Islands (Baker et al., 2020).

3.0 Projection of Future Year 2028 Visibility

The PM predictions from the 2016 and 2028 CMAQ model simulations were used to project 2014-2017[4] IMPROVE visibility data to 2028 following the approach described in EPA's ozone, $PM_{2.5}$ and regional haze modeling guidance (U.S. Environmental Protection Agency, 2018).[5] The SIP Modeling Guidance describes the recommended modeling analysis used to help set reasonable progress goals (RPGs) that reflect the regional haze SIP's long-term strategy containing adopted emissions control measures.

[4] Based on EPA modeling guidance, a five-year average centered on the base modeling year (2014-2018) would be the appropriate ambient data base period. However, as of September 2019, the 2018 IMPROVE data is not available. Therefore, a four-year average (2014-2017) period was used instead. The ambient data can be updated when the final 2018 IMPROVE data becomes available.

[5] The EPA's ozone, $PM_{2.5}$, and regional haze modeling guidance is referred to as "the SIP Modeling Guidance" in the remainder of this document.

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.[6] The baseline for each Class I area is the average visibility (in deciviews) for the years 2000 through 2004.[7] 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.[8] A line drawn between the end of the 2000-2004 baseline period and 2064 (dv/year) shows a uniform rate of progress (URP) or "glidepath" between these two points. The glidepath represents a linear or uniform rate of progress and is the amount of visibility improvement needed in each implementation period to stay on the glidepath. The URP is a framework for consideration but there is no rule requirement to be on or below the glidepath. An example glidepath plot is shown in Figure 3-1.

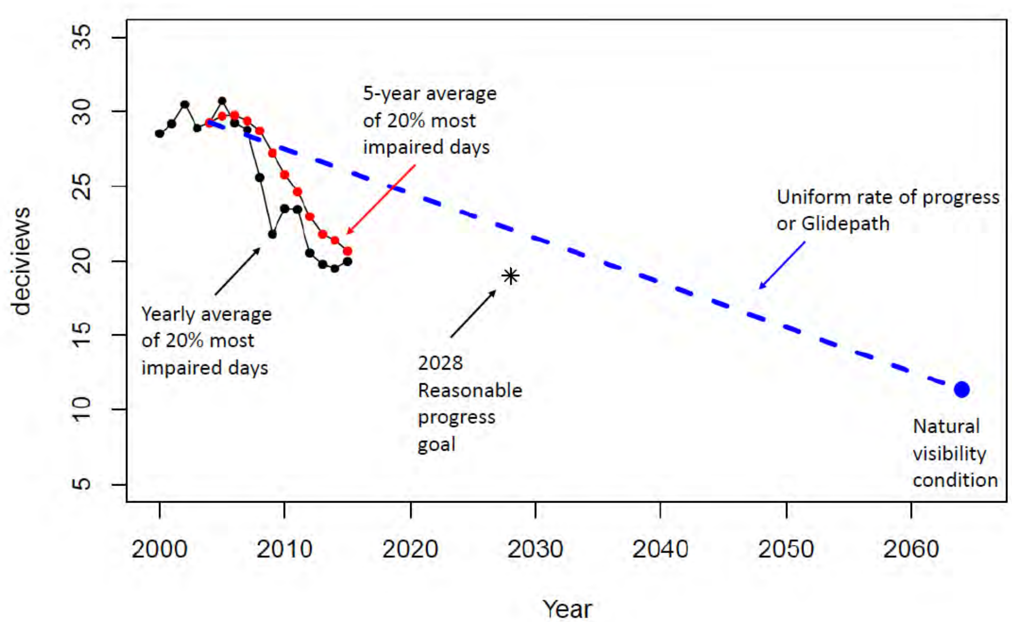

Figure 3-1 *Example Glidepath Plot.*

[6] 40 CFR 51.308(f)(3)(i).

[7] 40 CFR 51.308(f)(1) and definitions in 51.301.

[8] 40 CFR 51.308(f)(1).

The RHR requires states to submit an implementation plan that evaluates and contains measures found necessary to make reasonable progress for implementation periods in approximately ten-year increments. The next regional haze SIP is due in July 2021, for the implementation period which ends in 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 anthropogenically impaired and 20% clearest days at each Class I Area (IMPROVE site).[9] SMAT-CE is an EPA software tool which implements the procedures in the SIP Modeling Guidance to project visibility to a future year.[10]

3.2 Calculation of Visibility

The visibility calculations use the "revised" IMPROVE equation (Pitchford et al., 2007), which 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 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 mass 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.

[9] The base year (2014-2017) IMPROVE data for the 20% most impaired and 20% clearest days was calculated based on the EPA recommended method described in "Technical Guidance for the Second Implementation Period of the Regional Haze Rule." (December 2018).

[10] SMAT-CE is available here: https://www.epa.gov/scram/photochemical-modeling-tools

3.2.1 2000-2018 Visibility

The 2016 base year visibility on the 20% most anthropogenically impaired days and 20% clearest days at each Class I area is estimated by using observed IMPROVE data. The 2000-2018 average annual visibility for the 20% most anthropogenically impaired days is also estimated for each year.

Figures 3-2 to 3-8 below display stacked bar charts detailing the composition of $PM_{2.5}$ on the 20% most impaired and clearest days for light extinction (bext-1) at each IMPROVE monitoring site for the base year 2016. The plots also depict the annual average composition of $PM_{2.5}$ for light extinction from 2000-2018. The plots below are organized by region and display the amount of light extinction due to each species as follows: 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.

Alaska

Alaska has four Class I areas: Denali National Park, Tuxedni National Wildlife Refuge, Simeonof Wilderness Area, and Bering Sea Wilderness Area. There are two IMPROVE monitors associated with Denali National Park - the monitor designated DENA that is across the Park Road from park headquarters and the monitor designated TRCR that is located west of Trapper Creek, Alaska. The DENA monitor is the official monitor for Denali National Park. Tuxedni National Wildlife Refuge is located on a fairly isolated pair of islands in Tuxedni Bay, Cook Inlet in Southcentral Alaska. The original IMPROVE monitor, designated TUXE, for Tuxedni National Wildlife Refuge was installed near Lake Clark National Park to represent conditions at Tuxedni Wilderness Area. This site is on the west side of Cook Inlet, approximately 5 miles from the Tuxedni Wilderness Area. However, in 2014 the property owner and site operator could no longer service the site. A new site, designated KPBO (Kenai Peninsula Borough), was establish roughly 3 miles south of the community of Ninilchik. Simeonof Wilderness Area comprises 25,141 acres located in the Aleutian Chain, 58 miles from the mainland. It is one of 30 islands that make up the Shumagin Group on the western edge of the Gulf of Alaska. An IMPROVE monitor, designated SIME, in the community of Sand Point has been deemed as representative of the wilderness area. Sand Point is approximately 60 miles northwest of the Simeonof Wilderness Area. The Bering Sea Wilderness Area is located off the coast of Alaska about 350 miles southwest of Nome. Hall Island is at the northern tip of the larger St Matthew Island. Due to access difficulties, there is no IMPROVE monitor representing the Bering Sea Wilderness Area.

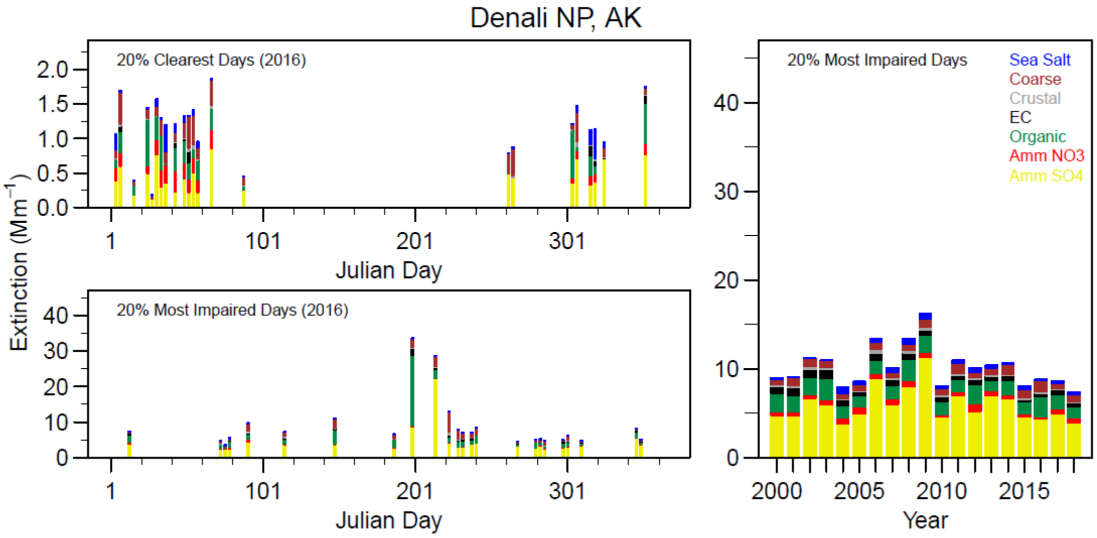

Figure 3-2 *Stacked bar charts detailing the composition of PM2.5 in 2016 on the 20% clearest days (top left) and 20% most impaired days (bottom left) for light extinction at Denali National Park. The right bar chart details the average composition for 2000-2018 for the 20% most impaired days. The plots display the amount of light extinction due to each species as follows from bottom to top: ammonium sulfate (yellow), ammonium nitrate (red), organic mass carbon (green), elemental carbon (black), crustal mass (grey), coarse mass (brown), and sea salt (blue).*

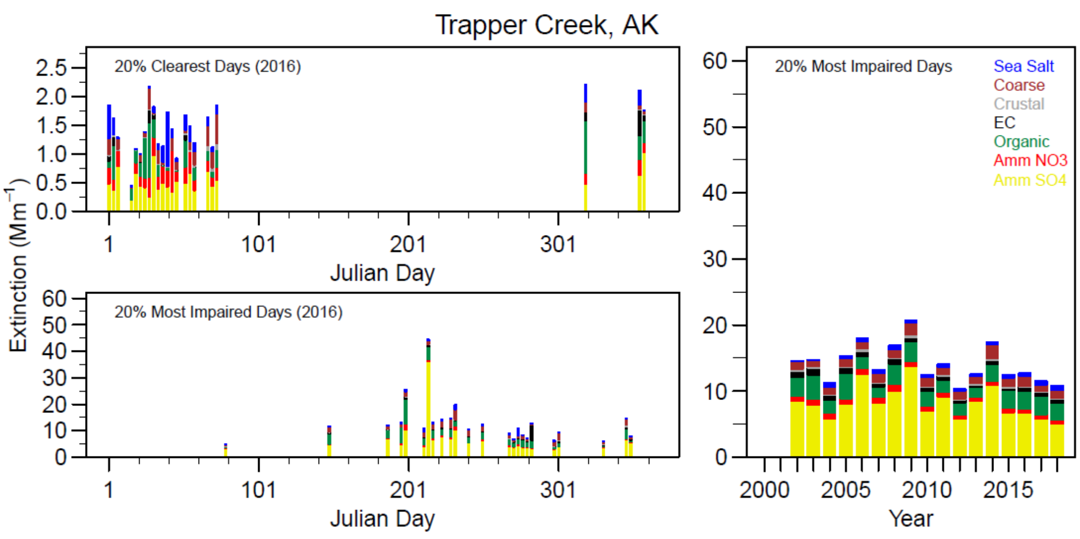

Figure 3-3 *Stacked bar charts detailing the composition of PM2.5 in 2016 on the 20% clearest days (top left) and 20% most impaired days (bottom left) for light extinction at Trapper Creek. The right bar chart details the average composition for 2000-2018 for the 20% most impaired days. The plots display the amount of light extinction due to each species as follows from bottom to top: ammonium sulfate (yellow), ammonium nitrate (red), organic mass carbon (green), elemental carbon (black), crustal mass (grey), coarse mass (brown), and sea salt (blue).*

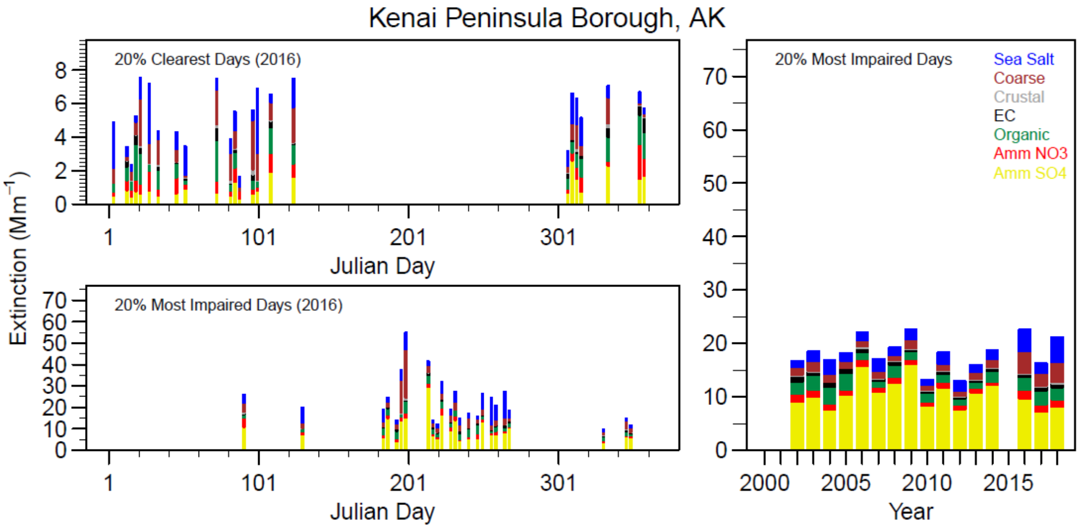

Figure 3-4 *Stacked bar charts detailing the composition of PM2.5 in 2016 on the 20% clearest days (top left) and 20% most impaired days (bottom left) for light extinction at Kenai Peninsula Borough. The right bar chart details the average composition for 2000-2018 for the 20% most impaired days. Data up through 2014 were measured at the TUXE site, data for 2016 and after were measured at the KPBO site. The plots display the amount of light extinction due to each species as follows from bottom to top: ammonium sulfate (yellow), ammonium nitrate (red), organic mass carbon (green), elemental carbon (black), crustal mass (grey), coarse mass (brown), and sea salt (blue).*

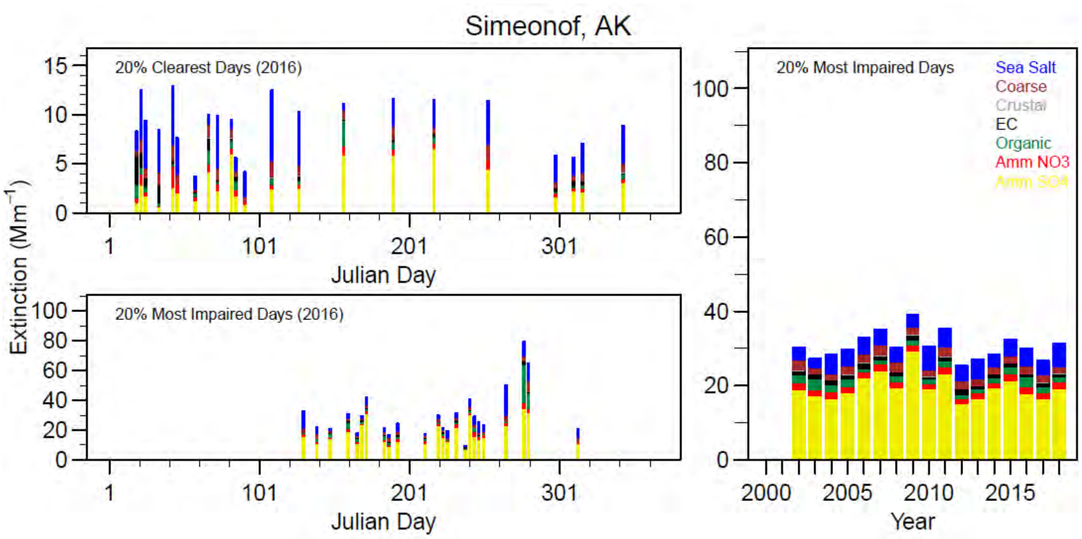

Figure 3-5 *Stacked bar charts detailing the composition of PM2.5 in 2016 on the 20% clearest days (top left) and 20% most impaired days (bottom left) for light extinction at Simeonof. The right bar chart details the average composition for 2000-2018 for the 20% most impaired days. The plots display the amount of light extinction due to each species as follows from bottom to top: ammonium sulfate (yellow), ammonium nitrate (red), organic mass carbon (green), elemental carbon (black), crustal mass (grey), coarse mass (brown), and sea salt (blue).*

Hawaii

Hawaii has IMPROVE monitors at Haleakala National Park (HACR1 and HALE1) and Hawaii Volcanoes National Park (HAVO1). The HALE1 IMPROVE monitor began operation on Maui in 1990 at a site about 3.5 miles outside of Haleakala National Park. In 2007, a second IMPROVE monitor (HACR1) was installed at a higher elevation within the park. The HACR1 site was considered more representative of visibility conditions within Haleakala National Park and replaced the HALE1 monitoring station in 2012. *See* 84 FR 14634 (April 11, 2019). The extinction data presented below indicate a combined site record using conditions at HALE1 from 2000-2007 and 2008-2018 conditions at HACR1. This combined site record is the EPA default and may not reflect the method of combining IMPROVE monitors representing Haleakala National Park in future SIPs.

The identification of the 20% most impaired days for these Hawaii IMPROVE monitors is based on a modification of the statistical approach detailed in the 2018 Technical Guidance on Tracking Visibility Progress for the Second Implementation Period of the Regional Haze Program. This 2018 Technical Guidance described an approach that screens out natural episodic events with high haze levels related to wildfire (based on organic and elemental carbon) or dust storm impacts (based on fine crustal and coarse mass) that are frequently experienced at Class I areas in western half of the Continental U.S. Although this approach effectively screens out natural episodic events at most Class I areas, it is insufficient for the Class I areas in Hawaii which have visibility conditions that are often impacted by volcanic emissions. For the two Class I areas in Hawaii, this approach was modified to also screen out natural episodic events related to volcanic activity (based on sulfate) using the same method used for wildfires and dust storms (episodic threshold determined by the lowest annual 95th percentile daily extinction from 2000-2014 at each site). Extinction values from the new set of 20% most impaired days following this modified approach are shown in Figure 3-6 for combined HALE1/HACR1 site and in Figure 3-7 for HAVO1. Note that this modified approach didn't affect the 20% clearest days.

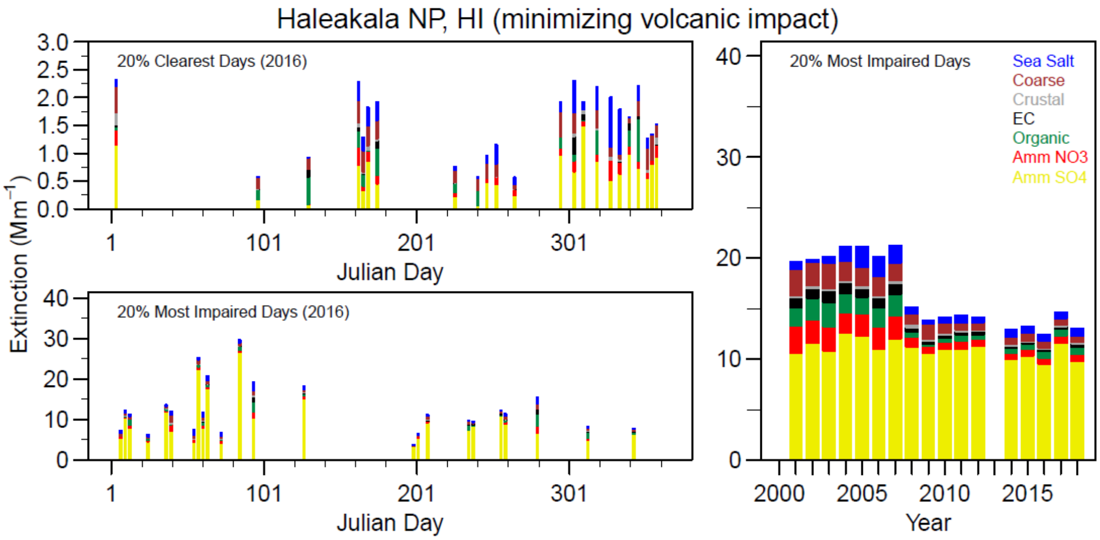

Figure 3-6 *Stacked bar charts detailing the composition of PM2.5 in 2016 on the 20% clearest days (top left) and 20% most impaired days (bottom left) for light extinction at Haleakala National Park. The right bar chart details the average composition for 2000-2018 for the 20% most impaired days. The plots display the amount of light extinction due to each species as follows from bottom to top: ammonium sulfate (yellow), ammonium nitrate (red), organic mass carbon (green), elemental carbon (black), crustal mass (grey), coarse mass (brown), and sea salt (blue).*

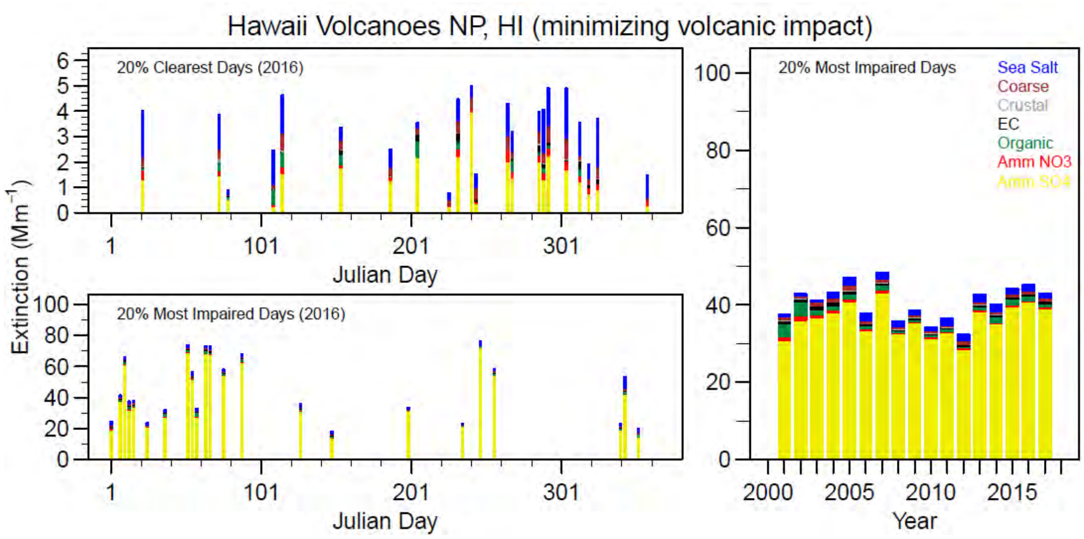

Figure 3-7 *Stacked bar charts detailing the composition of PM2.5 in 2016 on the 20% clearest days (top left) and 20% most impaired days (bottom left) for light extinction at Hawaii Volcanoes National Park. The right bar chart details the average composition for 2000-2018 for the 20% most impaired days. The plots display the amount of light extinction due to each species as follows from bottom to top: ammonium sulfate (yellow), ammonium nitrate (red), organic mass carbon (green), elemental carbon (black), crustal mass (grey), coarse mass (brown), and sea salt (blue).*

Virgin Islands

The Virgin Islands has one IMPROVE monitor, located at Virgin Islands National Park (VIIS1).

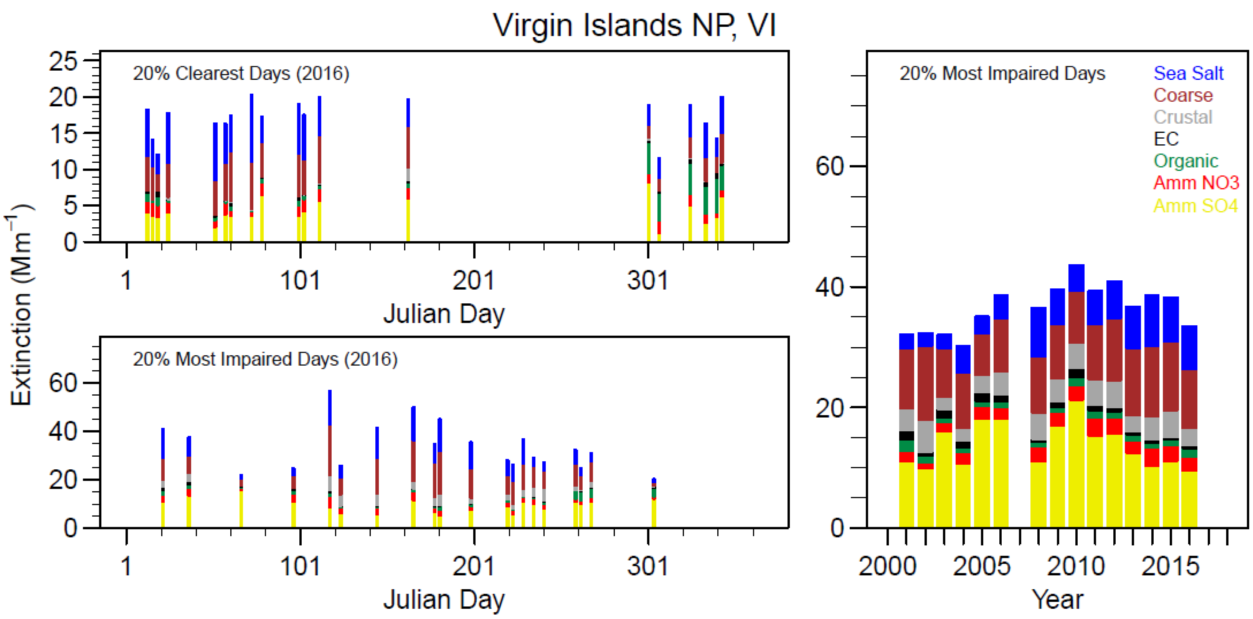

Figure 3-8 *Stacked bar charts detailing the composition of PM2.5 in 2016 on the 20% clearest days (top left) and 20% most impaired days (bottom left) for light extinction at Virgin Islands National Park. The right bar chart details the average composition for 2000-2018 for the 20% most impaired days. The plots display the amount of light extinction due to each species as follows from bottom to top: ammonium sulfate (yellow), ammonium nitrate (red), organic mass carbon (green), elemental carbon (black), crustal mass (grey), coarse mass (brown), and sea salt (blue).*

3.2.2 2028 Visibility

The visibility projections follow the procedures in section 5 of the SIP 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 2016, the ambient IMPROVE data should be from the 2014-2018 period.[11] However, since 2018 IMPROVE data was not available in the attainment test software tool, the most recent four-year average 2014-2017 base period was used.

The 2028 future year visibility on the 20% most anthropogenically impaired days and 20% clearest days at each Class I area is estimated by using the observed IMPROVE data (2014-2017) and the relative *percent modeled* change in PM species between 2016 and 2028. The process is described in the following six steps (see the SIP 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 (four years, 2014-2017 in this case) and rank the days on this indicator.[12] 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 (2016) emissions and future year (2028) emissions. Use the resulting information to develop site-specific relative response factors (RRFs) for each component of PM[13] identified in the "revised"

[11] 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 ambient data averaging calculation is a 5-year mean, where each year counts equally (unlike the 5-year weighted average values recommended for the ozone and $PM_{2.5}$ attainment test).

[12] The EPA recommended 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 Technical Guidance on Tracking Visibility Progress for the Second Implementation Period of the Regional Haze Program.

[13] 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.

IMPROVE equation. The RRFs are an average percent change in species concentrations based on the *measured* 20% most impaired and 20% clearest days from 2016 (the calendar days from 2016 identified from the IMPROVE data above are matched by day to the modeled days).

4) Multiply the species-specific RRFs by the measured daily species concentration data during the 2014-2017 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 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 1-1. 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
Temporal adjustment at monitor	3 x 3
Start monitor year	2014
End monitor year	2017
Base Model year	2016
Minimum years required for a valid monitor	1

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 (2014-2017) and future year (2028).

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 (2014-2017) and future year (2028)

Class I Area Name	**IMPROVE Site ID**	**Base Year (2014-2017) 20% Clearest Days (dv)**	**Future Year (2028) 20% Clearest Days (dv)**	**Base Year (2014-2017) 20% Most Impaired Days (dv)**	**Future Year (2028) 20% Most Impaired Days (dv)**
Denali NP	TRCR1	3.34	3.32	8.99	8.95
Denali NP	DENA1	2.19	2.16	6.86	6.84
Haleakala Crater NP	HALE1/HACR1	0.51	0.50	7.70	7.55
Hawaii Volcanoes NP	HAVO1	3.50	3.49	16.31	16.03
Tuxedni National Wildlife Refuge	KPBO1/TUXE1	4.62	4.23	11.43	10.9
Simeonof Wilderness Area	SIME1	7.68	7.42	13.86	13.43
Virgin Islands NP	VIIS1	9.90	9.7	15.45	15.14

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.[14] 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

[14] The projected 2028 visibility level is compared to the "unadjusted" glidepath for each Class I area. In this calculation, no adjustments have been made for impacts from international anthropogenic sources or wildland prescribed fires.

simple equation. The following formula was used to calculate the 2028 unadjusted glidepath value:

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).[15] Both "adjusted" and "unadjusted" glidepath values for 2028 are also provided. The observed 2014-2017 values and projected 2028 values are repeated from Table 3-2.

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

Class I Area Name	State	IMPROVE Site ID	Observed 00-04 Baseline 20% Most Impaired Days(dv)	Projected 2028 Impairment 20% Most Impaired Days(dv)	2028 Unadjusted Glidepath 20% Most Impaired Days(dv)	2028 Adjusted Glidepath 20% Most Impaired Days(dv)	Natural Conditions 20% Most Impaired Days (dv)	Adjusted Natural Conditions 20% Most Impaired Days (dv)
Denali NP	AK	TRCR1	9.16	8.95	8.05	8.52	6.38	7.55
Denali NP	AK	DENA1	7.06	6.84	6.15	6.47	4.79	5.60
Haleakala Crater NP	HI	HALE1/ HACR1	10.94	7.55	8.73	9.93	5.41	8.43
Hawaii Volcanoes NP	HI	HAVO1	15.6	16.03	12.01	15.06	6.62	14.26
Tuxedni National Wildlife Refuge	AK	KPBO1/ TUXE1	10.47	10.9	9.07	10.25	6.96	9.92
Simeonof Wilderness Area	AK	SIME1	13.67	13.43	11.6	13.35	8.49	12.86
Virgin Islands NP	VI	VIIS1	14.29	15.14	11.99	13.05	8.53	11.2

[15] 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.

The 2028 future year projected deciview values can be compared to the unadjusted glidepath for 2028. 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.[16] The RHR provides flexibility regarding adjustments of the glideslope related to international and natural contribution. Details about the approach used to estimate an adjusted glideslope are provided in section 3.4. Glideslopes are shown for each of the Class I areas in Figures 3-9-1 to 3-9-3.

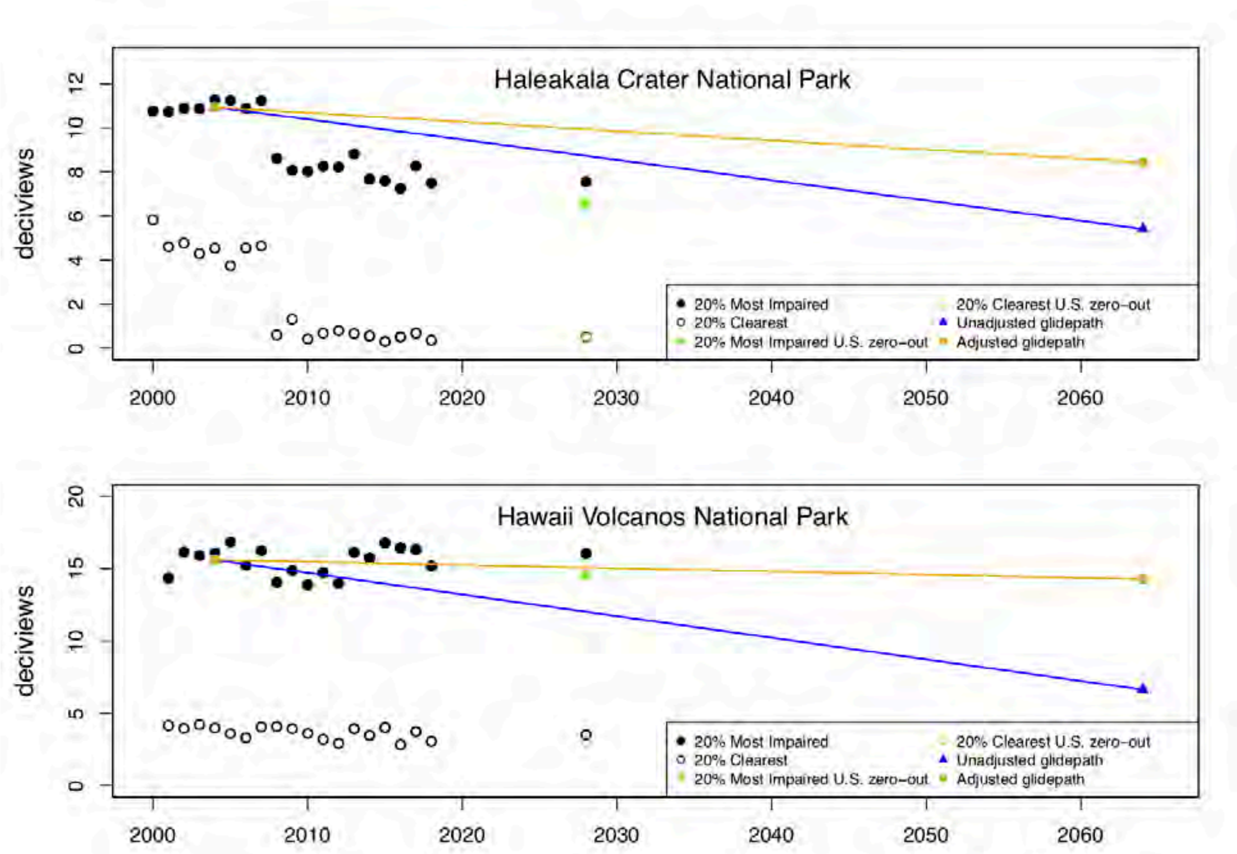

Figure 3-9-1. Unadjusted (blue triangle) and adjusted (orange square) glidepath (in deciviews) at each Class I area in Hawaii. The closed black circles represent the 20% most impaired days and the open black circles are the 20% clearest days. The green dots represent the 2028 RPG for the sensitivity simulation where all U.S. emissions were zeroed-out.

[16] See 40 CFR 51.308(f)(3)(ii) and (iii)

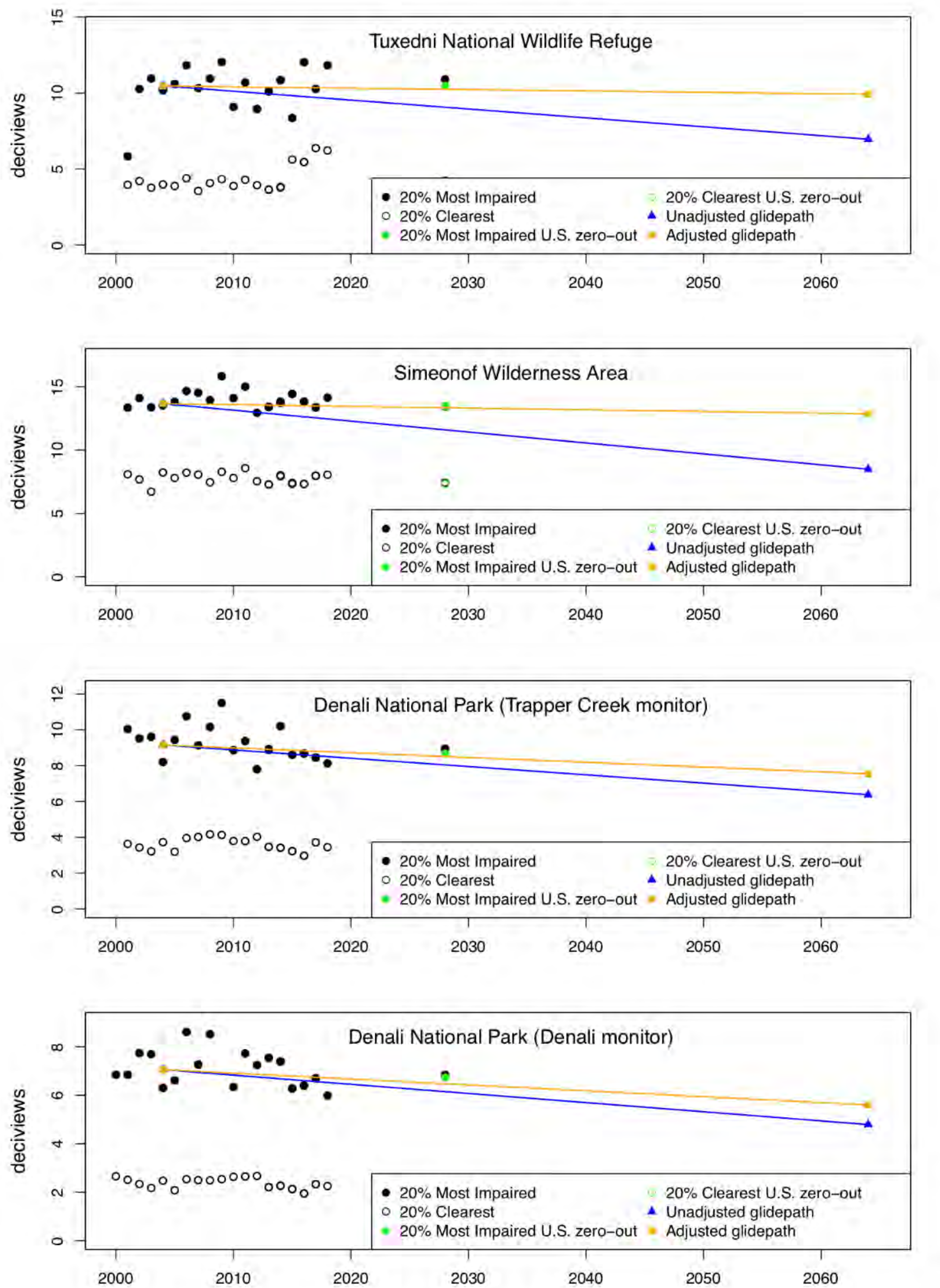

Figure 3-9-2. Unadjusted (blue triangle) and adjusted (orange square) glidepath (in deciviews) at each Class I area in Alaska. The closed black circles represent the 20% most impaired days and the open black circles are the 20% clearest days. The green dots represent the 2028 RPG for the sensitivity simulation where all U.S. emissions were zeroed-out.

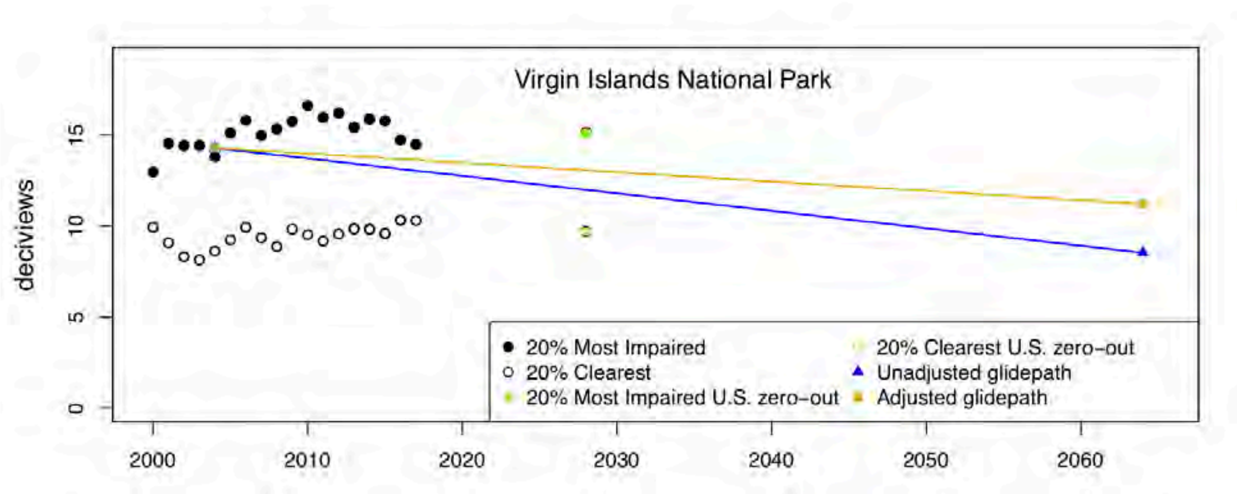

Figure 3-9-3. Unadjusted (blue triangle) and adjusted (orange square) glidepath (in deciviews) at each Class I area in the Virgin Islands. The closed black circles represent the 20% most impaired days and the open black circles are the 20% clearest days. The green dots represent the 2028 RPG for the sensitivity simulation where all U.S. emissions were zeroed-out.

3.4 Contribution from International & U.S. anthropogenic sources

Visibility at Class I areas is impacted not only by natural and anthropogenic emissions from within the U.S., but also by natural and anthropogenic *international* emissions. Due to the fact that international anthropogenic emissions are beyond the control of states preparing regional haze SIPs, the Regional Haze Rule allows states to optionally propose an adjustment of the 2064 URP endpoint to account for international anthropogenic impacts, if the adjustment has been developed using scientifically valid data and methods.[17] The URP can be adjusted by adding an estimate of the visibility impact of international anthropogenic sources to the value of the natural visibility conditions to get an adjusted 2064 endpoint. See the Technical Guidance on Tracking Visibility Progress[18] for more details. The regional haze rule also allows for an optional adjustment to the URP relating to certain prescribed fires. However, since prescribed fire activity is anticipated to be uncommon in these areas in 2028, only international anthropogenic contribution was considered as part of this analyses.

The EPA modeling calculates estimated Class I area (IMPROVE site) contributions from

[17] See 40 CFR 51.308(f)(1)(vi)

[18] "Technical Guidance on Tracking Visibility Progress for the Second Implementation Period of the Regional Haze Program", December 20, 2018, available at: https://www.epa.gov/visibility/technical-guidance-tracking-visibility-progress-second-implementation-period-regional

international anthropogenic emissions using hemispheric scale CMAQ zero-out model simulations. The hemispheric CMAQ zero-out simulations provided an estimate of international anthropogenic SO_2 emissions to sulfate related extinction. The estimate of international anthropogenic sulfate was added to the 2064 goal at each of these Class I areas to provide an alternative, or "adjusted" glideslope. Other international anthropogenic emissions were not added to the 2064 goal for several reasons: because non-linearity of secondary organics and nitrate are difficult to interpret, because sulfate was the dominant component of observed visibility at these Class I areas, and commercial shipping is the largest component of the global inventory near these Class I areas.

The estimate of international anthropogenic contribution is based on 2016 emissions and may not reflect all anticipated reductions in certain sectors such as commercial marine. Commercial marine emissions are expected to be lower in 2028 than 2016 which means this assumption may be over-stating international contribution to the 2064 endpoint. This adjustment to the international contribution would likely result in a smaller increment added to the 2064 goal and a steeper adjusted glideslope. However, the analysis is not considering the contribution of international emissions to nitrate or primary PM2.5 components. The inclusion of these species might increase the international contribution and increase the increment added to the 2064 goal to some extent.

Additional information about international and U.S. anthropogenic emission contribution was provided by model simulations where U.S. anthropogenic emissions were zeroed out. U.S. anthropogenic sources were any point, mobile, or area source located in the U.S. or territories. This included Class 1 and 2 commercial marine vessels but not Class 3 vessels.

4.0 References

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Appendix A Model Performance Evaluation – Alaska

A.1 Spatial Plots of Average Model Predictions on the Most Impaired Days

The plots in this section show average daily average measurements and model predictions for the major components of total PM2.5 mass aggregated over the most impaired days in 2016 at each of the Class I areas (left panels). The difference between the 2028 and 2016 simulations are also shown (middle panels) and the difference between the 2028 simulation and 2028 simulation with zero U.S. anthropogenic emissions (right panels).

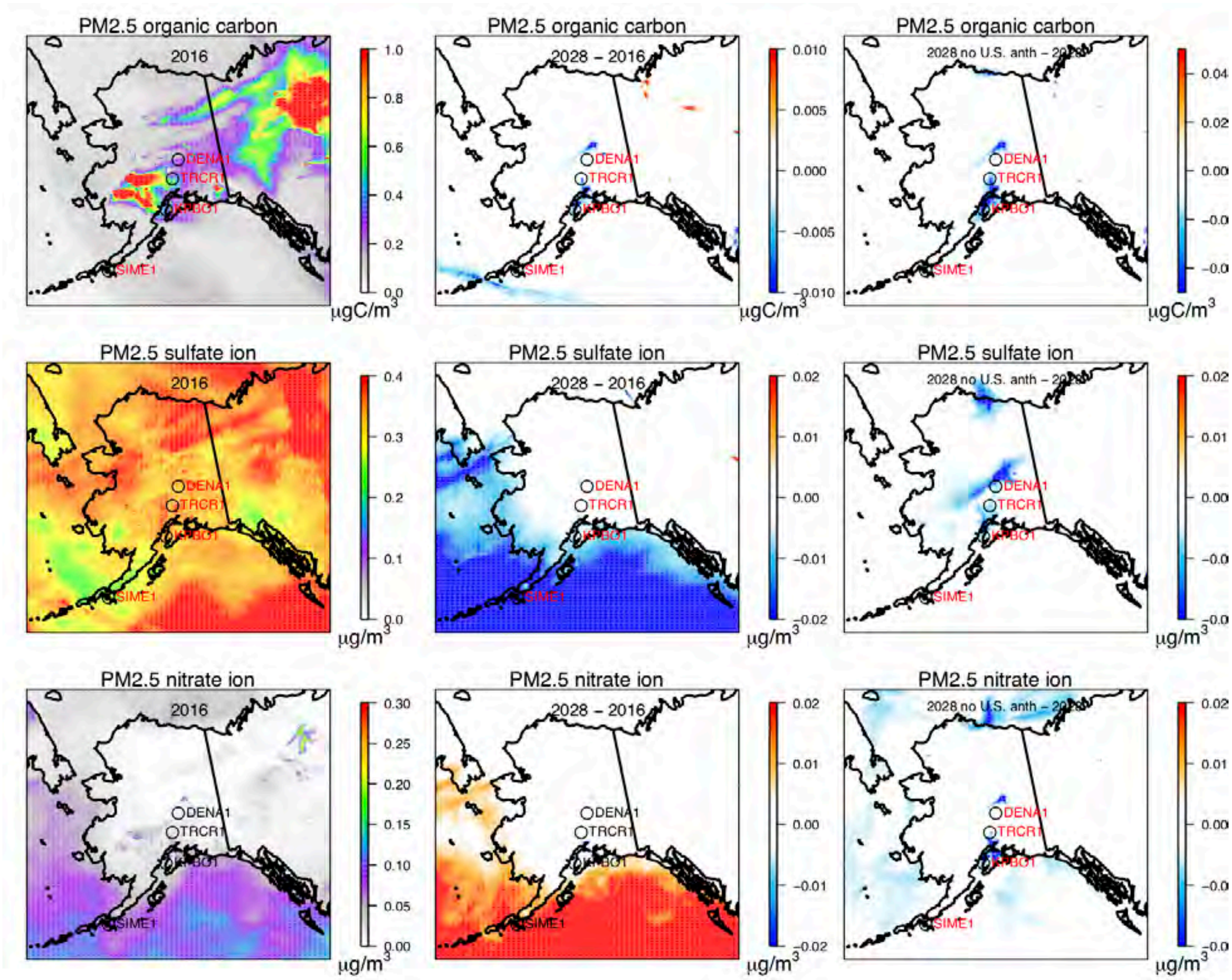

Figure A-1 *Spatial plots showing the average model predictions for $PM_{2.5}$ organic carbon (top three panels), $PM_{2.5}$ sulfate ion (middle three panels), and $PM_{2.5}$ nitrate ion (bottom three panels) on the 20% worst days at Denali National Park. The left panels depict concentrations for year 2016, the middle panels depict the differences in concentrations for year 2028 – 2016, and the right panels depict the differences in concentrations for year 2028 with no anthropogenic influences minus year 2028.*

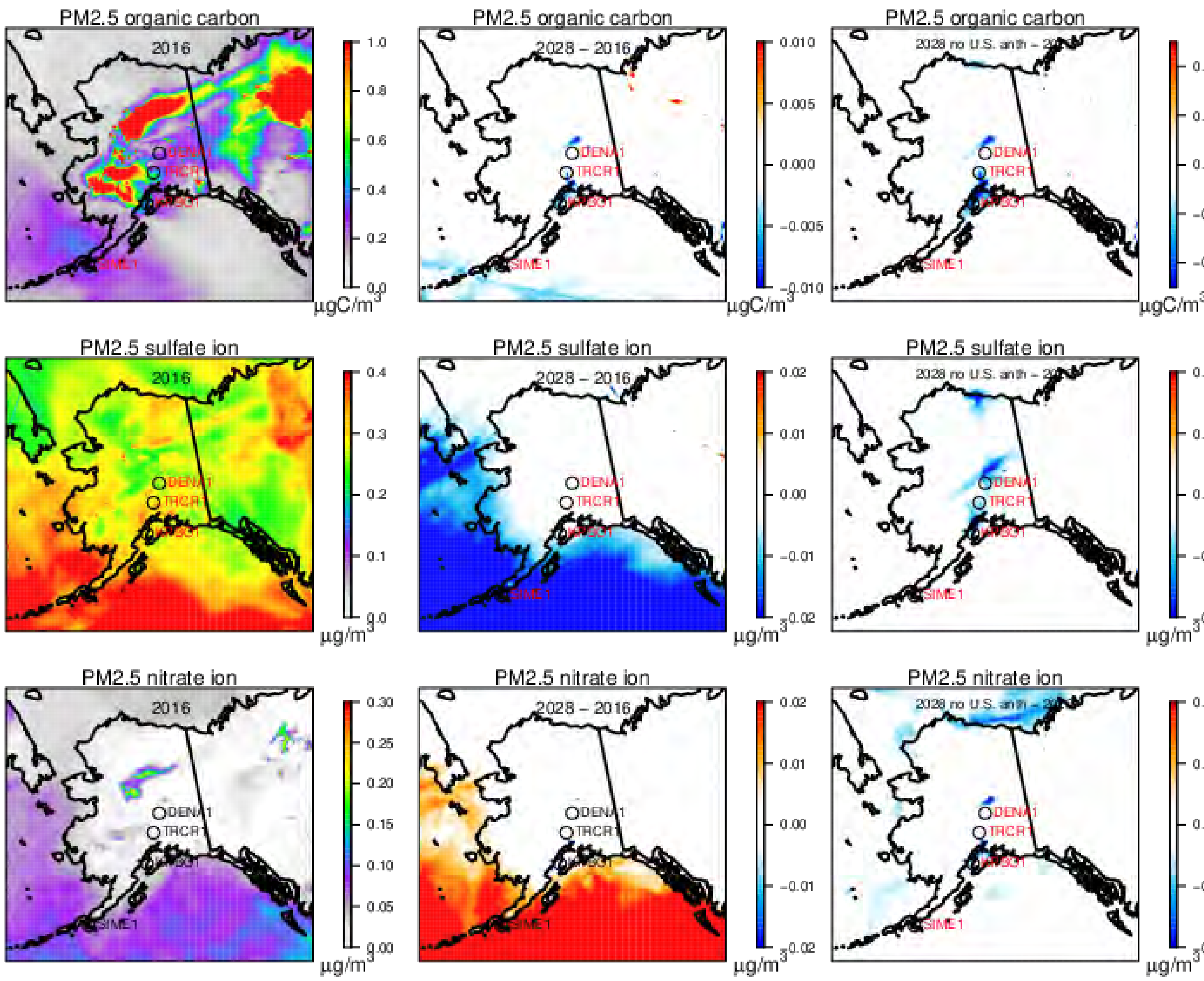

Figure A-2 *Spatial plots showing the average model predictions for $PM_{2.5}$ organic carbon (top three panels), $PM_{2.5}$ sulfate ion (middle three panels), and $PM_{2.5}$ nitrate ion (bottom three panels) on the 20% worst days at Trapper Creek. The left panels depict concentrations for year 2016, the middle panels depict the differences in concentrations for year 2028 – 2016, and the right panels depict the differences in concentrations for year 2028 with no anthropogenic influences minus year 2028.*

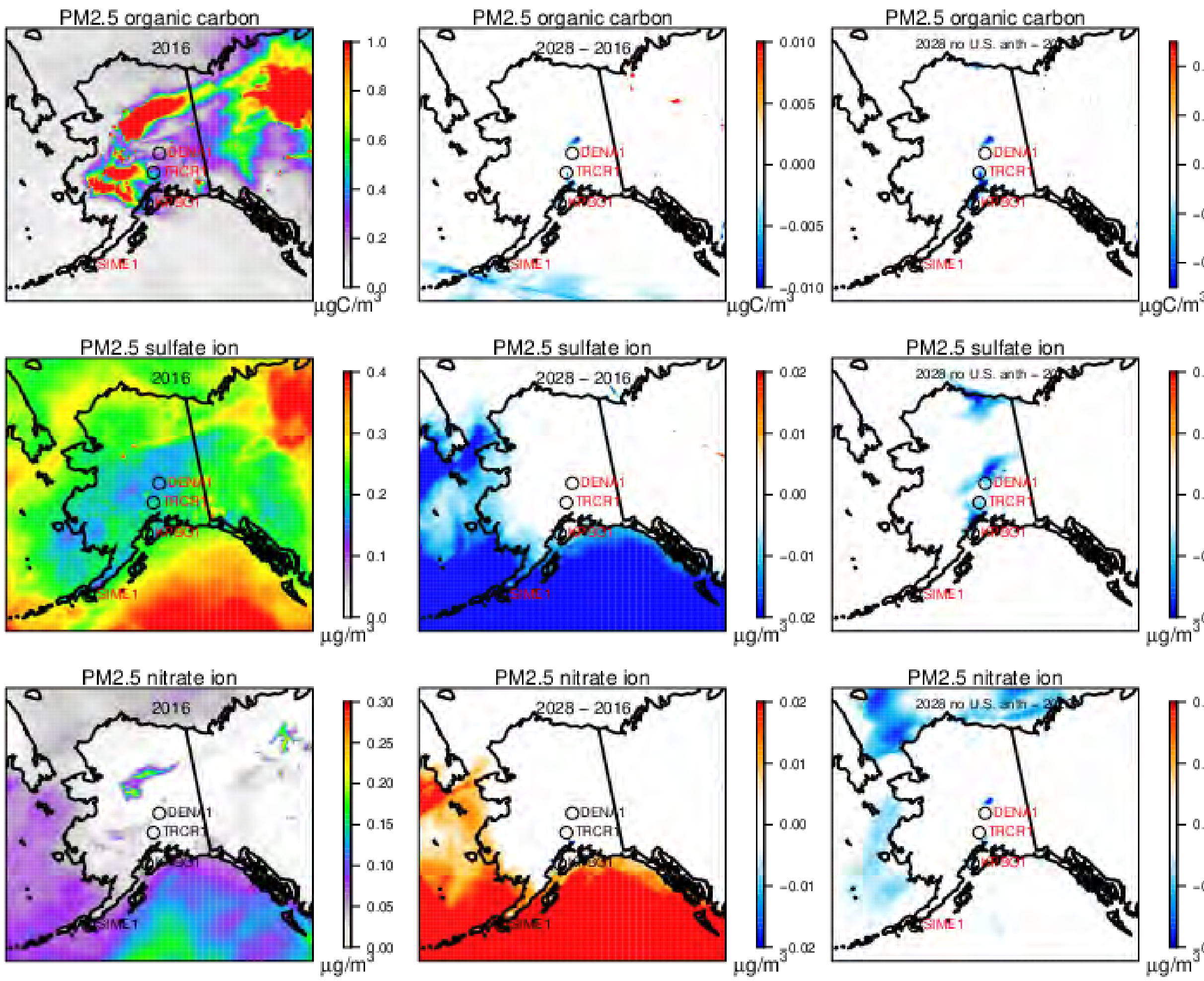

Figure A-3 *Spatial plots showing the average model predictions for $PM_{2.5}$ organic carbon (top three panels), $PM_{2.5}$ sulfate ion (middle three panels), and $PM_{2.5}$ nitrate ion (bottom three panels) on the 20% worst days at Kenai Peninsula Borough.*

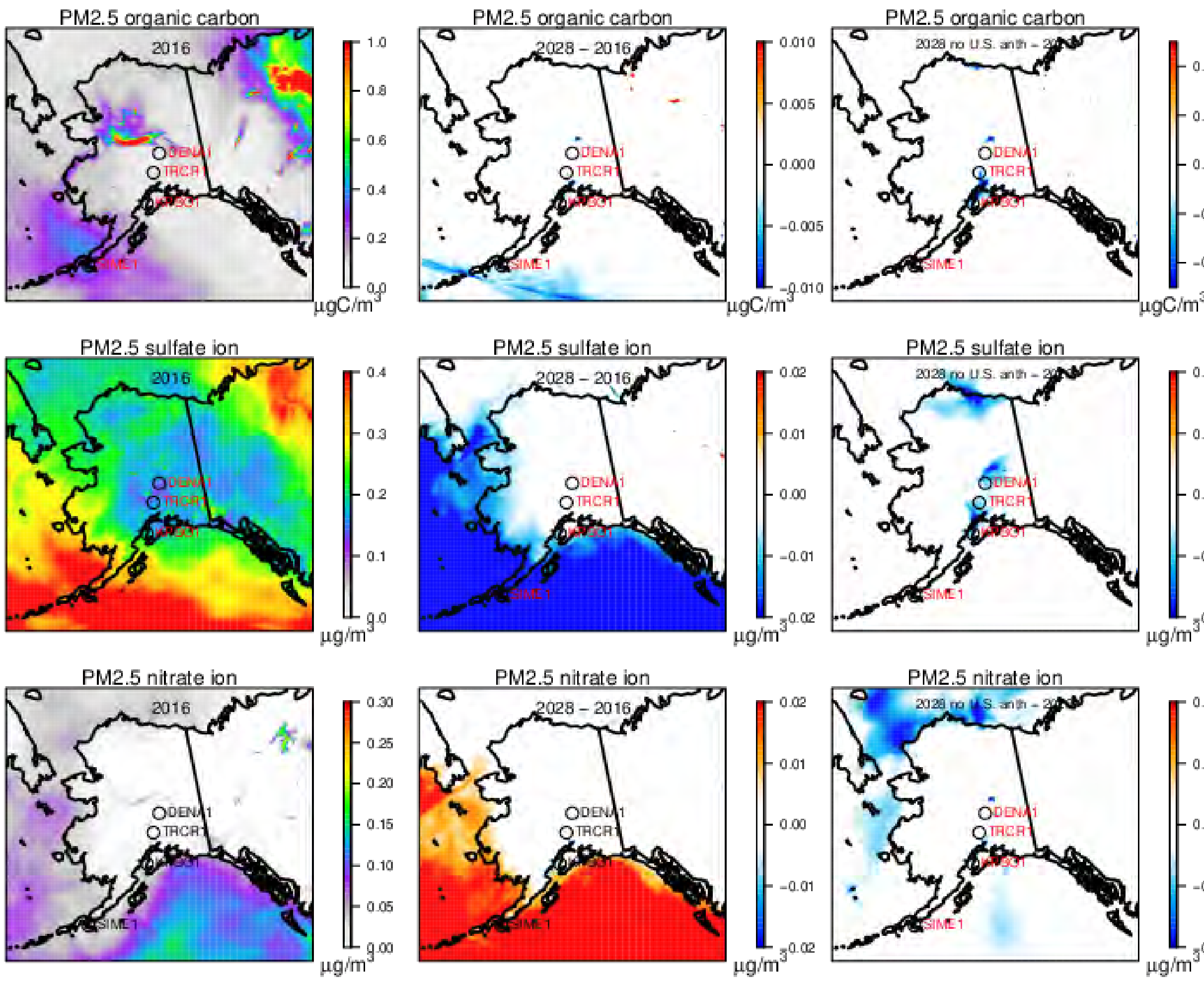

Figure A-4 *Spatial plots showing the average model predictions for $PM_{2.5}$ organic carbon (top three panels), $PM_{2.5}$ sulfate ion (middle three panels), and $PM_{2.5}$ nitrate ion (bottom three panels) on the 20% worst days at Simeonof Wilderness Area.*

A.2 Time Series for 2016

The plots in this section show daily average measurements and model predictions for the major components of total PM2.5 mass at each of the Class I areas.

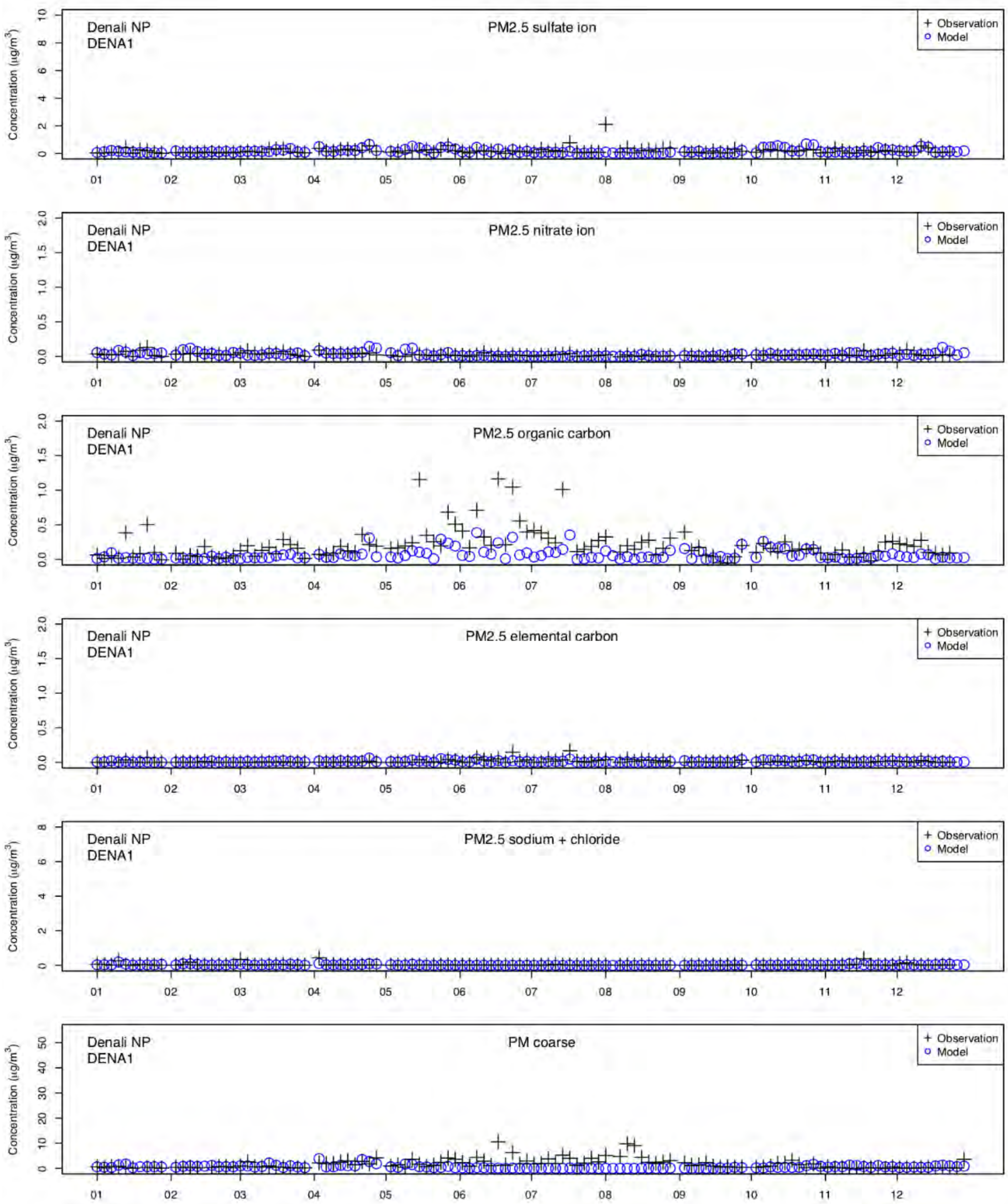

Figure A-5 *Time series plots for 2016 comparing model predictions (blue circles) with IMPROVE monitor measurements (black crosses) for* $PM_{2.5}$ *sulfate ion (top panel),* $PM_{2.5}$ *nitrate ion (second panel),* $PM_{2.5}$ *organic carbon (third panel),* $PM_{2.5}$ *elemental carbon (fourth panel), NaCl (fifth panel), and PM coarse (bottom panel) at Denali National Park.*

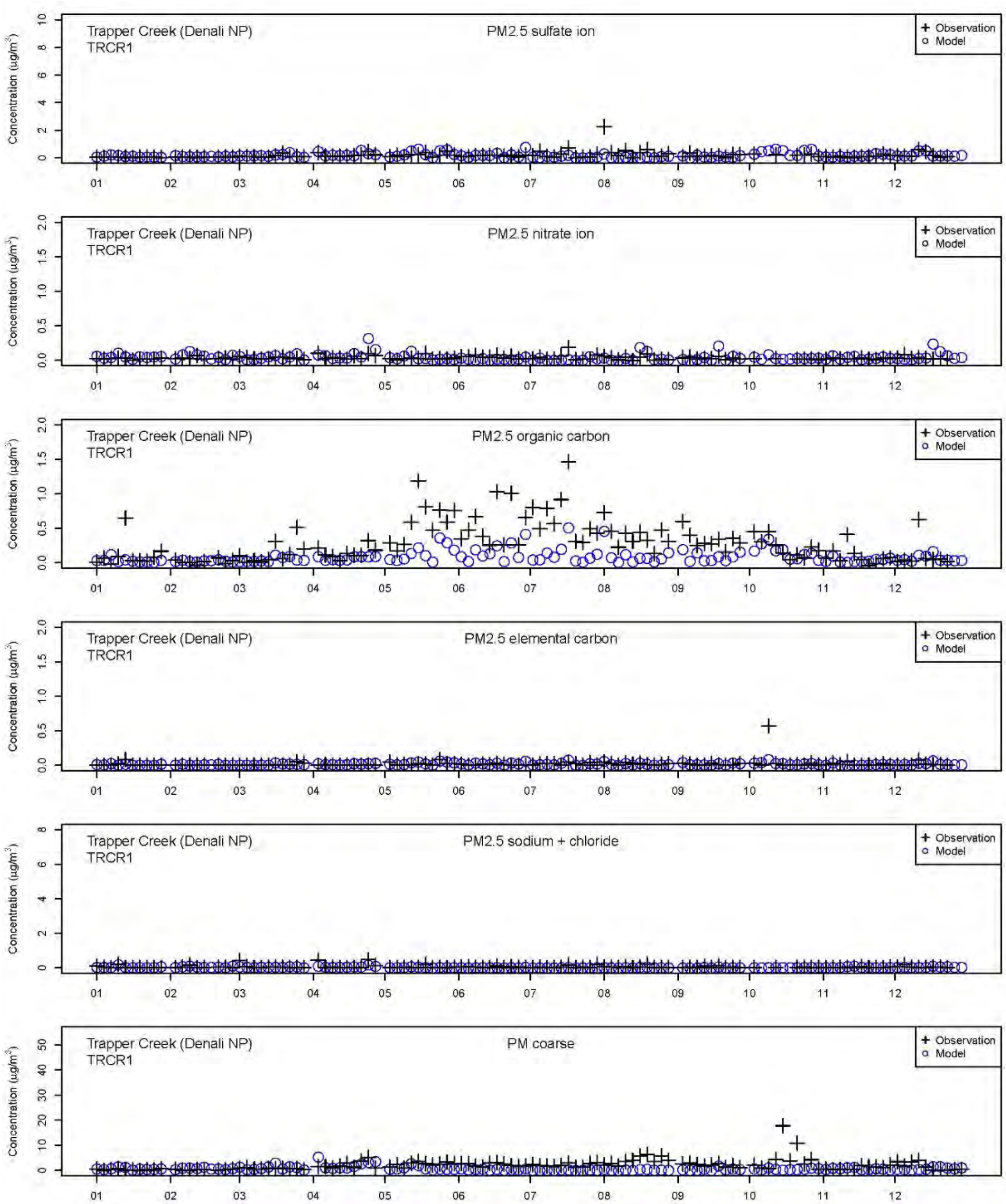

Figure A-6 *Time series plots for 2016 comparing model predictions (blue circles) with IMPROVE monitor measurements (black crosses) for $PM_{2.5}$ sulfate ion (top panel), $PM_{2.5}$ nitrate ion (second panel), $PM_{2.5}$ organic carbon (third panel), $PM_{2.5}$ elemental carbon (fourth panel), NaCl (fifth panel), and PM coarse (bottom panel) at Trapper Creek/Denali National Park.*

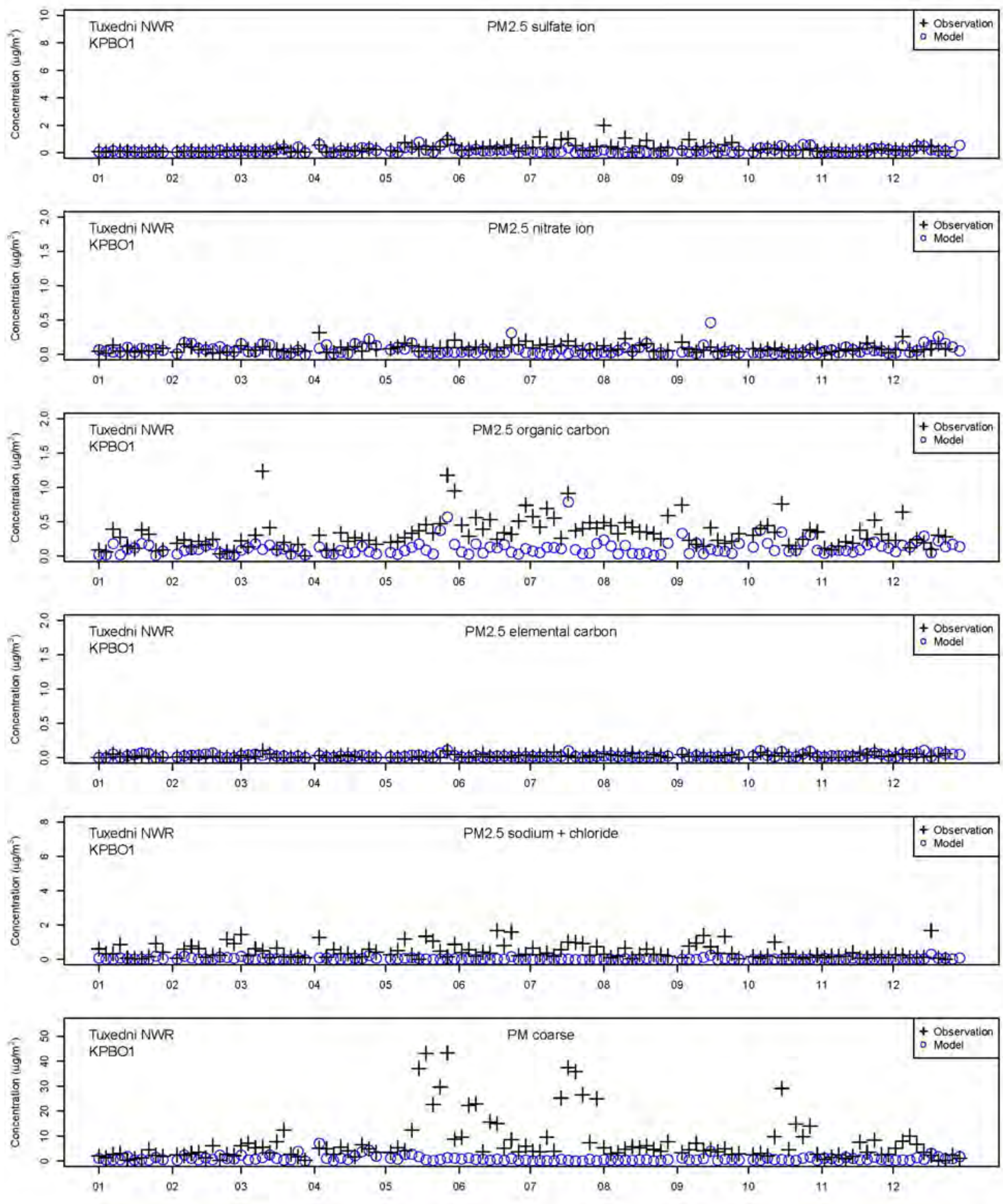

Figure A-7 *Time series plots for 2016 comparing model predictions (blue circles) with IMPROVE monitor measurements (black crosses) for $PM_{2.5}$ sulfate ion (top panel), $PM_{2.5}$ nitrate ion (second panel), $PM_{2.5}$ organic carbon (third panel), $PM_{2.5}$ elemental carbon (fourth panel), NaCl (fifth panel), and PM coarse (bottom panel) at Kenai Peninsula Borough.*

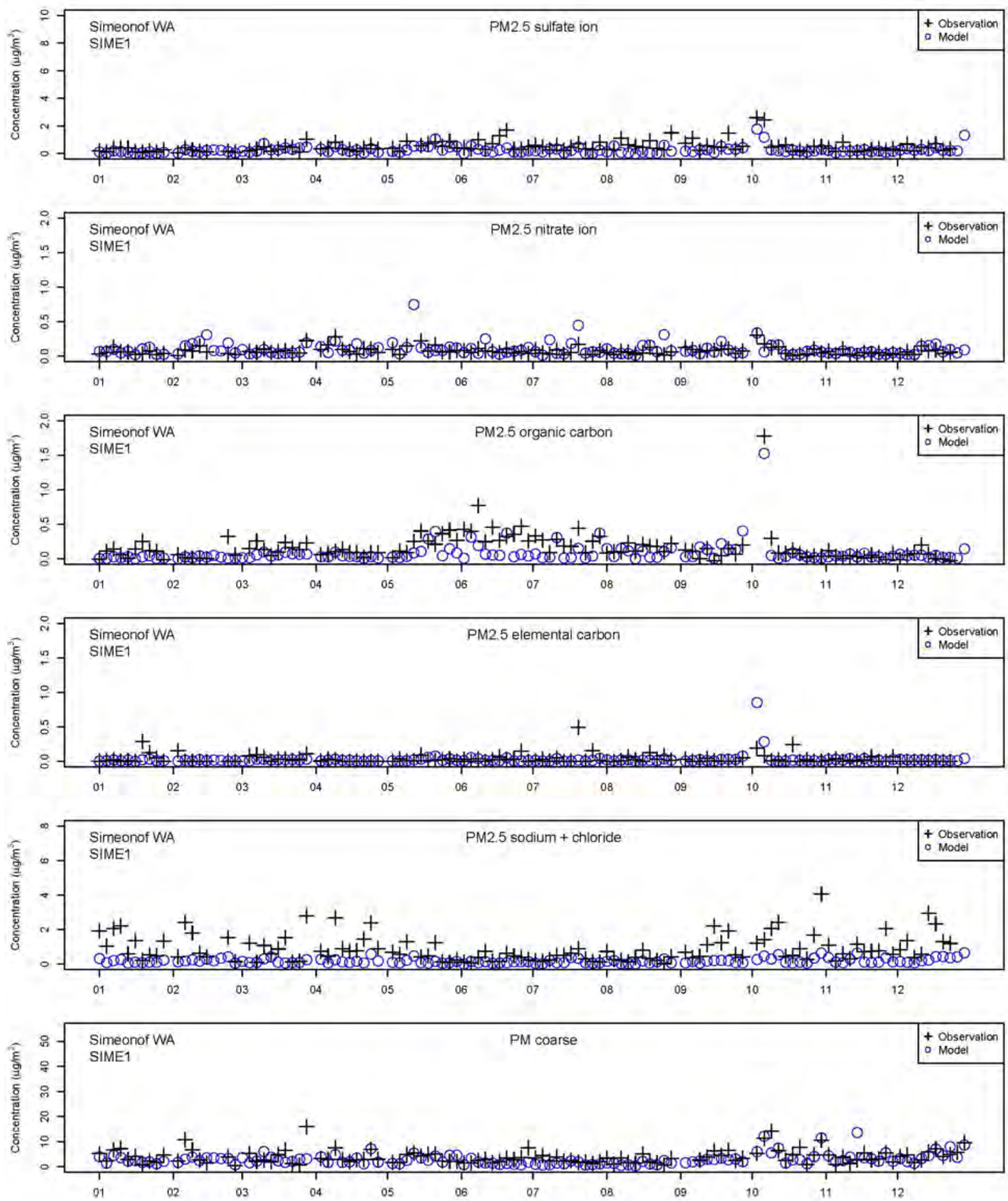

Figure A-8 *Time series plots for 2016 comparing model predictions (blue circles) with IMPROVE monitor measurements (black crosses) for $PM_{2.5}$ sulfate ion (top panel), $PM_{2.5}$ nitrate ion (second panel), $PM_{2.5}$ organic carbon (third panel), $PM_{2.5}$ elemental carbon (fourth panel), NaCl (fifth panel), and PM coarse (bottom panel) at Simeonof Wilderness Area.*

A.3 Particulate Matter Composition on Clearest and Most Impaired Days in 2016

The plots in this section show average daily average measurements and model predictions for the major components of total PM2.5 mass aggregated over the most and least impaired days in 2016 at each of the Class I areas.

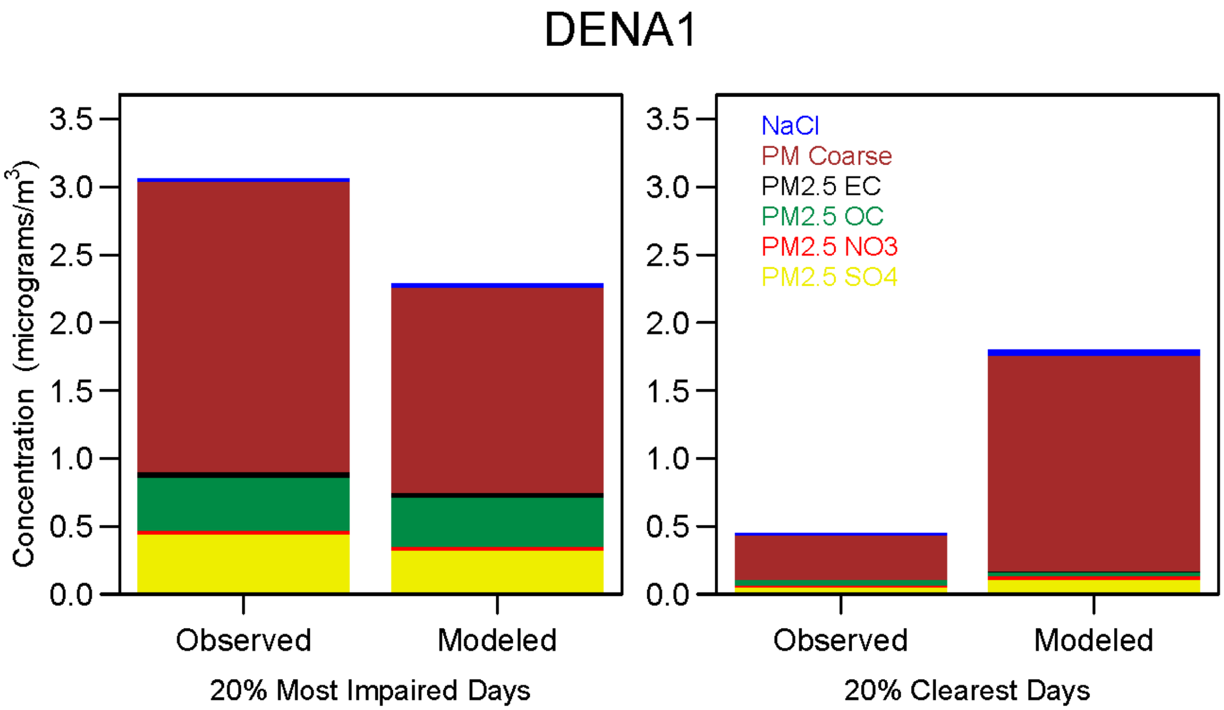

Figure A-9 *Stacked bar charts detailing the average composition of speciated particulate matter in 2016 on the 20% most impaired days (right) and 20% clearest days (right) at Denali National Park. The plots display concentration from bottom to top for the following:* $PM_{2.5}$ *sulfate (yellow),* $PM_{2.5}$ *nitrate (red),* $PM_{2.5}$ *organic carbon (green),* $PM_{2.5}$ *elemental carbon (black), PM coarse (brown), and sea salt (blue).*

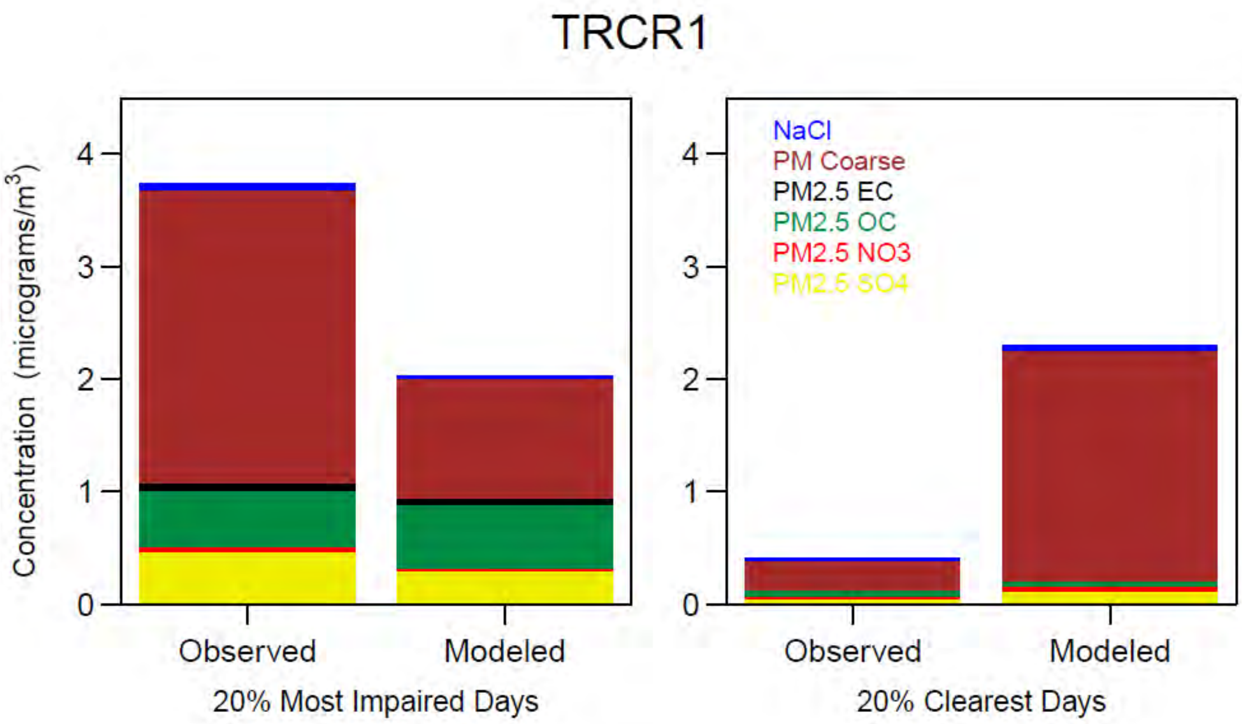

Figure A-10 *Stacked bar charts detailing the average composition of speciated particulate matter in 2016 on the 20% most impaired days (right) and 20% clearest days (right) at Trapper Creek. The plots display concentration from bottom to top for the following: $PM_{2.5}$ sulfate (yellow), $PM_{2.5}$ nitrate (red), $PM_{2.5}$ organic carbon (green), $PM_{2.5}$ elemental carbon (black), PM coarse (brown), and sea salt (blue).*

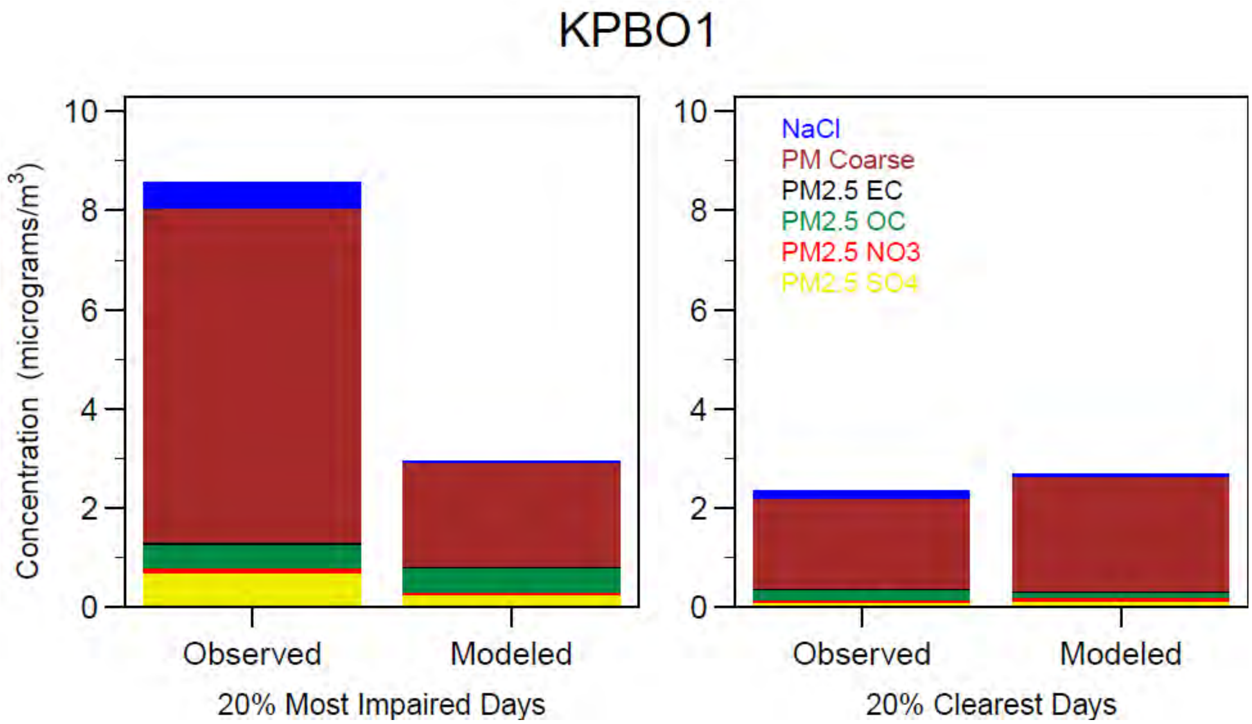

Figure A-11 *Stacked bar charts detailing the average composition of speciated particulate matter in 2016 on the 20% most impaired days (right) and 20% clearest days (right) at Kenai Peninsula Borough. The plots display concentration from bottom to top for the following:* $PM_{2.5}$ *sulfate (yellow),* $PM_{2.5}$ *nitrate (red),* $PM_{2.5}$ *organic carbon (green),* $PM_{2.5}$ *elemental carbon (black), PM coarse (brown), and sea salt (blue).*

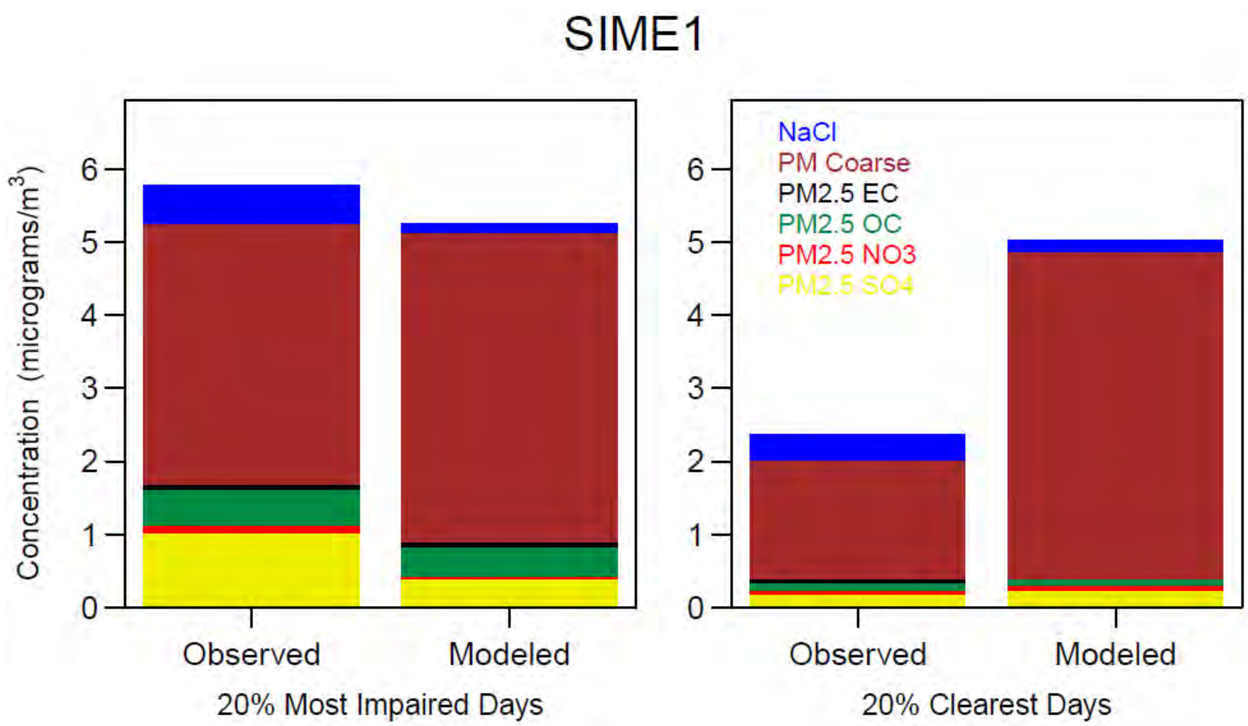

Figure A-12 *Stacked bar charts detailing the average composition of speciated particulate matter in 2016 on the 20% most impaired days (right) and 20% clearest days (right) at Simeonof Wilderness Area. The plots display concentration from bottom to top for the following: $PM_{2.5}$ sulfate (yellow), $PM_{2.5}$ nitrate (red), $PM_{2.5}$ organic carbon (green), $PM_{2.5}$ elemental carbon (black), PM coarse (brown), and sea salt (blue).*

Appendix B Model Performance Evaluation – Hawaii

B.1 Spatial Plots of Average Model Predictions on the Most Impaired Days

The plots in this section show average daily average measurements and model predictions for the major components of total PM2.5 mass aggregated over the most impaired days in 2016 at each of the Class I areas (left panels). The difference between the 2028 and 2016 simulations are also shown (middle panels) and the difference between the 2028 simulation and 2028 simulation with zero U.S. anthropogenic emissions (right panels).

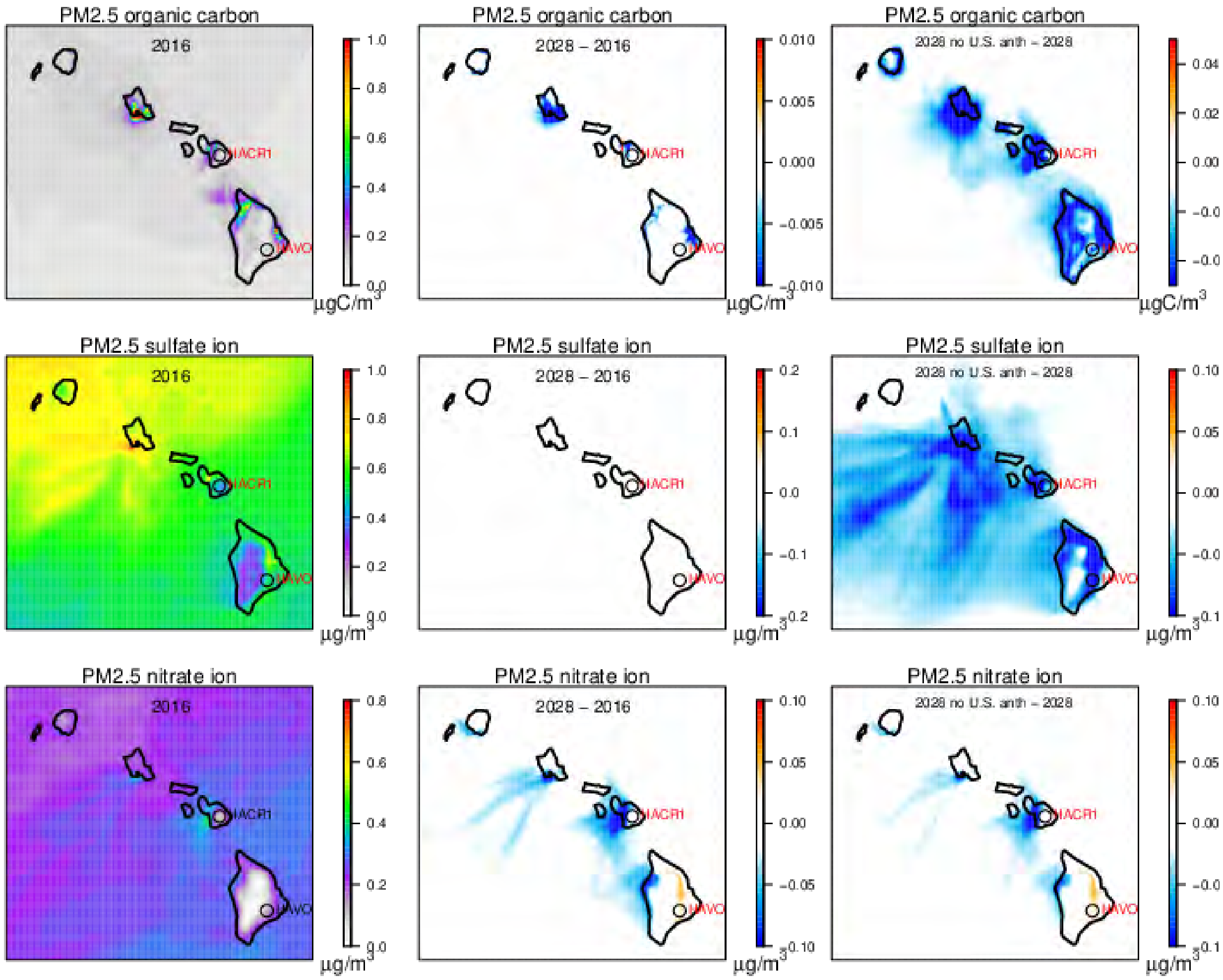

Figure B-1 *Spatial plots showing the average model predictions for $PM_{2.5}$ organic carbon (top three panels), $PM_{2.5}$ sulfate ion (middle three panels), and $PM_{2.5}$ nitrate ion (bottom three panels) on the 20% worst days at Haleakala National Park. The left panels depict concentrations for year 2016, the middle panels depict the differences in concentrations for year 2028 – 2016, and the right panels depict the differences in concentrations for year 2028 with no anthropogenic influences minus year 2028.*

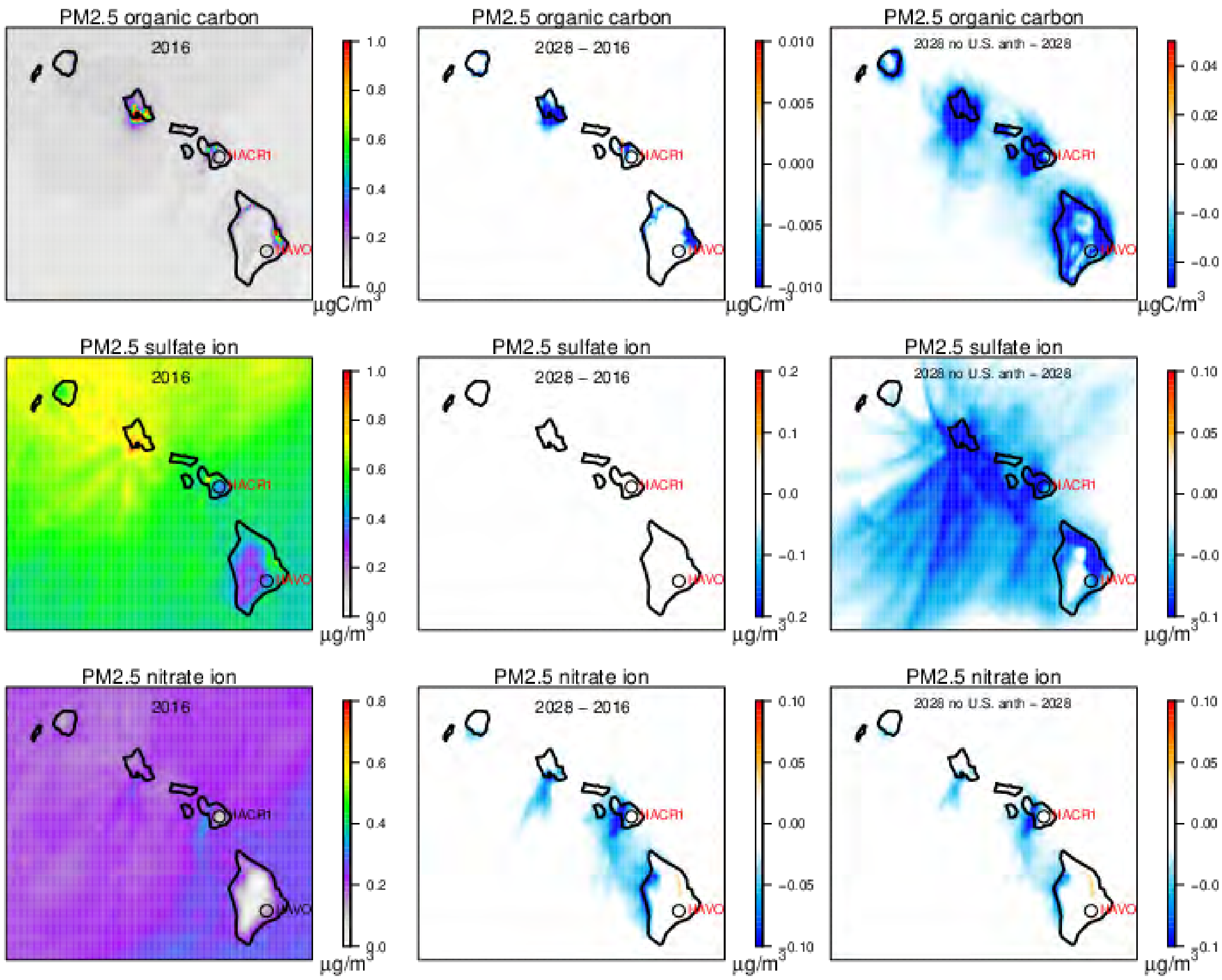

Figure B-2 *Spatial plots showing the average model predictions for $PM_{2.5}$ organic carbon (top three panels), $PM_{2.5}$ sulfate ion (middle three panels), and $PM_{2.5}$ nitrate ion (bottom three panels) on the 20% worst days at Hawaii Volcanoes National Park.*

B.2 Time Series for 2016

The plots in this section show daily average measurements and model predictions for the major components of total PM2.5 mass at each of the Class I areas.

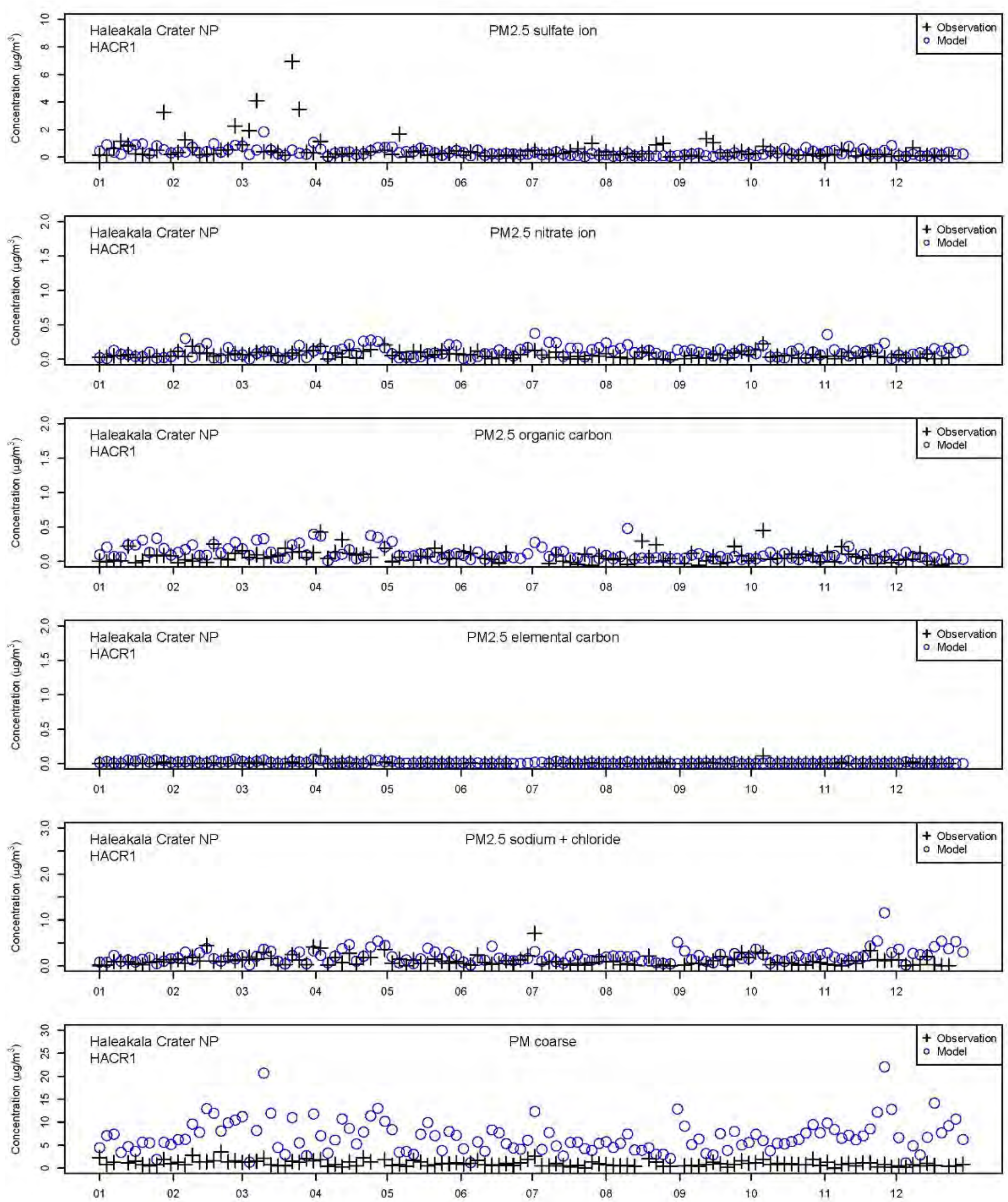

Figure B-3 *Time series plots for 2016 comparing model predictions (blue circles) with IMPROVE monitor measurements (black crosses) for $PM_{2.5}$ sulfate ion (top panel), $PM_{2.5}$ nitrate ion (second panel), $PM_{2.5}$ organic carbon (third panel), $PM_{2.5}$ elemental carbon (fourth panel), NaCl (fifth panel), and PM coarse (bottom panel) at Haleakala National Park.*

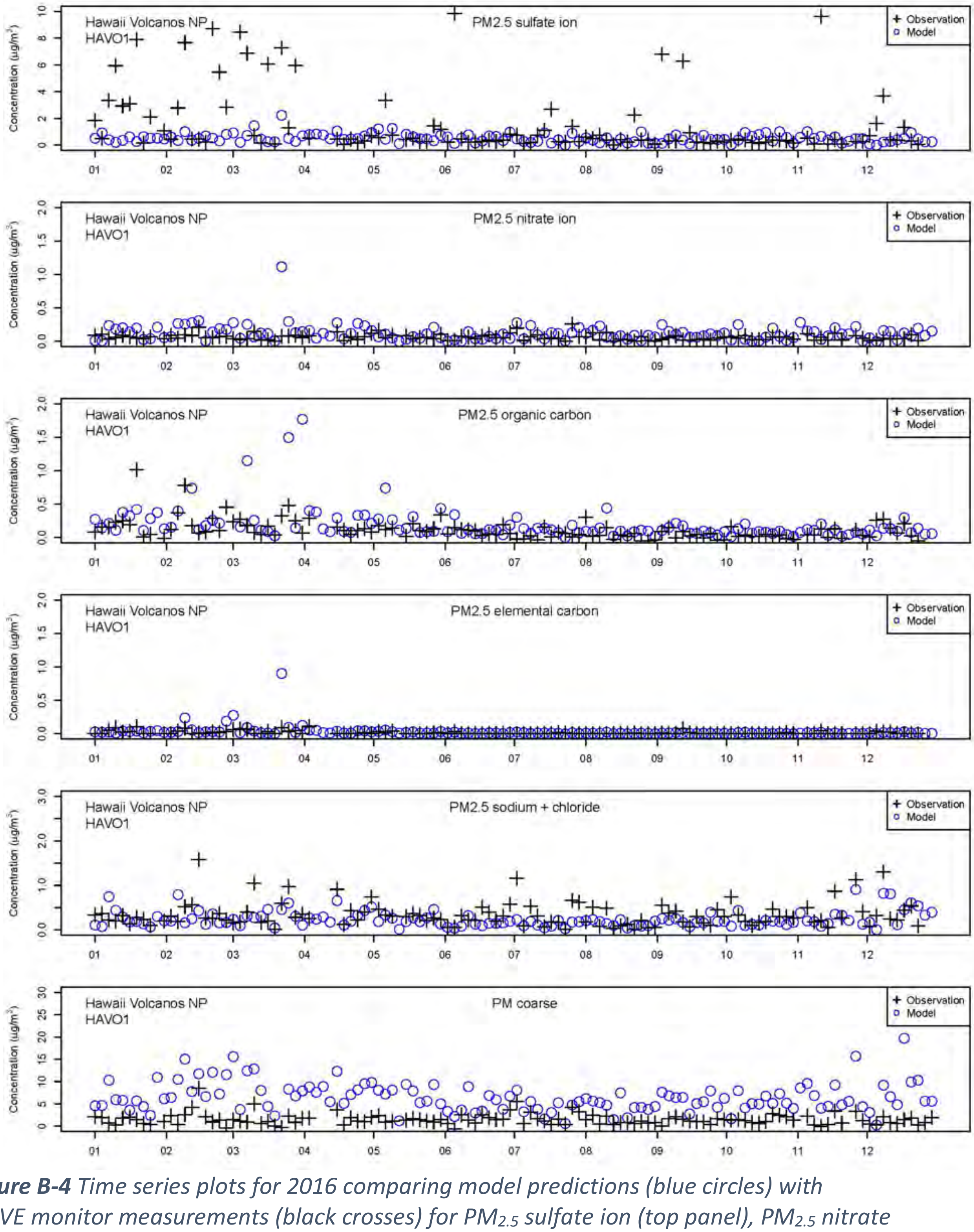

Figure B-4 *Time series plots for 2016 comparing model predictions (blue circles) with IMPROVE monitor measurements (black crosses) for* $PM_{2.5}$ *sulfate ion (top panel),* $PM_{2.5}$ *nitrate ion (second panel),* $PM_{2.5}$ *organic carbon (third panel),* $PM_{2.5}$ *elemental carbon (fourth panel), NaCl (fifth panel), and PM coarse (bottom panel) at Hawaii Volcanoes National Park.*

B.3 Particulate Matter Composition on Clearest and Most Impaired Days in 2016

The plots in this section show average daily average measurements and model predictions for the major components of total PM2.5 mass aggregated over the most and least impaired days in 2016 at each of the Class I areas.

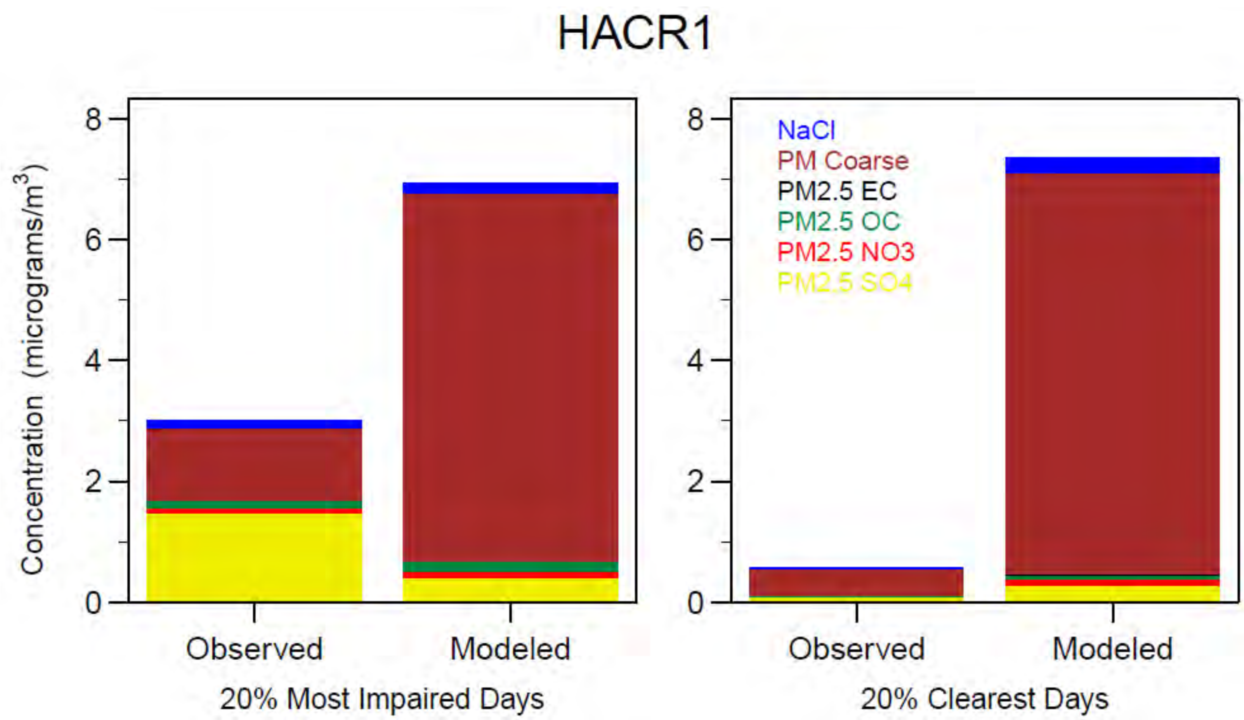

Figure B-5 *Stacked bar charts detailing the average composition of speciated particulate matter in 2016 on the 20% most impaired days (right) and 20% clearest days (right) at Haleakala National Park. The plots display concentration from bottom to top for the following: $PM_{2.5}$ sulfate (yellow), $PM_{2.5}$ nitrate (red), $PM_{2.5}$ organic carbon (green), $PM_{2.5}$ elemental carbon (black), PM coarse (brown), and sea salt (blue).*

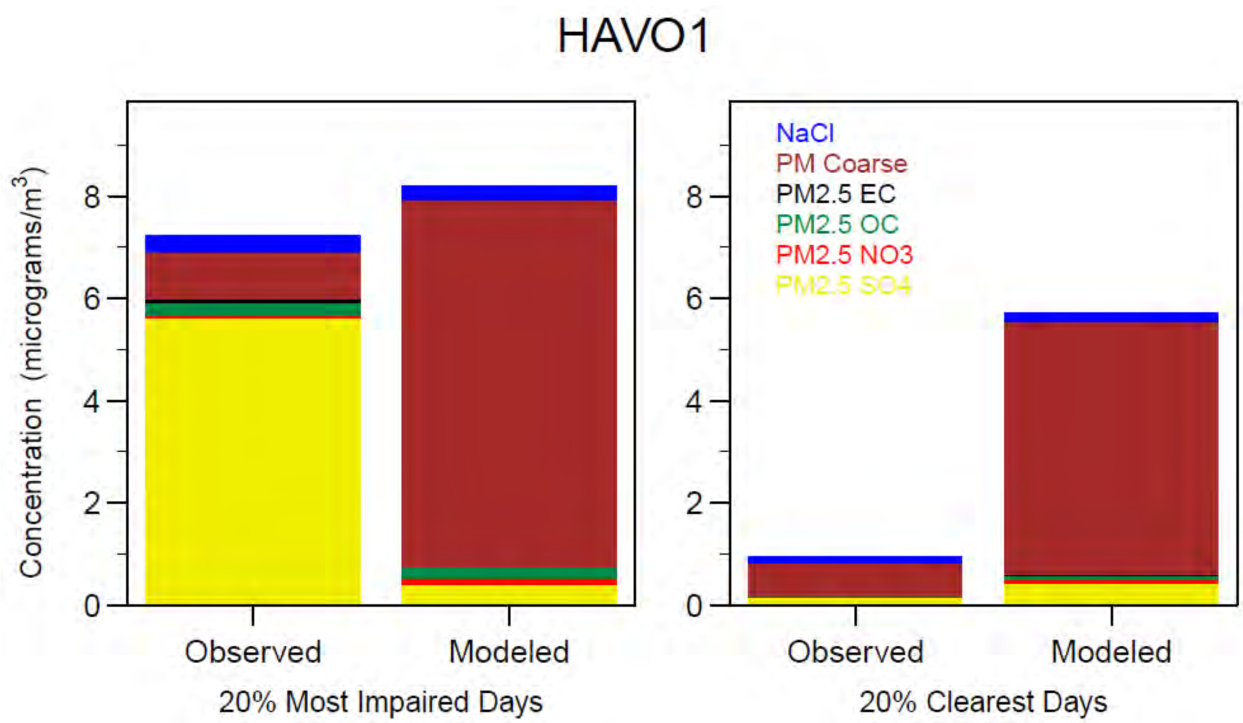

Figure B-6 *Stacked bar charts detailing the average composition of speciated particulate matter in 2016 on the 20% most impaired days (right) and 20% clearest days (right) at Hawaii Volcanoes National Park. The plots display concentration from bottom to top for the following: $PM_{2.5}$ sulfate (yellow), $PM_{2.5}$ nitrate (red), $PM_{2.5}$ organic carbon (green), $PM_{2.5}$ elemental carbon (black), PM coarse (brown), and sea salt (blue).*

Appendix C Model Performance Evaluation – Virgin Islands

C.1 Spatial Plots of Average Model Predictions on the Most Impaired Days

The plots in this section show average daily average measurements and model predictions for the major components of total PM2.5 mass aggregated over the most impaired days in 2016 at each of the Class I areas (left panels). The difference between the 2028 and 2016 simulations are also shown (middle panels) and the difference between the 2028 simulation and 2028 simulation with zero U.S. anthropogenic emissions (right panels).

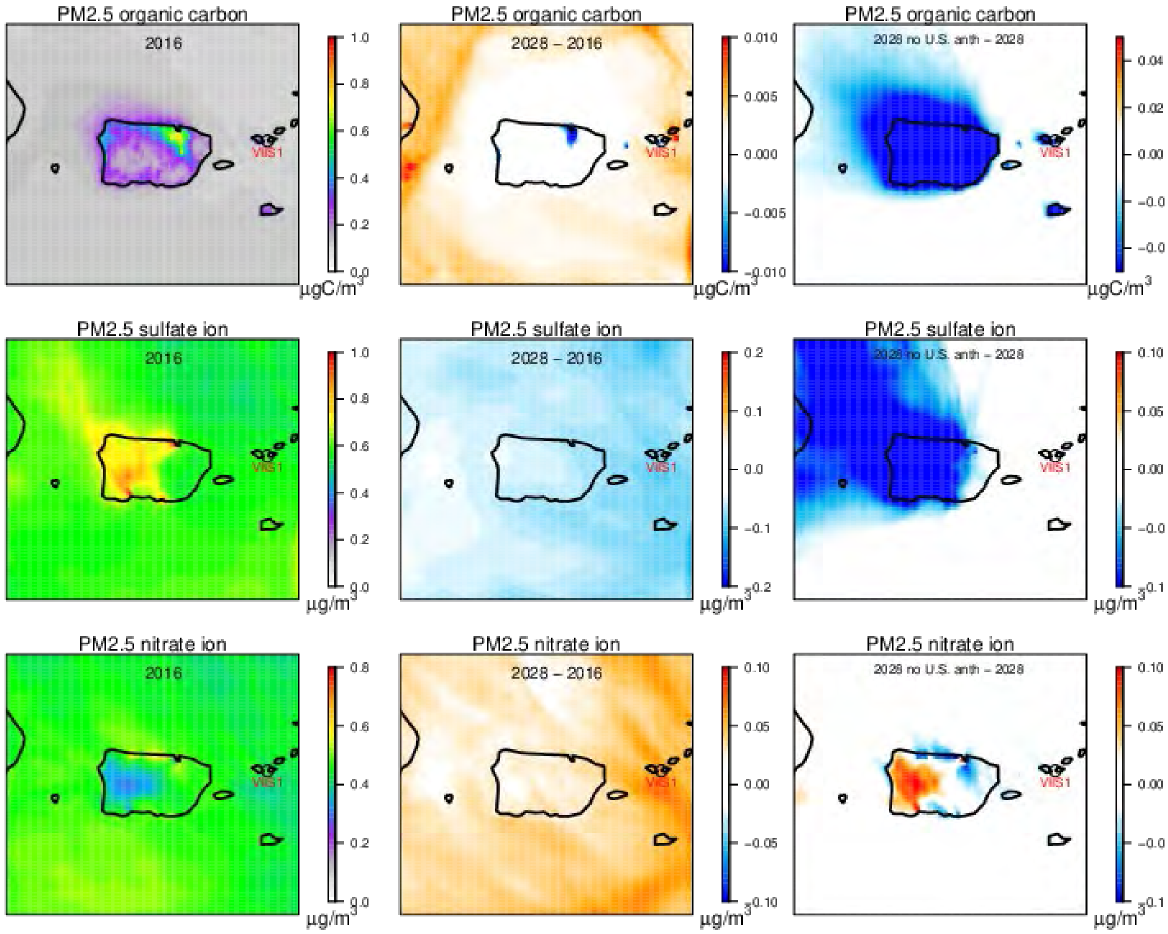

Figure C-1 *Spatial plots showing the average model predictions for $PM_{2.5}$ organic carbon (top three panels), $PM_{2.5}$ sulfate ion (middle three panels), and $PM_{2.5}$ nitrate ion (bottom three panels) on the 20% worst days at Virgin Islands National Park. The left panels depict concentrations for year 2016, the middle panels depict the differences in concentrations for year 2028 – 2016, and the right panels depict the differences in concentrations for year 2028 with no anthropogenic influences minus year 2028.*

C.2 Time Series for 2016

The plots in this section show daily average measurements and model predictions for the major components of total PM2.5 mass at each of the Class I areas.

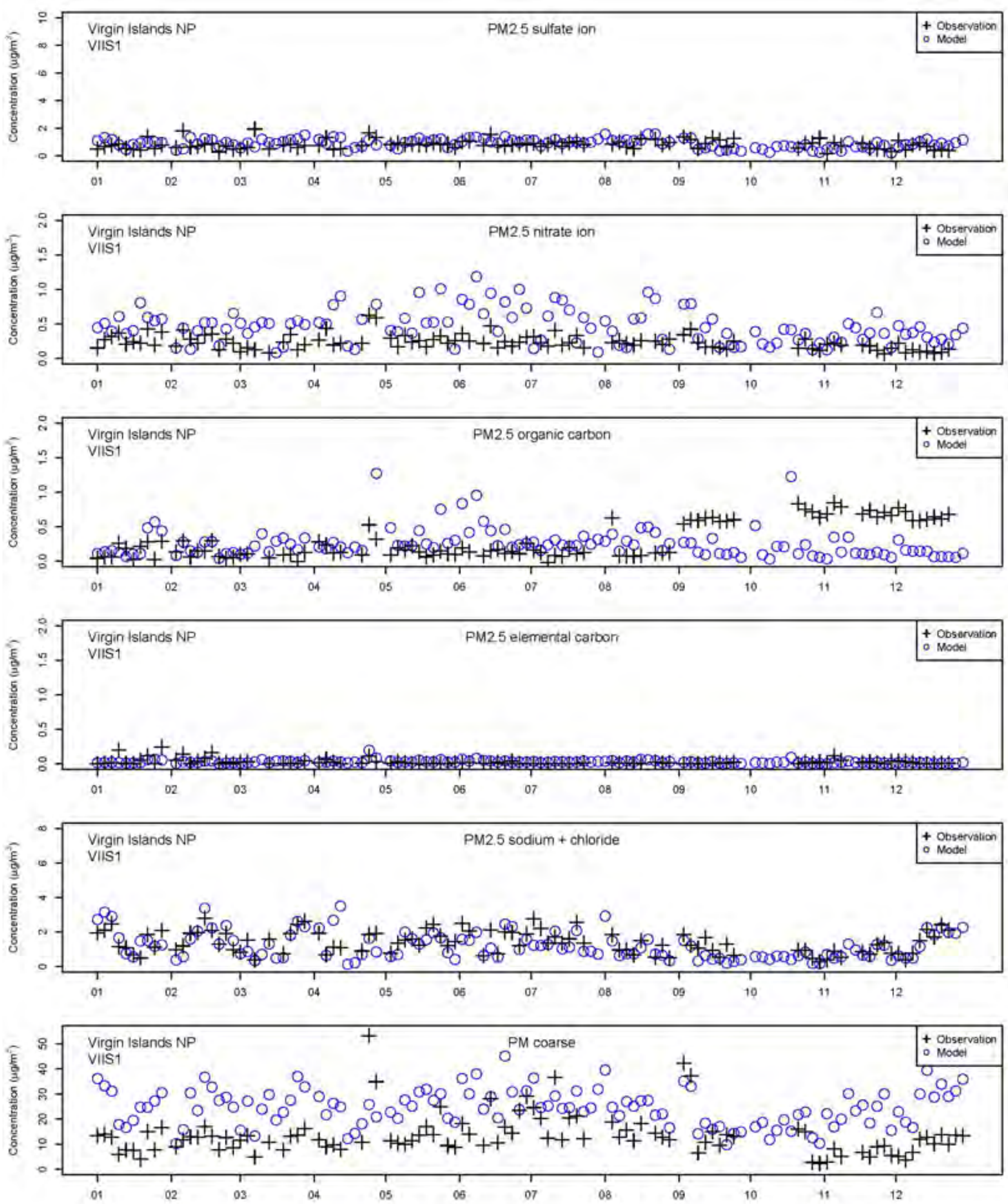

__Figure C-2__ Time series plots for 2016 comparing model predictions (blue circles) with IMPROVE monitor measurements (black crosses) for $PM_{2.5}$ sulfate ion (top panel), $PM_{2.5}$ nitrate ion (second panel), $PM_{2.5}$ organic carbon (third panel), $PM_{2.5}$ elemental carbon (fourth panel), NaCl (fifth panel), and PM coarse (bottom panel) at Virgin Islands National Park.

C.3 Particulate Matter Composition on Clearest and Most Impaired Days in 2016

The plots in this section show average daily average measurements and model predictions for the major components of total PM2.5 mass aggregated over the most and least impaired days in 2016 at each of the Class I areas.

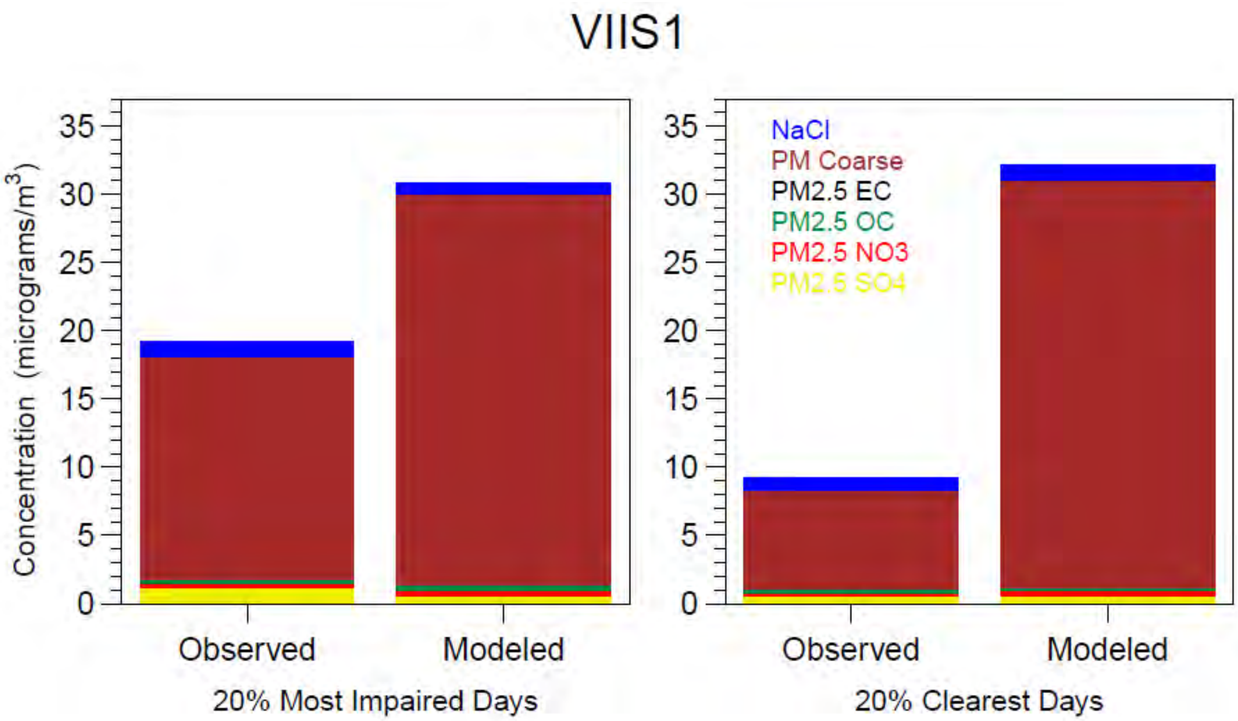

Figure C-3 *Stacked bar charts detailing the average composition of speciated particulate matter in 2016 on the 20% most impaired days (right) and 20% clearest days (right) at Virgin Islands National Park. The plots display concentration from bottom to top for the following:* $PM_{2.5}$ *sulfate (yellow),* $PM_{2.5}$ *nitrate (red),* $PM_{2.5}$ *organic carbon (green),* $PM_{2.5}$ *elemental carbon (black), PM coarse (brown), and sea salt (blue).*

Appendix D Emissions Summary

D.1 Emissions summary table for Alaska

This table shows annual total (tpy) emissions for the 9 km Alaska modeling domain.

Grid	State	Sector	Species	2016 annual emissions (tpy)	2028 annual emissions (tpy)
9AK1	Non-US SECA C3	cmv_c1c2_9ak1	CO	1.23	1.24
9AK1	Non-US SECA C3	cmv_c1c2_9ak1	NH3	0	0
9AK1	Non-US SECA C3	cmv_c1c2_9ak1	NOX	8.38	4.64
9AK1	Non-US SECA C3	cmv_c1c2_9ak1	PM2_5	0.22	0.13
9AK1	Non-US SECA C3	cmv_c1c2_9ak1	SO2	0.05	0.02
9AK1	Non-US SECA C3	cmv_c1c2_9ak1	VOC_INV	0.31	0.16
9AK1	Non-US SECA C3	cmv_c3_9ak1	CO	376.81	538.62
9AK1	Non-US SECA C3	cmv_c3_9ak1	NH3	6.2	4.56
9AK1	Non-US SECA C3	cmv_c3_9ak1	NOX	4062.34	5824.12
9AK1	Non-US SECA C3	cmv_c3_9ak1	PM2_5	357.04	262.32
9AK1	Non-US SECA C3	cmv_c3_9ak1	SO2	2793.74	742
9AK1	Non-US SECA C3	cmv_c3_9ak1	VOC_INV	183.68	261.26
9AK1	Offshore to EEZ	cmv_c1c2_9ak1	CO	357.19	358.27
9AK1	Offshore to EEZ	cmv_c1c2_9ak1	NH3	1.14	0.65
9AK1	Offshore to EEZ	cmv_c1c2_9ak1	NOX	2350.5	1302.18
9AK1	Offshore to EEZ	cmv_c1c2_9ak1	PM2_5	59.22	33.52
9AK1	Offshore to EEZ	cmv_c1c2_9ak1	SO2	3.31	1.13
9AK1	Offshore to EEZ	cmv_c1c2_9ak1	VOC_INV	79.77	42.12
9AK1	Offshore to EEZ	cmv_c3_9ak1	CO	3666.08	5210.37
9AK1	Offshore to EEZ	cmv_c3_9ak1	NH3	57.54	43.62
9AK1	Offshore to EEZ	cmv_c3_9ak1	NOX	39986.75	53896.96
9AK1	Offshore to EEZ	cmv_c3_9ak1	PM2_5	2989.71	2266.16
9AK1	Offshore to EEZ	cmv_c3_9ak1	SO2	23219.04	6645.79
9AK1	Offshore to EEZ	cmv_c3_9ak1	VOC_INV	1714.89	2437.43

Grid	State	Sector	Species	2016 annual emissions (tpy)	2028 annual emissions (tpy)
9AK1	Alaska	afdust_adj	PM2_5	1053.73	1062.96
9AK1	Alaska	ag	NH3	108.93	119.49
9AK1	Alaska	ag	VOC_INV	8.71	9.56
9AK1	Alaska	airports	CO	13478.15	14914.81
9AK1	Alaska	airports	NOX	4417.41	4370.87
9AK1	Alaska	airports	PM2_5	270.59	257.09
9AK1	Alaska	airports	SO2	575.9	597.75
9AK1	Alaska	airports	VOC_INV	2007.75	1945.41
9AK1	Alaska	cmv_c1c2_9ak1	CO	598.36	600.15
9AK1	Alaska	cmv_c1c2_9ak1	NH3	1.94	1.1
9AK1	Alaska	cmv_c1c2_9ak1	NOX	3966.48	2197.43
9AK1	Alaska	cmv_c1c2_9ak1	PM2_5	100.97	57.15
9AK1	Alaska	cmv_c1c2_9ak1	SO2	7.69	2.62
9AK1	Alaska	cmv_c1c2_9ak1	VOC_INV	136.17	71.9
9AK1	Alaska	cmv_c3_9ak1	CO	644.27	907.96
9AK1	Alaska	cmv_c3_9ak1	NH3	2.57	3.15
9AK1	Alaska	cmv_c3_9ak1	NOX	6250.89	6092.58
9AK1	Alaska	cmv_c3_9ak1	PM2_5	133.28	163.41
9AK1	Alaska	cmv_c3_9ak1	SO2	517.09	434.32
9AK1	Alaska	cmv_c3_9ak1	VOC_INV	282.96	398.38
9AK1	Alaska	nonpt	CO	28955.95	29241.97
9AK1	Alaska	nonpt	NH3	563.76	650
9AK1	Alaska	nonpt	NOX	6306.51	6725.3
9AK1	Alaska	nonpt	PM2_5	2500.06	2518.3
9AK1	Alaska	nonpt	SO2	1510.39	1523.71
9AK1	Alaska	nonpt	VOC_INV	8223.59	8043.48
9AK1	Alaska	nonroad	CO	34125.88	30034.58
9AK1	Alaska	nonroad	NH3	6.2	6.54
9AK1	Alaska	nonroad	NOX	2579.85	1722.26
9AK1	Alaska	nonroad	PM2_5	358.22	200.99
9AK1	Alaska	nonroad	SO2	7.42	4.08
9AK1	Alaska	nonroad	VOC_INV	8599.75	5297.39
9AK1	Alaska	np_oilgas	CO	2943.75	2917.36
9AK1	Alaska	np_oilgas	NH3	0	0
9AK1	Alaska	np_oilgas	NOX	2095.26	2019.19
9AK1	Alaska	np_oilgas	PM2_5	35.87	32.9
9AK1	Alaska	np_oilgas	SO2	44.17	39.81
9AK1	Alaska	np_oilgas	VOC_INV	25280.67	24912.9
9AK1	Alaska	onroad_nonconus	CO	60100.75	30960.75

9AK1	Alaska	onroad_nonconus	NH3	152.64	136.44
9AK1	Alaska	onroad_nonconus	NOX	11977.35	4788.96
9AK1	Alaska	onroad_nonconus	PM2_5	488.55	216.9
9AK1	Alaska	onroad_nonconus	SO2	32.55	23.33
9AK1	Alaska	onroad_nonconus	VOC_INV	8228.21	4142.01
9AK1	Alaska	pt_oilgas	CO	10184.09	10184.09
9AK1	Alaska	pt_oilgas	NH3	0.05	0.05
9AK1	Alaska	pt_oilgas	NOX	40683.42	40683.42
9AK1	Alaska	pt_oilgas	PM2_5	503.66	503.66
9AK1	Alaska	pt_oilgas	SO2	1657.44	1657.44
9AK1	Alaska	pt_oilgas	VOC_INV	1692.96	1692.96
9AK1	Alaska	ptegu	CO	2444.71	2444.71
9AK1	Alaska	ptegu	NH3	1.77	1.77
9AK1	Alaska	ptegu	NOX	7792.55	7792.55
9AK1	Alaska	ptegu	PM2_5	239.76	239.76
9AK1	Alaska	ptegu	SO2	1304.07	1304.07
9AK1	Alaska	ptegu	VOC_INV	307.19	307.19
9AK1	Alaska	ptfire	CO	3165510.9	3165510.9
9AK1	Alaska	ptfire	NH3	51691.05	51691.05
9AK1	Alaska	ptfire	NOX	29644.16	29644.16
9AK1	Alaska	ptfire	PM2_5	262648.3	262648.3
9AK1	Alaska	ptfire	SO2	19645.81	19645.81
9AK1	Alaska	ptfire	VOC_INV	743059.87	743059.87
9AK1	Alaska	ptnonipm	CO	2561.58	2558.95
9AK1	Alaska	ptnonipm	NH3	48.16	47.58
9AK1	Alaska	ptnonipm	NOX	7291.09	7268.83
9AK1	Alaska	ptnonipm	PM2_5	478.06	483.49
9AK1	Alaska	ptnonipm	SO2	1394.23	1403.5
9AK1	Alaska	ptnonipm	VOC_INV	800.1	735.82
9AK1	Alaska	rail	CO	47.54	48.08
9AK1	Alaska	rail	NH3	0.15	0.15
9AK1	Alaska	rail	NOX	386.37	390.77
9AK1	Alaska	rail	PM2_5	10.94	11.06
9AK1	Alaska	rail	SO2	0.17	0.17
9AK1	Alaska	rail	VOC_INV	16.92	18.02
9AK1	Alaska	rwc	CO	5072.5	4730.64
9AK1	Alaska	rwc	NH3	33.89	30.47
9AK1	Alaska	rwc	NOX	90.09	93.04
9AK1	Alaska	rwc	PM2_5	711.98	646.74
9AK1	Alaska	rwc	SO2	15.54	12.84
9AK1	Alaska	rwc	VOC_INV	820.28	759.24

D.2 Emissions summary table for Hawaii

This table shows annual total (tpy) emissions for the 3 km Hawaii modeling domain.

Grid	State	Sector	Species	2016 annual emissions (tpy)	2028 annual emissions (tpy)
3HI1	Non-US SECA C3	cmv_c1c2_3hi1	CO	0.1	0.1
3HI1	Non-US SECA C3	cmv_c1c2_3hi1	NH3	0	0
3HI1	Non-US SECA C3	cmv_c1c2_3hi1	NOX	0.64	0.36
3HI1	Non-US SECA C3	cmv_c1c2_3hi1	PM2_5	0.02	0.01
3HI1	Non-US SECA C3	cmv_c1c2_3hi1	SO2	0	0
3HI1	Non-US SECA C3	cmv_c1c2_3hi1	VOC_INV	0.02	0.01
3HI1	Non-US SECA C3	cmv_c3_3hi1	CO	3.2	4.56
3HI1	Non-US SECA C3	cmv_c3_3hi1	NH3	0.06	0.09
3HI1	Non-US SECA C3	cmv_c3_3hi1	NOX	34.59	49.32
3HI1	Non-US SECA C3	cmv_c3_3hi1	PM2_5	3.11	4.43
3HI1	Non-US SECA C3	cmv_c3_3hi1	SO2	23.71	4.83
3HI1	Non-US SECA C3	cmv_c3_3hi1	VOC_INV	1.68	2.4
3HI1	Offshore to EEZ	cmv_c1c2_3hi1	CO	180.8	181.34
3HI1	Offshore to EEZ	cmv_c1c2_3hi1	NH3	0.58	0.33
3HI1	Offshore to EEZ	cmv_c1c2_3hi1	NOX	1204.24	667.15
3HI1	Offshore to EEZ	cmv_c1c2_3hi1	PM2_5	30.33	17.17
3HI1	Offshore to EEZ	cmv_c1c2_3hi1	SO2	0.87	0.3
3HI1	Offshore to EEZ	cmv_c1c2_3hi1	VOC_INV	42.55	22.46
3HI1	Offshore to EEZ	cmv_c3_3hi1	CO	383.59	559.51
3HI1	Offshore to EEZ	cmv_c3_3hi1	NH3	1.12	1.63
3HI1	Offshore to EEZ	cmv_c3_3hi1	NOX	3812.24	2517.1
3HI1	Offshore to EEZ	cmv_c3_3hi1	PM2_5	58.02	84.63
3HI1	Offshore to EEZ	cmv_c3_3hi1	SO2	147.32	214.89
3HI1	Offshore to EEZ	cmv_c3_3hi1	VOC_INV	174.82	254.99

Grid	State	Sector	Species	2016 annual emissions (tpy)	2028 annual emissions (tpy)
3HI1	Hawaii	afdust_adj	PM2_5	3764.3	3808.93
3HI1	Hawaii	ag	NH3	1495.69	1535.9
3HI1	Hawaii	ag	VOC_INV	119.66	122.87
3HI1	Hawaii	airports	CO	10079.7	12764.45
3HI1	Hawaii	airports	NOX	3500.91	4223.8
3HI1	Hawaii	airports	PM2_5	150.57	165.29
3HI1	Hawaii	airports	SO2	524.55	662.42
3HI1	Hawaii	airports	VOC_INV	1091.71	1223.5
3HI1	Hawaii	cmv_c1c2_3hi1	CO	244.54	245.28
3HI1	Hawaii	cmv_c1c2_3hi1	NH3	0.79	0.45
3HI1	Hawaii	cmv_c1c2_3hi1	NOX	1621.4	898.26
3HI1	Hawaii	cmv_c1c2_3hi1	PM2_5	41.02	23.22
3HI1	Hawaii	cmv_c1c2_3hi1	SO2	2.19	0.75
3HI1	Hawaii	cmv_c1c2_3hi1	VOC_INV	55.26	29.18
3HI1	Hawaii	cmv_c3_3hi1	CO	306.63	447.25
3HI1	Hawaii	cmv_c3_3hi1	NH3	0.87	1.27
3HI1	Hawaii	cmv_c3_3hi1	NOX	2309.82	1525.09
3HI1	Hawaii	cmv_c3_3hi1	PM2_5	45.23	65.98
3HI1	Hawaii	cmv_c3_3hi1	SO2	94.4	137.7
3HI1	Hawaii	cmv_c3_3hi1	VOC_INV	198.63	289.72
3HI1	Hawaii	nonpt	CO	10019.69	10019.69
3HI1	Hawaii	nonpt	NH3	53.29	53.29
3HI1	Hawaii	nonpt	NOX	396.78	396.78
3HI1	Hawaii	nonpt	PM2_5	1498.37	1498.37
3HI1	Hawaii	nonpt	SO2	89.33	89.33
3HI1	Hawaii	nonpt	VOC_INV	14675.31	14051.12
3HI1	Hawaii	nonroad	CO	47219.26	49901.07
3HI1	Hawaii	nonroad	NH3	6.81	8.1
3HI1	Hawaii	nonroad	NOX	3440.76	2085.28
3HI1	Hawaii	nonroad	PM2_5	320.43	198.08
3HI1	Hawaii	nonroad	SO2	8.03	5.59
3HI1	Hawaii	nonroad	VOC_INV	4423.67	3020.56
3HI1	Hawaii	onroad_nonconus	CO	82599.39	43003.13
3HI1	Hawaii	onroad_nonconus	NH3	315.68	271.01
3HI1	Hawaii	onroad_nonconus	NOX	10384.35	3220.21
3HI1	Hawaii	onroad_nonconus	PM2_5	310.4	167.17
3HI1	Hawaii	onroad_nonconus	SO2	63.17	34.15
3HI1	Hawaii	onroad_nonconus	VOC_INV	8953.71	3959.28
3HI1	Hawaii	ptagfire	CO	1079.98	1079.98

3HI1	Hawaii	ptagfire	NH3	390.38	390.38
3HI1	Hawaii	ptagfire	NOX	55.3	55.3
3HI1	Hawaii	ptagfire	PM2_5	81.58	81.58
3HI1	Hawaii	ptagfire	SO2	30.09	30.09
3HI1	Hawaii	ptagfire	VOC_INV	82.68	82.68
3HI1	Hawaii	ptegu	CO	1599.16	1375.28
3HI1	Hawaii	ptegu	NH3	170.9	146.97
3HI1	Hawaii	ptegu	NOX	17520.17	15067.35
3HI1	Hawaii	ptegu	PM2_5	1374.39	1181.97
3HI1	Hawaii	ptegu	SO2	18003.18	15482.73
3HI1	Hawaii	ptegu	VOC_INV	162.82	140.03
3HI1	Hawaii	ptfire_nonconus	CO	57641.9	57641.9
3HI1	Hawaii	ptfire_nonconus	NH3	836.78	836.78
3HI1	Hawaii	ptfire_nonconus	NOX	3373.68	3373.68
3HI1	Hawaii	ptfire_nonconus	PM2_5	5752.35	5752.35
3HI1	Hawaii	ptfire_nonconus	SO2	257.9	257.9
3HI1	Hawaii	ptfire_nonconus	VOC_INV	19201.73	19201.73
3HI1	Hawaii	ptnonipm	CO	3993.81	4794.87
3HI1	Hawaii	ptnonipm	NH3	67.33	70.45
3HI1	Hawaii	ptnonipm	NOX	2716.33	2810.61
3HI1	Hawaii	ptnonipm	PM2_5	495.15	541.74
3HI1	Hawaii	ptnonipm	SO2	913.17	883.25
3HI1	Hawaii	ptnonipm	VOC_INV	2917.09	2860.38
3HI1	Hawaii	rwc	CO	3700.83	3704.72
3HI1	Hawaii	rwc	NH3	26.97	27.14
3HI1	Hawaii	rwc	NOX	66.94	71.64
3HI1	Hawaii	rwc	PM2_5	512.77	504.04
3HI1	Hawaii	rwc	SO2	8.82	9.31
3HI1	Hawaii	rwc	VOC_INV	599.47	572.4

D.3 Emissions summary table for Puerto Rico/Virgin Islands

This table shows annual total (tpy) emissions for the 3 and 9 km Puerto Rico/Virgin Islands modeling domains.

Grid	State	Sector	Species	2016 annual emissions (tpy)	2028 annual emissions (tpy)		Grid	2016 annual emissions (tpy)	2028 annual emissions (tpy)
3PR1	Non-US SECA C3	cmv_c1c2_3pr1	CO	150.86	151.32		9PR1	286.84	287.7
3PR1	Non-US SECA C3	cmv_c1c2_3pr1	NH3	0.5	0.28		9PR1	0.93	0.53
3PR1	Non-US SECA C3	cmv_c1c2_3pr1	NOX	998.65	553.25		9PR1	1875.83	1039.21
3PR1	Non-US SECA C3	cmv_c1c2_3pr1	PM2_5	25.94	14.68		9PR1	48.52	27.46
3PR1	Non-US SECA C3	cmv_c1c2_3pr1	SO2	3.58	1.22		9PR1	7.09	2.42
3PR1	Non-US SECA C3	cmv_c1c2_3pr1	VOC_INV	34.95	18.46		9PR1	64.94	34.29
3PR1	Non-US SECA C3	cmv_c3_3pr1	CO	624.45	890.35		9PR1	7721.46	11009.4
3PR1	Non-US SECA C3	cmv_c3_3pr1	NH3	12.8	18.25		9PR1	119.75	170.74
3PR1	Non-US SECA C3	cmv_c3_3pr1	NOX	7283.57	10385.14		9PR1	88718.6	126491.11
3PR1	Non-US SECA C3	cmv_c3_3pr1	PM2_5	664.98	948.15		9PR1	7681.77	10952.96
3PR1	Non-US SECA C3	cmv_c3_3pr1	SO2	5436.66	1107.39		9PR1	63277.74	12888.49
3PR1	Non-US SECA C3	cmv_c3_3pr1	VOC_INV	285.24	406.71		9PR1	3572.1	5093.31
3PR1	Offshore to EEZ	cmv_c1c2_3pr1	CO	115.97	116.32		9PR1	136.28	136.69
3PR1	Offshore to EEZ	cmv_c1c2_3pr1	NH3	0.38	0.22		9PR1	0.45	0.25
3PR1	Offshore to EEZ	cmv_c1c2_3pr1	NOX	751.84	416.52		9PR1	880.73	487.93
3PR1	Offshore to EEZ	cmv_c1c2_3pr1	PM2_5	19.82	11.22		9PR1	23.16	13.11
3PR1	Offshore to EEZ	cmv_c1c2_3pr1	SO2	3.14	1.07		9PR1	3.64	1.24
3PR1	Offshore to EEZ	cmv_c1c2_3pr1	VOC_INV	26.69	14.09		9PR1	30.89	16.31
3PR1	Offshore to EEZ	cmv_c3_3pr1	CO	1311.09	1788.41		9PR1	1922.89	2622.98
3PR1	Offshore to EEZ	cmv_c3_3pr1	NH3	19.97	27.24		9PR1	31.23	42.6
3PR1	Offshore to EEZ	cmv_c3_3pr1	NOX	14488.85	12691.72		9PR1	21587.73	18910.14
3PR1	Offshore to EEZ	cmv_c3_3pr1	PM2_5	1037.59	1415.36		9PR1	1622.51	2213.23
3PR1	Offshore to EEZ	cmv_c3_3pr1	SO2	8295.21	11315.27		9PR1	13087.73	17852.67
3PR1	Offshore to EEZ	cmv_c3_3pr1	VOC_INV	615.91	840.14		9PR1	893.47	1218.76

Grid	State	Sector	Species	2016 annual emissions (tpy)	2028 annual emissions (tpy)		Grid	2016 annual emissions (tpy)	2028 annual emissions (tpy)
3PR1	Puerto Rico	afdust_adj	PM2_5	329.02	353.11		9PR1	329.02	353.11
3PR1	Puerto Rico	cmv_c1c2_3pr1	CO	181.1	181.64		9PR1	184.47	185.02
3PR1	Puerto Rico	cmv_c1c2_3pr1	NH3	0.59	0.33		9PR1	0.6	0.34
3PR1	Puerto Rico	cmv_c1c2_3pr1	NOX	1201.67	665.73		9PR1	1224.69	678.48
3PR1	Puerto Rico	cmv_c1c2_3pr1	PM2_5	30.69	17.37		9PR1	31.32	17.73
3PR1	Puerto Rico	cmv_c1c2_3pr1	SO2	2.23	0.76		9PR1	2.41	0.82
3PR1	Puerto Rico	cmv_c1c2_3pr1	VOC_INV	41.8	22.07		9PR1	42.71	22.55
3PR1	Puerto Rico	cmv_c3_3pr1	CO	241.8	329.83		9PR1	258.31	352.36
3PR1	Puerto Rico	cmv_c3_3pr1	NH3	0.78	1.07		9PR1	0.84	1.15
3PR1	Puerto Rico	cmv_c3_3pr1	NOX	2095.94	1835.97		9PR1	2218.17	1943.04
3PR1	Puerto Rico	cmv_c3_3pr1	PM2_5	40.59	55.37		9PR1	43.76	59.69
3PR1	Puerto Rico	cmv_c3_3pr1	SO2	129.48	176.63		9PR1	139.05	189.67
3PR1	Puerto Rico	cmv_c3_3pr1	VOC_INV	133.11	181.57		9PR1	142.46	194.33
3PR1	Puerto Rico	nonpt	CO	18201.9	18203.75		9PR1	18201.9	18203.75
3PR1	Puerto Rico	nonpt	NH3	75.86	75.86		9PR1	75.86	75.86
3PR1	Puerto Rico	nonpt	NOX	865.51	894.84		9PR1	865.51	894.84
3PR1	Puerto Rico	nonpt	PM2_5	2694.82	2695.49		9PR1	2694.82	2695.49
3PR1	Puerto Rico	nonpt	SO2	188.84	189.66		9PR1	188.84	189.66
3PR1	Puerto Rico	nonpt	VOC_INV	28265.96	28272.42		9PR1	28265.96	28272.42
3PR1	Puerto Rico	nonroad	CO	122296.1	140808.4		9PR1	122296.05	140808.37
3PR1	Puerto Rico	nonroad	NH3	14.19	17.81		9PR1	14.19	17.81
3PR1	Puerto Rico	nonroad	NOX	6367.25	4384.58		9PR1	6367.25	4384.58
3PR1	Puerto Rico	nonroad	PM2_5	761.51	576.92		9PR1	761.51	576.92
3PR1	Puerto Rico	nonroad	SO2	17.42	12.29		9PR1	17.42	12.29
3PR1	Puerto Rico	nonroad	VOC_INV	10985.53	9126.3		9PR1	10985.53	9126.3
3PR1	Puerto Rico	onroad_nonconus	CO	103859	103859		9PR1	103858.97	103858.97
3PR1	Puerto Rico	onroad_nonconus	NH3	404.28	404.28		9PR1	404.28	404.28
3PR1	Puerto Rico	onroad_nonconus	NOX	9974.92	9974.92		9PR1	9974.92	9974.92
3PR1	Puerto Rico	onroad_nonconus	PM2_5	346.89	346.89		9PR1	346.89	346.89
3PR1	Puerto Rico	onroad_nonconus	SO2	85.88	85.88		9PR1	85.88	85.88
3PR1	Puerto Rico	onroad_nonconus	VOC_INV	9199.22	9199.22		9PR1	9199.22	9199.22
3PR1	Puerto Rico	ptegu	CO	2842.89	2842.89		9PR1	2842.89	2842.89
3PR1	Puerto Rico	ptegu	NH3	0	0		9PR1	0	0
3PR1	Puerto Rico	ptegu	NOX	18479.36	18479.36		9PR1	18479.36	18479.36
3PR1	Puerto Rico	ptegu	PM2_5	1140.9	1140.9		9PR1	1140.9	1140.9

3PR1	Puerto Rico	ptegu	SO2	24553.14	24553.14		9PR1	24553.14	24553.14
3PR1	Puerto Rico	ptegu	VOC_INV	221.92	221.92		9PR1	221.92	221.92
3PR1	Puerto Rico	ptfire_nonconus	CO	14.47	14.47		9PR1	14.47	14.47
3PR1	Puerto Rico	ptfire_nonconus	NH3	0.29	0.29		9PR1	0.29	0.29
3PR1	Puerto Rico	ptfire_nonconus	NOX	0.4	0.4		9PR1	0.4	0.4
3PR1	Puerto Rico	ptfire_nonconus	PM2_5	1.78	1.78		9PR1	1.78	1.78
3PR1	Puerto Rico	ptfire_nonconus	SO2	0.13	0.13		9PR1	0.13	0.13
3PR1	Puerto Rico	ptfire_nonconus	VOC_INV	4.05	4.05		9PR1	4.05	4.05
3PR1	Puerto Rico	ptnonipm	CO	487.71	462.38		9PR1	487.71	462.38
3PR1	Puerto Rico	ptnonipm	NH3	172.42	172.42		9PR1	172.42	172.42
3PR1	Puerto Rico	ptnonipm	NOX	1720.61	1658.09		9PR1	1720.61	1658.09
3PR1	Puerto Rico	ptnonipm	PM2_5	77.01	67.98		9PR1	77.01	67.98
3PR1	Puerto Rico	ptnonipm	SO2	1362.95	1089.96		9PR1	1362.95	1089.96
3PR1	Puerto Rico	ptnonipm	VOC_INV	247.21	244.38		9PR1	247.21	244.38

Grid	State	Sector	Species	2016 annual emissions (tpy)	2028 annual emissions (tpy)		Grid	2016 annual emissions (tpy)	2028 annual emissions (tpy)
3PR1	Virgin Islands	afdust_adj	PM2_5	271.75	279.14		9PR1	271.75	279.14
3PR1	Virgin Islands	cmv_c1c2_3pr1	CO	181.89	182.44		9PR1	175.84	176.36
3PR1	Virgin Islands	cmv_c1c2_3pr1	NH3	0.63	0.36		9PR1	0.61	0.34
3PR1	Virgin Islands	cmv_c1c2_3pr1	NOX	1243.97	689.16		9PR1	1203.94	666.98
3PR1	Virgin Islands	cmv_c1c2_3pr1	PM2_5	32.63	18.47		9PR1	31.62	17.9
3PR1	Virgin Islands	cmv_c1c2_3pr1	SO2	3.46	1.18		9PR1	3.41	1.16
3PR1	Virgin Islands	cmv_c1c2_3pr1	VOC_INV	47.91	25.3		9PR1	46.56	24.58
3PR1	Virgin Islands	cmv_c3_3pr1	CO	217.81	297.11		9PR1	216.52	295.35
3PR1	Virgin Islands	cmv_c3_3pr1	NH3	0.69	0.94		9PR1	0.69	0.95
3PR1	Virgin Islands	cmv_c3_3pr1	NOX	1816.28	1591		9PR1	1814.14	1589.13
3PR1	Virgin Islands	cmv_c3_3pr1	PM2_5	35.97	49.06		9PR1	36.08	49.21
3PR1	Virgin Islands	cmv_c3_3pr1	SO2	85.03	115.99		9PR1	86.66	118.21
3PR1	Virgin Islands	cmv_c3_3pr1	VOC_INV	121.87	166.25		9PR1	120.22	163.99
3PR1	Virgin Islands	nonpt	CO	478.41	483.11		9PR1	478.41	483.11
3PR1	Virgin Islands	nonpt	NH3	3.31	3.39		9PR1	3.31	3.39
3PR1	Virgin Islands	nonpt	NOX	59.37	62.31		9PR1	59.37	62.31
3PR1	Virgin Islands	nonpt	PM2_5	163.63	166.06		9PR1	163.63	166.06
3PR1	Virgin Islands	nonpt	SO2	13.87	13.31		9PR1	13.87	13.31
3PR1	Virgin Islands	nonpt	VOC_INV	902.59	902.79		9PR1	902.59	902.79
3PR1	Virgin Islands	nonroad	CO	4315.93	4760.68		9PR1	4315.93	4760.68
3PR1	Virgin Islands	nonroad	NH3	0.66	0.8		9PR1	0.66	0.8
3PR1	Virgin Islands	nonroad	NOX	328.41	197.08		9PR1	328.41	197.08
3PR1	Virgin Islands	nonroad	PM2_5	33.14	19.99		9PR1	33.14	19.99
3PR1	Virgin Islands	nonroad	SO2	0.76	0.55		9PR1	0.76	0.55
3PR1	Virgin Islands	nonroad	VOC_INV	471.29	321.78		9PR1	471.29	321.78
3PR1	Virgin Islands	onroad_nonconus	CO	3092.04	3092.04		9PR1	3092.04	3092.04
3PR1	Virgin Islands	onroad_nonconus	NH3	14.53	14.53		9PR1	14.53	14.53
3PR1	Virgin Islands	onroad_nonconus	NOX	442.65	442.65		9PR1	442.65	442.65
3PR1	Virgin Islands	onroad_nonconus	PM2_5	16.08	16.08		9PR1	16.08	16.08
3PR1	Virgin Islands	onroad_nonconus	SO2	2.97	2.97		9PR1	2.97	2.97
3PR1	Virgin Islands	onroad_nonconus	VOC_INV	351.8	351.8		9PR1	351.8	351.8

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