III.K.13.E EMISSION INVENTORY

1. OVERVIEW

The State of Alaska, under its reporting obligations to the EPA, submits emissions data for the yearly and triennial NEI. This data provides a complete snapshot of the emissions-generating activity nationally and at the state level. By collecting this data, DEC can provide a detailed dataset to its contractors and the EPA to assist in haze modeling to isolate potential sources of visibility impairment.

For the purposes of this RH SIP, DEC will be using one current and one future forecasting inventory. The current inventory used is the 2016 inventory compiled by the EPA and MJOs in a joint EPA/MJO 2016 Inventory Collaborative Study[1] (2016 EI) that was built off the 2014 NEI. The EPA and contractors used the EPA/MJO 2016 collaborative modeling platform to model visibility impacts and facility emissions. The platform also includes a 2028 future forecasting inventory (2028 EI) which uses the most recent emissions data available to project emissions at the end of the second planning period in 2028.

Given ongoing challenges from COVID-19 and the long-term economic fallout, the available data may not be reflective of economic trends in a post-COVID setting. As this is the only dataset available to DEC or its contractors, the 2028 future forecasting inventory has been used in this planning document. DEC anticipates revisiting the issue of future emissions forecasting in the status update in 2024 and post-2020 data will be used to update the emissions forecast with post-COVID emissions data.

This section presents anthropogenic emissions from the 2016 and 2028 EI for Alaska. Given that air quality in the state is strongly affected by natural emissions as well as human activities, this section also discusses various natural sources that can contribute to visibility impairment in Alaska.

2. BASE-YEAR AND FUTURE-YEAR EMISSIONS INVENTORIES

DEC is using the 2016 EI to represent emissions for the current visibility period (2014-18), while the 2028 inventory is included to represent the end of the second planning period. The 2028 EI was put together using the 2016 EI as a base dataset and uses statistical data to predict emissions in 2028 based on economic growth, population expansion or contraction, and other factors. Both inventories allow DEC to understand potential growth areas in state emissions and model potential impacts.

Key considerations in the development of these regional haze emission inventories are outlined below.

Pollutants – Within the EPA 2016 EI are pollution inventories broken down by source categories with specific amounts for each type of visibility-impairing pollutant. These match up with criteria air pollutants (CAPs) defined by the EPA in the 1970 CAA. These pollutants are

[1] https://views.cira.colostate.edu/wiki/wiki/9169#Overview

volatile organic compounds (VOCs), carbon monoxide (CO), oxides of nitrogen (NO_x), sulfur oxides (SO_x), ammonia (NH_3), and coarse and fine particulate matter (PM_{10} and $PM_{2.5}$ respectively). Although CO is not considered a haze-generating pollutant, EPA collects emissions data on CO for its NEI datasets. As a result, CO emissions data was included in datasets used for haze analysis in this plan.

Areal Extent – The inventories represent sources within the entire state of Alaska, encompassing a total of 27 boroughs/census areas.[2] EPA used these inventories to complete preliminarily modeling for Alaska using the Community Multiscale Air Quality Modeling System (CMAQ) modeling platform for the base year 2016 and future year 2028 (See Chapter III.K.13.G for more details). Figure III.K.13.E-1 shows the extent of the rectangular modeling domains used by EPA, along with the locations of the four Class I monitoring sites in Alaska. For the Alaska modeling domain, Canada (Yukon and Northwest Territories) emissions (those that fell within the 9/27 km modeling domain) were included in the CMAQ regional model. The rest of the international emissions (Russia, East Asia, and the rest of the world) were included in the hemispheric CMAQ modeling that provided boundary conditions for the CMAQ regional model. These international emissions are not included in the emission summary below.

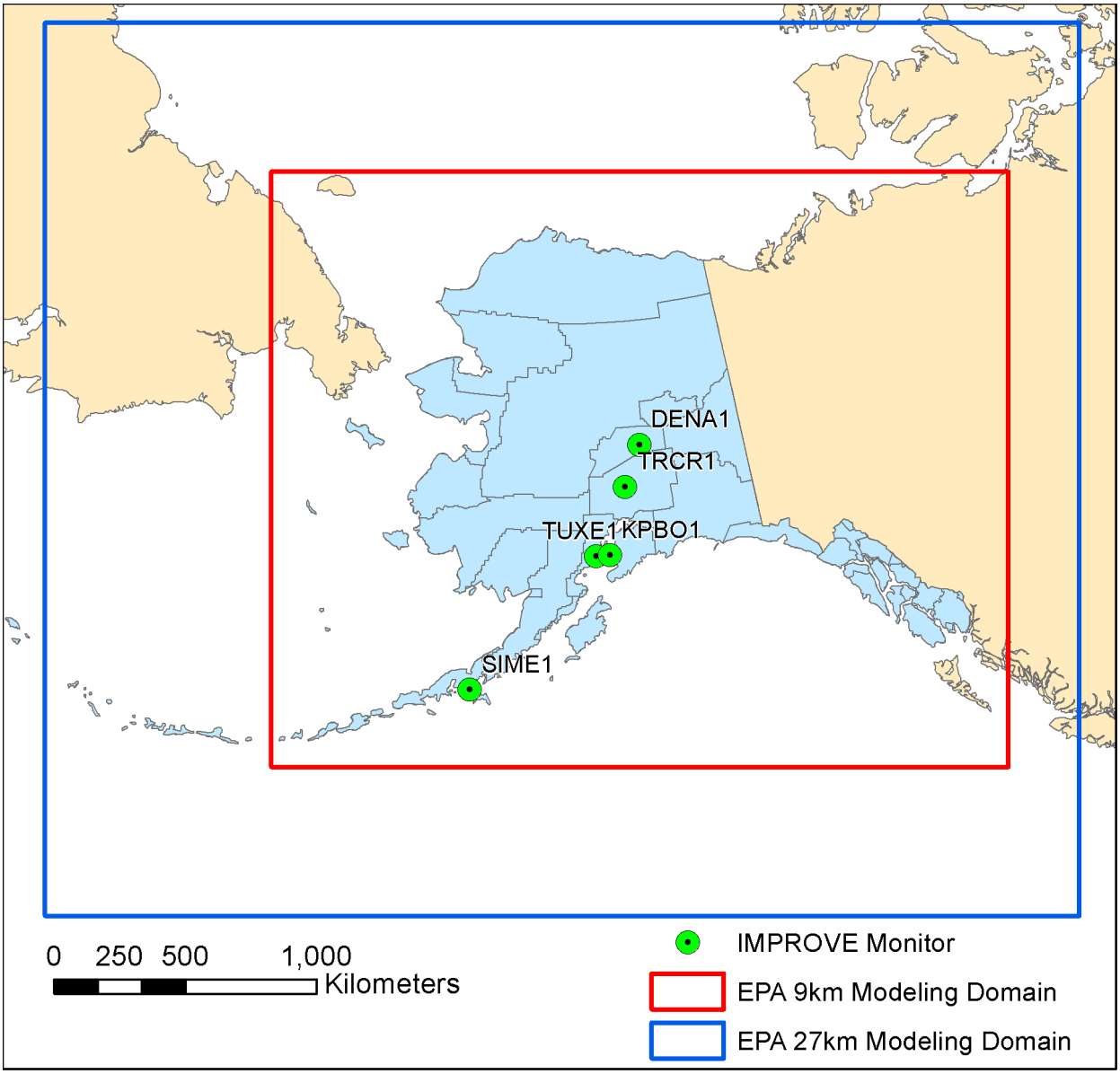
Included Sources – The 2016 and 2028 EIs include all known stationary point and area sources including fugitive dust, both anthropogenic and natural fires, and on-road and non-road mobile sources. Included sources are briefly described below:

- Electrical generating units (EGU) are stationary point sources and include both external combustion boilers and internal combustion (IC) engines (turbines and reciprocating IC engines). Fuel types included subbituminous coal, distillate oil, and natural gas.
- Non-EGU point sources are the remaining point sources including fuel combustion from external boilers and IC engines used in non-electricity generation industrial, commercial/institutional, and space heating applications. They also include major point source facility emissions from various industrial processes (e.g., chemical manufacturing, metal production, petroleum industry, oil and gas production), petroleum and solvent evaporation, and waste disposal.
- Stationary area sources (non-point) include those stationary sources not directly represented as major facility point sources, as well as other source categories for which emissions occur over areas rather than individual locations (e.g., fugitive dust).
- Non-road mobile sources include off-road vehicles and equipment (loaders, excavators, tractors/dozers, forklifts, scrapers, graders, etc.), lawn and garden, agricultural equipment, pleasure craft, snowmobiles and snowblowers, all-terrain vehicles, and off-road motorcycles. Commercial marine vessels and aviation emissions (from both aircraft and ground support equipment) were also included but were treated separately for reporting and tabulation purposes within the regional haze inventory.
- On-road mobile sources include all on-road vehicle types (e.g., passenger cars, light-duty trucks, heavy-duty trucks, buses, and motorcycles).

[2] What are referred to as "counties" in the contiguous states within the U.S. are termed "boroughs," "municipalities" or "census areas" in Alaska. From this point forward, they are referred to interchangeably.

Biogenic sources were included in the EPA's CMAQ modeling but were not included in the emission summary. Geogenic sources and oceanic DMS emissions were not included in the 2016 EI (thus, not in the EPA's CMAQ modeling platform). These emissions were calculated separately to provide relative contributions of sulfur emissions from natural sources common to Alaska (See Section III.K.13.E.4).

Figure III.K.13.E-1 Areal Extent of Alaska Regional Haze Modeling Domain



Given this overview, specific elements of the 2016 baseline and 2028 forecasted inventories are described below.

A. 2016 Baseline Inventory

The emissions inventory used for this planning period is the 2016 EI. The State of Alaska submits emissions inventory data to the EPA on a yearly and triennial basis, with triennial being the more complete dataset. Each triennial EI is composed of both stationary and mobile source data, including major emissions categories like aviation and highway/on-road emissions from cars and trucks. Yearly emissions data, by comparison, is comprised of only the larger stationary emissions sources, such as factories or electrical generation units. The smaller emissions sources and non-point source are only updated during triennial emissions years. As a result, on-road and mobile source emissions are carried forward from the last full triennial inventory. In this inventory, then, all non-point data has been carried forward from the 2014 NEI as it was submitted to the EPA.

The NEI figures, while representing a full estimation of the emissions generated within the state, do not provide seasonal differentiation. For Alaska, this is important to note as there can be significant differences in seasonal emissions for some categories of non-point sources, like woodstoves or maritime activity. These activities are largely limited seasonally, although woodstoves have some limited use during summer. Leaving out seasonal differentiation makes it difficult for analysts to connect seasonal increases of specific categories with impairment events that show up in yearly datasets, such as local use of woodstoves during winter months.

Certain categories of emissions can be assumed to have occurred during specific seasons. Wildfires are a spring and summer occurrence in Alaska and very rarely burn before April or after October. Prescribed burning and crop burning generally occur during fall and winter to prevent wildfire ignition. This is a result of unfavorable weather and climatic conditions with snowfall and cooler weather making natural (or anthropogenic) ignition difficult. Wildfire activity can significantly vary between years due to yearly changes in rainfall and weather patterns. During the current visibility period (2014-18), 2015 had significantly higher wildfire activity with over five million acres burned that year. The following year only a half-million acres burned, a significant variance in acreage that can have large impacts on visibility measurements at Class I areas throughout the state.

B. 2028 Future-Year Inventory

Rather than using baseline inventory figures and Alaska Department of Labor population growth statistics, DEC is relying on the 2028 future year inventory developed by the EPA. This inventory uses the 2016 EI as a baseline inventory, along with state and national growth figures, to project future year emissions. DEC was heavily involved with fact-checking certain categories of emissions data provided to the state by EPA, including maritime and aviation emissions, which are significant areas of human activity within the state.

During the data review period for the 2028 future inventory, DEC analysts spent a significant amount of time reviewing the 2028 marine inventory. Like aviation, the marine industry operates throughout most of the state and provides critical transportation services to residents and private businesses. Given port sizes and infrastructure capacity in rural Alaska, it was necessary for DEC to spend more time reviewing and fact-checking emissions data provided by EPA to ensure that

marine engine class results would match infrastructure and port specifications. In addition, marine sector-related impairment has been identified as a source of visibility impairment at coastal Class I areas. For future forecasting purposes, EPA modeling used 2016 emissions as the 2028 baseline while including emissions reductions predicted with the advent of global low-sulfur diesel use under IMO regulations. See Section K.13.H for the state's long-term strategy and closer analysis of this sector.

In addition to the 2028 marine inventory, DEC reviewed EPA's 2028 aviation inventory. This is due to the central role of aviation in the state's transportation infrastructure, as most off-road communities rely on small aircraft to bring residents to and from hub communities. As a result, several inconsistencies and data gaps were identified within the inventory which resulted in significant problems for its use. This included leaving out take-off and landing (LTO) emissions from major hub communities, including Anchorage, as well as smaller regional hubs like Unalaska and Nome. Without Anchorage LTO data, it is extremely difficult to apply the dataset to Class I area haze estimates at the end of the implementation period.

Along with these inventory-specific problems, the more general problem is that the rapid pace of economic changes brought about by the COVID-19 pandemic makes it difficult to project pre-2020 emissions data into the future. The economic and logistical fallout from COVID, including the suspension of cruise ships up the Inside Passage and the halting of most tourist activity, has created an environment of significant uncertainty moving into the decade. Any 2028 emissions estimates should be taken as products of pre-COVID projections. It is likely that all future estimates for stationary and mobile source emissions will need to be recalculated once the pandemic has been brought under control and economic fallout can be properly estimated. Given the scale of the economic and social impact from the pandemic, more complete economic loss figures will take time to calculate.

C. Summary of 2016 and 2028 Emission Inventories

Tables III.K.13.E-1 and III.K.13.E-2 (and Figures III.K.13.E-2 and III.K.13.E-3) show total statewide annual emissions (in tons/year) by source sector and pollutant for the calendar years 2016 and 2028 inventories, respectively. In addition to the totals across all source sectors, anthropogenic emission fractions (defined as all sectors except natural fires divided by total emissions) are also shown at the bottom of each table. Clearly, natural wildfires represent an overwhelming majority of emissions for all pollutants except NO_x and SO_2 for which they contribute 18% and 39%, respectively, of all emissions statewide. Note that uncontrollable sources including volcanoes, oceanic DMS, and international shipping (non-US SECA C3 sector in the EPA inventories) emissions that contribute the majority of SO_2 emissions in Alaska areas are not included in these tables.

Table III.K.13.E-1. 2016 Alaska Statewide Regional Haze Inventory Summary

Source Sector	Annual Emissions (tons/year)					
	VOC	CO	NO_x	$PM_{2.5}$	SO_2	NH_3
Agriculture	9	-	-	-	-	109
Airports	2,008	13,478	4,417	271	576	-
Rail	17	48	386	11	0	0
CMV - C1/C2*	216	956	6,317	160	11	3
CMV – C3*	1,998	4,310	46,238	3,123	23,736	60
Non-road	8,600	34,126	2,580	358	7	6
On-road	8,228	60,101	11,977	489	33	153
Non-point	8,224	28,956	6,307	2,500	1,510	564
RWC	820	5,073	90	712	16	34
Fugitive dust	-	-	-	1,054	-	-
Oil & Gas	26,974	13,128	42,779	540	1,702	0
EGU	307	2,445	7,793	240	1,304	2
Other Points	800	2,562	7,291	478	1,394	48
Fires	743,060	3,165,511	29,644	262,648	19,646	51,691
Total - All Sources	801,260	3,330,692	165,819	272,583	49,935	52,670
Anthropogenic Fraction	7%	5%	82%	4%	61%	2%

* This table includes marine emissions in Alaska waters and offshore to EZZ.

Table III.K.13.E-2. 2028 Alaska Statewide Regional Haze Inventory Summary

Source Sector	Annual Emissions (tons/year)					
	VOC	CO	NO_x	$PM_{2.5}$	SO_2	NH_3
Agriculture	10	-	-	-	-	119
Airports	1,945	14,915	4,371	257	598	-
Rail	18	48	391	11	0	0
CMV - C1/C2*	114	958	3,500	91	4	2
CMV – C3*	2,836	6,118	59,990	2,430	7,080	47
Non-road	5,297	30,035	1,722	201	4	7
On-road	4,142	30,961	4,789	217	23	136
Non-point	8,043	29,242	6,725	2,518	1,524	650

RWC	759	4,731	93	647	13	30
Fugitive dust	-	-	-	1,063	-	-
Oil & Gas	26,606	13,101	42,703	537	1,697	0
EGU	307	2,445	7,793	240	1,304	2
Other Points	736	2,559	7,269	483	1,404	48
Fires	743,060	3,165,511	29,644	262,648	19,646	51,691
Total - All Sources	793,874	3,300,624	168,989	271,342	33,296	52,732
Anthropogenic Fraction	6%	4%	82%	3%	41%	2%

* This table includes marine emissions in Alaska waters and offshore to EZZ.

Figure III.K.13.E-2. 2016 Alaska Statewide Regional Haze Inventory Summary. The right panel shows SO_2 and NO_x from anthropogenic sources only.

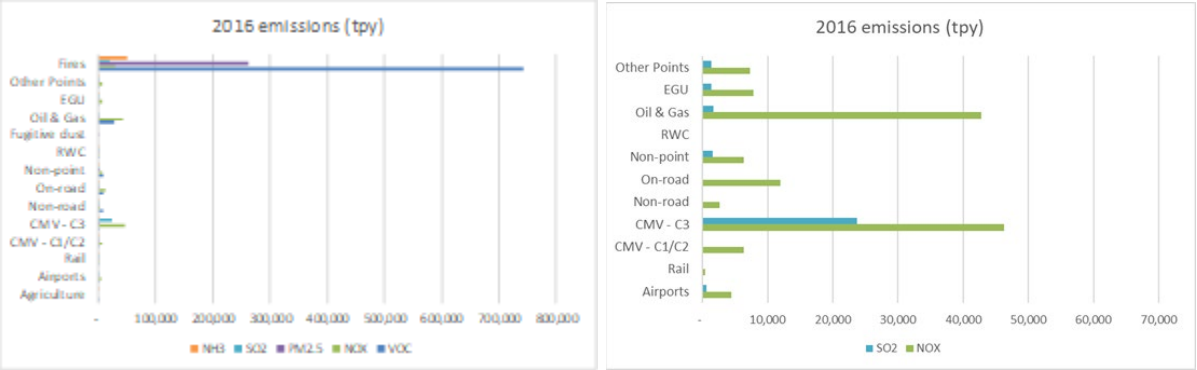


Figure III.K.13.E-3. 2028 Alaska Statewide Regional Haze Inventory Summary. The right panel shows SO_2 and NO_x from anthropogenic sources only.

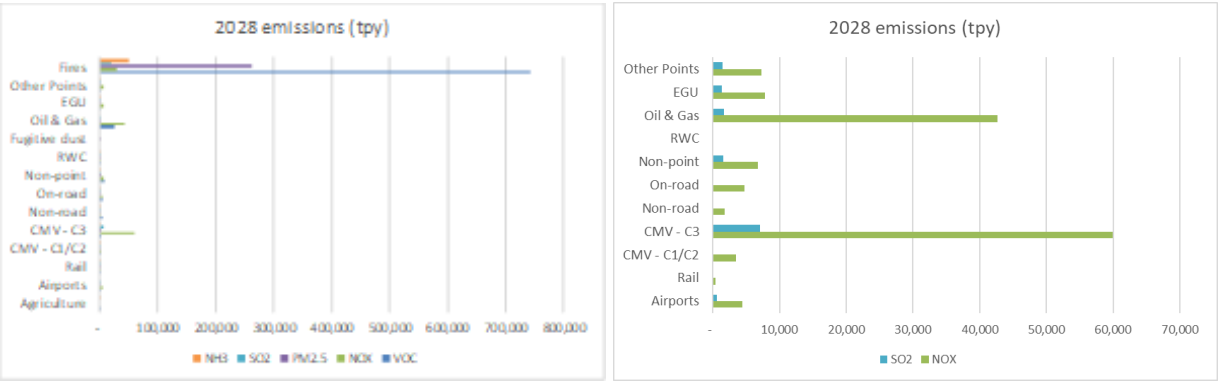


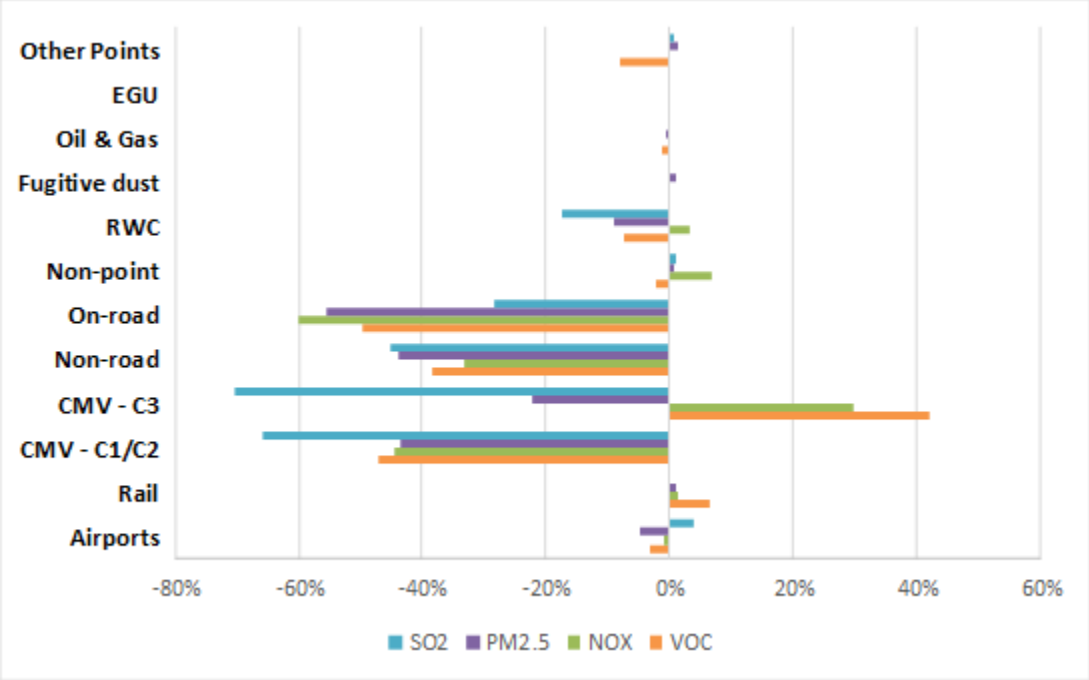
Table III.K.13.E-3 and Figure III.K.13.E-4 summarize the relative changes in statewide emissions by source sector and pollutant from 2016 to 2028. Emission increases (positive changes) are shown in red; emission decreases (negative changes) are shown in black. The relative changes in total pollutant emissions from 2016 to 2028 are very modest due to the large

emissions contribution from natural fires, which were assumed to remain constant over this period. Decrease in total SO_x emissions of 33% is projected on a statewide basis, while changes to other pollutants are minimal (within 2%). Anthropogenic SO_2 emissions decrease notably from commercial marine vessels, category 3 (CMV C3) (-70%); commercial marine vessels, categories 1 and 2 (CMV C1/C2) (-66%); non-road (-45%); and on-road (-28%). Anthropogenic NO_x emissions decrease significantly from CMV C1/C2 (-45%), on-road (-60%), and non-road (-33%) decrease significantly. However, these emission decreases are offset by increases in CMV C3 (30%).

Table III.K.13.E-3. Relative Change in Alaska Regional Haze Emissions from 2016 to 2028

Source Sector	Percentage Emissions Change 2016-2028					
	VOC	CO	NO_x	$PM_{2.5}$	SO_2	NH_3
Agriculture	10%					10%
Airports	-3%	11%	-1%	-5%	4%	
Rail	7%	1%	1%	1%	0%	0%
CMV - C1/C2	-47%	0%	-45%	-43%	-66%	-43%
CMV - C3	42%	42%	30%	-22%	-70%	-22%
Non-road	-38%	-12%	-33%	-44%	-45%	5%
On-road	-50%	-48%	-60%	-56%	-28%	-11%
Non-point	-2%	1%	7%	1%	1%	15%
RWC	-7%	-7%	3%	-9%	-17%	-10%
Fugitive dust				1%		
Oil & Gas	-1%	0%	0%	-1%	0%	0%
EGU	0%	0%	0%	0%	0%	0%
Other Points	-8%	0%	0%	1%	1%	-1%
Fires						
Total - All Sources	-1%	-1%	2%	0%	-33%	0%

Figure III.K.13.E-4. Relative Change in Alaska Regional Haze Emissions from 2016 to 2028 by source category



3. CURRENT ALASKA POPULATION STATISTICS

The population of Alaska as of 2021 has dropped below 730,000 for the first time since 2010, following trends that have picked up speed over the last decade. This is in large part a result of a statewide economic recession and market forces that resulted in oil industry job losses associated with North Slope oil developments. The oil and natural gas industry has remained stable in the Cook Inlet region, though this field represents a much smaller percentage of petroleum reserves in the state than the remaining wells in the Prudhoe Bay region.[3, 4]

The oil and natural gas industry has been the major economic engine of the state since the discovery of large petroleum deposits and subsequent lease sale in the late 1960s. Along with driving economic growth, it played a large role in population migration from the contiguous United States to Alaska starting with the construction of the Trans-Alaska Pipeline System (TAPS) in the mid-1970s. Since then, the boom and bust nature of the oil and natural gas sector has been mirrored in the state's population figures.

Marked population declines occurred during periods of depressed global petroleum prices in the 1980s. More recently, national and global market forces depressed petroleum prices worldwide, which has had an impact on Alaska North Slope crude oil and gas activities. Along with the recent economic disturbances caused by the ongoing COVID-19 epidemic, the state petroleum

[3] For more information on current Cook Inlet oil production, see the following fact sheet from the Alaska Oil and Gas Commission: http://www.circac.org/wp-content/uploads/AOGA_CI_Fact_Sheet.pdf (Accessed 4/5/2021).
[4] Information on Arctic North Slope (ANS) daily production figures starting in 1981 are available from the U.S. Energy Information Administration at: https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MANFPAK2&f=M (Accessed 4/5/2021).

industry has experienced challenges that impact the size and scope of individual oil and gas development projects and production activities.

This was (until recently) the opposite in the state's burgeoning tourism industry. Tourist numbers and revenue have been growing throughout much of the last decade, with yearly increases of annual travelers. Large ocean-going cruise vessels have been increasing in size and numbers, most utilizing routes traveling up the Inside Passage, originating in Seattle and Vancouver, British Columbia, and terminating in Whittier or Seward on the Kenai Peninsula or at the Port of Anchorage.

This industry has been significantly impacted by the COVID-19 epidemic, with the 2020 cruise season all but cancelled and the 2021 season also impacted. While the tourist industry was not as significant of a population migration pull as the petroleum industry, multiple years of no or limited tourist activity could act as an accelerant on these population loss trends. DEC planners should revisit the issue of population loss trends during the progress report to update 2028 emissions modeling using post-COVID population statistics. As with most other economic or population indicators at this time, the long-term impact of the 2019-2021 COVID pandemic will likely not be apparent for several years after viral spread has been brought under control.

For emissions calculation purposes, this population trend will impact short and long-term calculations for most sectors of emissions, including power plants. These calculations are used in the EI future projections, and DEC uses current and future population figures by borough or census area when building residential emissions inventories. As discussed in the first Regional Haze plan, representative communities (RepComs) are used as stand-ins for boroughs or census areas, and population fractions are calculated to allow for population scaling. For future forecasting purposes, population growth or reduction percentages are used for calculating each population fraction applied to RepCom emissions.

Table III.K.13.E-4 lists the Alaska 2020 population by Region and Borough/Census Area (CA). The Anchorage Borough and Municipality has 40% of the Alaska population with the Fairbanks North Star Borough (FNSB) accounting for another 13%.

Table III.K.13.E-4. Current (2020) Population by Region and Borough/Census Area[5]

Region and Borough/CA	Population Size
Southcentral Alaska	
Anchorage Borough and Municipality	288,970
Matanuska-Susitna Borough	107,305
Regional Total	*399,269*
Alaska Gulf Coast	
Chugach Census Area	6,751
Copper River Census Area	2,699
Kenai Peninsula Borough	58,934

[5] Table taken from Alaska Department of Labor and Workforce Development 2020 Population Estimates, available at: https://live.laborstats.alaska.gov/pop/ (Accessed 1/12/2021).

Region and Borough/CA	Population Size
Kodiak Island Borough	12,611
Regional Total	*81,048*
Interior Alaska	
Fairbanks North Star Borough	97,159
Southeast Fairbanks Census Area	6,937
Denali Borough	1,806
Yukon-Koyukuk Census Area	5,044
Regional Total	*110,067*
Northern Alaska	
North Slope Borough	9,771
Northwest Arctic Borough	7,583
Nome Census Area	9,769
Regional Total	*27,484*
Southeastern Alaska	
Haines Borough	2,520
Hoonah-Angoon Census Area	2,074
City and Borough of Juneau	31,773
Ketchikan Gateway Borough	13,677
Petersburg Borough	3,189
Prince of Wales-Hyder Census Area	6,090
City and Borough of Sitka	8,523
Municipality of Skagway	1,147
City and Borough of Wrangell	2,379
City and Borough of Yakutat	574
Regional Total	*72,571*
Southwest Alaska	
Aleutians East Borough	2,925
Aleutians West Census Area	5,544
Bethel Census Area	17,868
Bristol Bay Borough	868
Dillingham Census Area	4,773
Kusilvak Census Area	8,088
Lake and Peninsula Borough	1,552
Regional Total	*42,295*
Alaska State Total	***728,903***

4. NATURAL EMISSIONS

Alaska's landscape is dominated by natural ecosystems rather than human dominated systems. Consequently, air quality in the state is strongly affected by natural emissions as well as human activities. Natural sources of visibility impairment emissions are those not directly attributed to human activities; they are not included in the anthropogenic point and area source inventory listed above. Natural emission impacts from within Alaska are seasonally driven with wildfire

smoke in the summer, windblown dust in the spring and summer, and oceanic DMS peaking in summer. Volcano eruptions are episodic while volcano degassing can occur year-round. Natural sources outside of Alaska can also contribute to visibility impairment at Alaska Class I areas.

The EPA's CMAQ modeling includes several natural sources such as biogenic, sea-salt, and oceanic halogen sources. Lightning, wind-blown dust, volcanic, and DMS emissions were not included in EPA's CMAQ modeling. Natural source emissions were assumed to remain constant in 2028 from 2016.

A. Biogenic Emissions Sources

Forest and tundra ecosystems produce a wide variety of volatile organic hydrocarbons, with common groups being isoprenes and monoterpenes. Production of biogenic VOCs varies by latitude, plant species, diurnal cycles, temperatures, ultraviolet light, meteorology, and even browsing pressure. Some biogenic VOC species (e.g., isoprene and terpenes) can form secondary organic aerosols (SOA) that can impair visibility. Biogenic emissions of VOC and nitric oxide (NO) were included in the EPA's 2016 CMAQ modeling platform, hence were included in the visibility impact modeling. EPA used the Model of Emissions for Gases in Nature (MEGAN) version 2.06 and 2016 meteorology to estimate the 2016 biogenic emissions.

B. Wildland and Prescribed Fires

Historically, the most significant source of visibility impairment in the Alaska airshed is from wildfire activity in the Alaska and Canadian interiors. Prior to the 1990s, the state had large wildfires which would ignite once or twice per decade and cause air quality decline in urban areas and at Class I areas. In the past three decades the wildfire cycle has sped up with increasing change in the Arctic climate. As a result, the large wildfire cycle has shrunk to once every three years, with instances of higher temperatures, lower rainfall, and the regional spread of spruce-bark beetle infestation expanding areas of elevated wildfire risk. In addition, there has been an increase in tundra fires along the northern and western coasts, which further expands the total acreage at risk from wildfire activity.

The seasonal fires in the Alaska interior ignite in spring following the winter snowmelt in April and May. These wildfires burn through the end of August when warm weather gives way to late summer and early fall rains. In some instances, such as the 2016 and 2019 wildfire seasons, significant fire activity continued into September due to irregular dry spells compared to normal weather patterns.

Two sets of fire emissions are considered for regional haze planning: the EPA's fire emission inventory (see Table III.K.13.E-5) and the DEC's fire emission inventory (Table III.K.13.E-6). EPA used SmartFire2/BlueSky framework[7] to estimate day-specific wildland fire emissions.

[6] Guenther, A., Karl, T., Harley, P., Wiedinmyer, C., Palmer, P., Geron, C., 2006. Estimates of global terrestrial isoprene emissions using MEGAN (Model of Emissions of Gases and Aerosols from Nature).
[7] Baker, K., Woody, M., Tonnesen, G., Hutzell, W., Pye, H., Beaver, M., Pouliot, G., Pierce, T., 2016. Contribution of regional-scale fire events to ozone and PM 2.5 air quality estimated by photochemical modeling approaches. Atmospheric Environment 140, 539-554.

DEC generated fire emissions are based data from the Alaska Interagency Coordination Center (AICC). The perimeters of the fires use LANDFIRE to incorporate accurate Alaska vegetation types. DEC submits wildfire emissions to EPA every three years in the triennial emissions inventory. While there are differences between the two fire emission inventories, they both indicate large inter-annual variability of wildfires in the state. The DEC fire emission inventory was not used in the visibility analysis.

Table III.K.13.E-5. EPA Fire Emissions Inventory for Alaska.

Year	$PM_{2.5}$	CO	NH_3	NO_x	SO_2	VOC
NEI 2014	173,409	2,104,317	34,331.	18,135	12,579	49,3519
2016	262,648	3,165,511	51,591.	29,644	19,646	743,060
NEI 2017	372,347	4,529,099	73,869	37,869	26,718	1,060,873

Table III.K.13.E-6. ADEC Fire Emissions Inventory for Alaska

Year	$PM_{2.5}$	CO	NH_3	NO_x	SO_2	VOC
2014	160,933	1,919,071	8,632	41,170	11,288	90,310
2015	3,147,159	37,739,788	169,764	809,643	221,999	1,775,990
2016	239,006	2,866,092	12,892	61,487	16,859	134,875
2017	112,824	1,047,849	7,051	87,438	23,975	88,849

Alaska has been recording fire emissions since the early 1980s, and this data shows the increase of both the numbers and acreage of wildfires that trends upwards (see Figure III.K.13.E-5 and Figure III.K.13.E-6).

Figure III.K.13.E-5. 1990-2017 Wildfire in Numbers

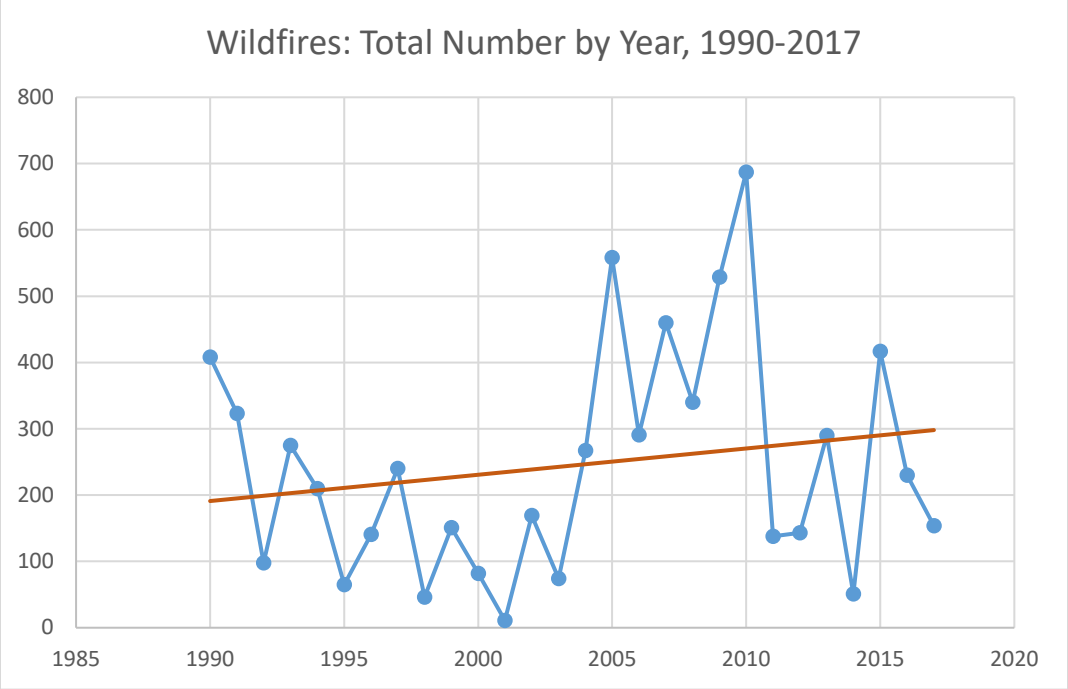
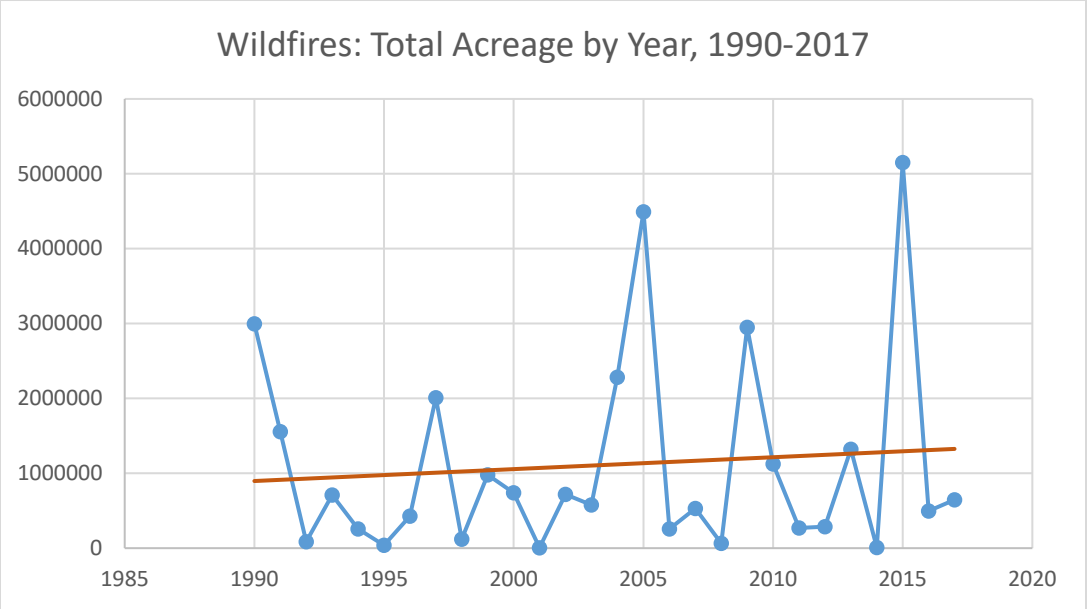


Figure III.K.13.E-6. Wildfires 1990-2017 in Acres



Similarly, Alaska maintains information on human caused and prescribed fire information which EPA data includes but is not specifically identified. Alaska data for human caused fires – both

prescribed and land clearing and accidental fires is available and is used for developing goals in Section III.K.13.H (Long Term Strategy).

C. Sea Salt

Sea salt, a major component of marine aerosols, is formed by the evaporation of water ejected from wind whipped whitecaps and breaking waves. The production of sea salt aerosol and its size distribution are very sensitive to wind speed and surface conditions. Although most of the sea salt aerosol mass is in the size fraction above 1 μm diameter, a small but significant fraction of the sea salt aerosol is in the submicrometer fraction. The large particles have high settling velocities, resulting in relatively short residence times. The remaining particles are smaller, have a longer residence time, transport over longer distances, and impact visibility. Sea salt has been identified as a significant contributor to visibility impairment at all of the Class I areas in Alaska.

D. Oceanic Dimethyl Sulfide

Oceanic DMS emissions are the main natural source of global atmospheric sulfur (Simó, 2001)[8] that is precursor to sulfate aerosol. DMS [$(CH_3)_2S$] is an organosulfur compound produced by the breakdown of dimethylsulfoniopropionate (DMSP), a compound in some marine algae, through synthesis by phytoplankton. DMS emissions are estimated for Alaska using monthly climatologies of surface ocean DMS concentration and sea-to-air emission flux as a function of wind speed and temperature as described by Lana et al. (2011)[9]. The North American Mesoscale Forecast System (NAM)[10] data provides temperature and wind speed at 12 km resolution to derive DMS emissions flux (Figure III.K.13.E-7). The yield of DMS to SO_2 can vary. The yield of DMS into SO_2 as implemented in a GEOS-Chem global model is 75%[11]. Recent discovery of stable intermediate in the DMS oxidation process, hydroperoxymethyl thioformate (HPMTF) suggests that addition of the HPMTF pathway may reduce SO_2 approximately 10-30% in the Gulf of Alaska[12]. In this analysis the DMS emissions were scaled by a 0.6 factor to account for the amount of DMS that is likely ultimately oxidized to SO_2.

8 Simó, R. 2001. Production of atmospheric sulfur by oceanic plankton: biogeochemical, ecological and evolutionary links, Trends Ecol. Evol., 16(6), 287–294

9 Lana, A., Bell, T.G., Simó, R., Vallina, S.M., Ballabrera-Poy, J., Kettle, A.J., Dachs, J., Bopp, L., Saltzman, E.S., Stefels, J.J.G.B.C. and Johnson, J.E., 2011. An updated climatology of surface dimethlysulfide concentrations and emission fluxes in the global ocean. Global Biogeochemical Cycles, 25(1).

10 The North American Mesoscale Forecast System (NAM) is one of the major regional weather forecast models run by the National Centers for Environmental Prediction (NCEP) for producing weather forecasts. https://www.ready.noaa.gov/data/archives/nams/README.TXT

11 Chen, Q., T. Sherwen, M. Evans and B. Alexander. 2018. DMS oxidation and sulfur aerosol formation in the marine troposphere: a focus on reactive halogen and multiphase chemistry. Atmos. Chem. Phys., 18, 13617-13637. http://eprints.whiterose.ac.uk/136782/1/acp_18_13617_2018.pdf

12 Veres, P.R., et al., 2020. Global airborne sampling reveals a previously unobserved dimethyl sulfide oxidation mechanism in marine atmosphere. PNAS March 3, 2020 117 (9) 4505-4510. https://www.pnas.org/content/117/9/4505

Figure III.K.13.E-7. Monthly DMS flux in July, August, and September 2016 (from left to right). The domain coverage is defined by the NAM data available for Alaska

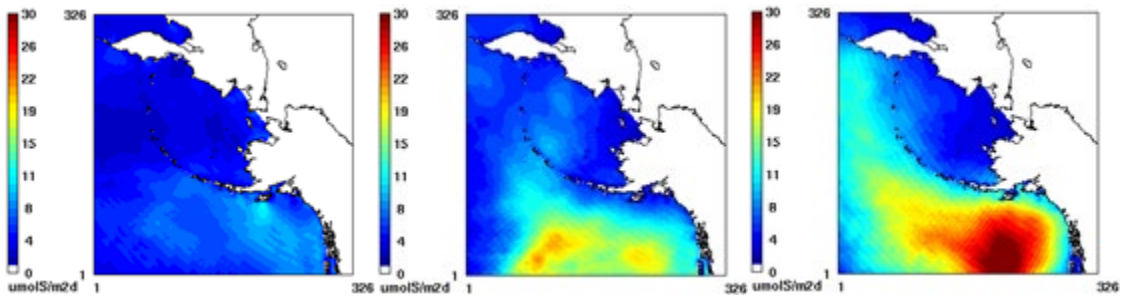
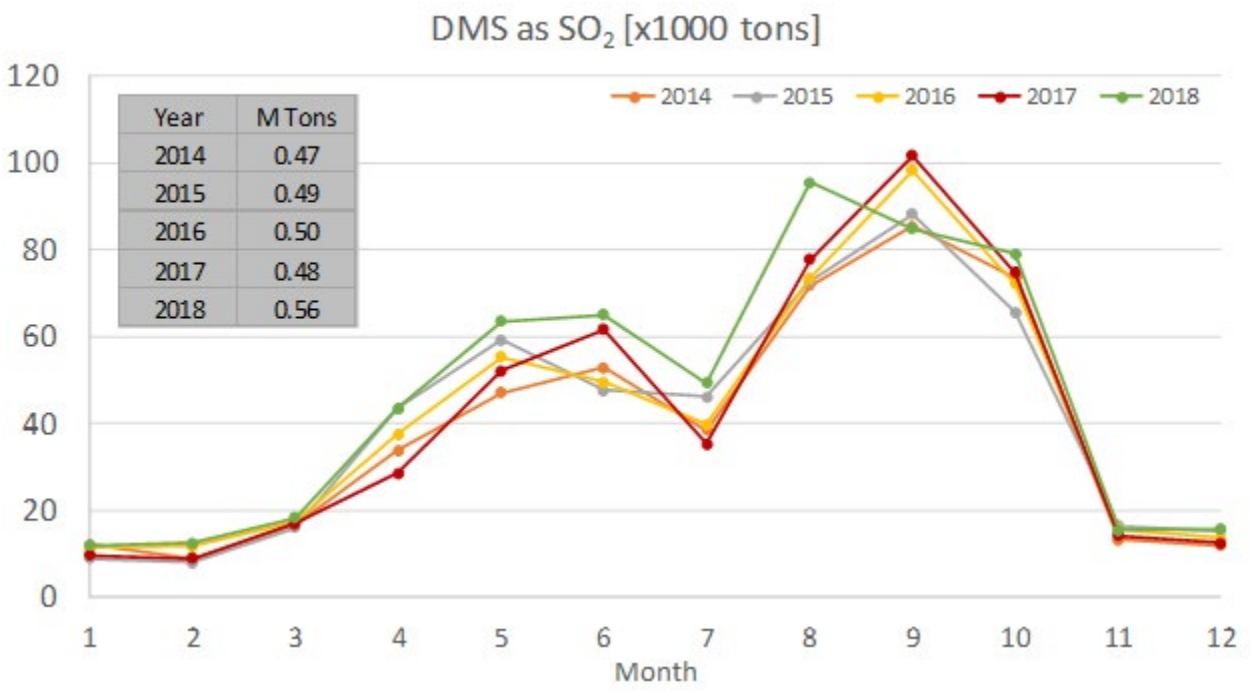


Figure III.K.13.E-8 displays monthly emissions for years 2014 to 2018 for areas approximating the EPA's CMAQ 27-km grid resolution domain (domain extent shown in Figure III.K.13.E-1). DMS emissions increase during the summer due to higher biological activity. The estimated DMS emissions exhibit limited inter-annual variability with an average annual emission of 454 thousand tons per year (SO_2 equivalent) or 37% of total SO_2 emissions in 2016 within the CMAQ 27-km domain (more detail in Section III.K.13.G). Undoubtedly, oceanic DMS is a significant natural sulfur source that can impact measured sulfate at Alaska IMPROVE sites, especially at Simenof and Tuxedni given their proximity to the ocean.

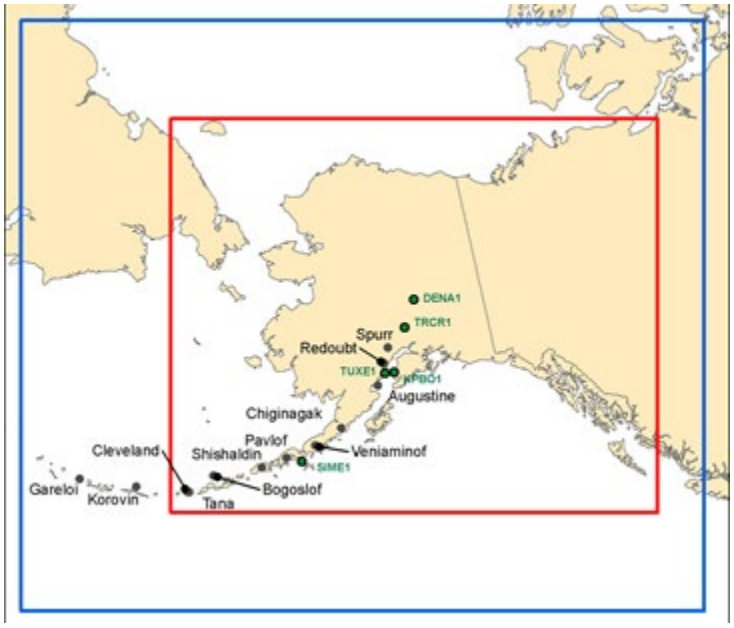
Figure III.K.13.E-8. Monthly DMS emissions during 2014-2018 for the area approximating the EPA's CMAQ 27-km grid resolution domain



E. Geogenic Sources

Alaska is home to many active and dormant volcanoes and has seen some of the largest eruptive events of the last century. The largest volcanic eruption of the twentieth century took place in 1912 at what is now Katmai National Park in an eruption known as 'Novarupta.' The U.S. Geological Survey (USGS) operates the Alaska Volcano Observatory (AVO) with the Alaska Division of Geological and Geophysical Surveys and the University of Alaska Fairbanks (UAF) Geophysical Institute. There are currently 40 active volcanoes in the state. There are several active and dormant volcanoes located near Class I areas, including Mount Pavlof located near the Simeonof Class I area. Near the Tuxedni Class I area are Mount Iliamna and Redoubt Volcano (Figure III.K.13.E-9). There have been several major and minor eruptions during the first planning period from Alaska volcanoes.

Figure III.K.13.E-9. Alaska Volcanoes and IMPROVE monitors



For Alaska air quality planning purposes, geogenic visibility is an unpredictable influence with little warning of potential eruptive events that can have significant visibility impacts. As a natural process and one which is relatively common in Alaska and in the other non-contiguous state (Hawaii), it is a reality that must be expected. In addition to Alaska volcanoes, Class I areas have received noticeable amounts of geogenic emissions from active volcanoes located on the Kamchatka Peninsula and Kurile Islands in the Russian Far East. Air quality impacts are nominal compared with eruptive events from Alaska volcanoes due to distances involved, along with atmospheric scouring over the Bering Sea and North Pacific Ocean. Generally, the impacts from Russian volcanic eruptions are mild, and the greatest impact is felt by airlines and air cargo companies rerouting to avoid volcanic plumes.

Volcanic activity can be organized under two broad categories: volcanic eruptions and volcanic degassing. Both represent different activities that can have measurable impacts on Alaska Class I areas. Active eruptions are periodic events which could disrupt visibility with the large release of

volcanic gases and particles. These are generally limited in terms of their yearly impact. Degassing, by comparison, is the low-level release of volcanic gases, like SO_2, at levels not high enough to be classified as a volcanic eruption, but still large enough to potentially impact visibility. Volcanic degassing is a regular occurrence in Alaska. The AVO and USGS maintain active and passive monitoring of all Alaska's active and dormant volcanoes to ensure locals and air companies have warning if and when volcanoes move from degassing into erupting.

The most abundant gas typically released into the atmosphere from volcanic systems is water vapor, followed by carbon dioxide (CO_2) and SO_2. Volcanoes also release smaller amounts of other gases, including hydrogen sulfide (H_2S), hydrogen (H), carbon monoxide (CO), hydrogen chloride (HCl), hydrogen fluoride (HF), and helium (He). Large explosive eruptions inject a tremendous volume of sulfur aerosols into the stratosphere, which depending on wind speed and direction can significantly impact any of the Class I areas located in Alaska.

Volcanoes are important sources of sulfur dioxide (VSO_2) and are required as climate model inputs because they impact the tropospheric burden of sulfate aerosols. The non-explosive gas release can occur by advection through fractures or diffuse degassing through permeable ground and on an annual basis can be much more than eruptive emissions. Fischer et al (2019)[13] estimated that during 2005 to 2015, global VSO_2 emissions (from approximately 900 volcanoes) during eruptions were 2.6 Tg (teragram) per year compared to 23.2 Tg per year from passive degassing.

Accurate inventories of the spatial and temporal distribution of VSO_2 are difficult to obtain from ground-based measurements due to their sparse coverage spatially and temporally. Satellite-derived measurements allow for greater and more consistent coverage. Recent advances in satellite remote sensing techniques have greatly improved limitations on the eruptive and non-eruptive flux of SO_2 from volcanoes[14,15,16,17]. The NASA Goddard Earth Science Data and Information Services Center (GES DISC) produces a new global inventory of VSO_2 emissions for 2005-2019 by means of combining measurements from backscatter ultraviolet (BUV), thermal infrared (IR) and microwave (MLS) instruments on multiple satellites. Specifically, eruptive emissions are obtained from the Ozone Mapping and Profiler Suite (OMPS) nadir mapper (NM) located on the Suomi National Polar-orbiting Partnership (SNPP) satellite (Carn, 2019)[18]. Degassing emissions are obtained from Ozone Monitoring Instrument (OMI), a UV

[13] Fischer, T.P., Arellano, S., Carn, S., Aiuppa, A., Galle, B., Allard, P., Lopez, T., Shinohara, H., Kelly, P., Werner, C. and Cardellini, C., 2019. The emissions of CO2 and other volatiles from the world's subaerial volcanoes. *Scientific reports*, *9*(1), pp.1-11.
[14] Carn, S. A., Clarisse, L. & Prata, A. J., 2016. Multi-decadal satellite measurements of global volcanic degassing. *J. Volcanol. Geotherm. Res.* **311**, 99–134, http://dx.doi.org/10.1016/j.jvolgeores.2016.01.002.
[15] Carn, S.A., Fioletov, V.E., McLinden, C.A., Li, C. and Krotkov, N.A., 2017. A decade of global volcanic SO2 emissions measured from space. *Scientific reports*, *7*, p.44095.
[16] Clarisse, L. et al., 2012. Retrieval of sulphur dioxide from the infrared atmospheric sounding interferometer (IASI). *Atmos. Meas. Tech*. **5**, 581–594, http://dx.doi.org/10.5194/amt-5-581-2012.
[17] Theys, N. et al., 2013. Volcanic SO2 fluxes derived from satellite data: a survey using OMI, GOME-2, IASI and MODIS. *Atmos. Chem. Phys.*, **13**, 5945–5968, doi: 10.5194/acp-13-5945-2013.
[18] Carn, S.A., 2019. Multi-Satellite Volcanic Sulfur Dioxide L4 Long-Term Global Database V3, Greenbelt, MD, USA, Goddard Earth Science Data and Information Services Center (GES DISC), Accessed on November 2, 2020, 10.5067/MEASURES/SO2/DATA404

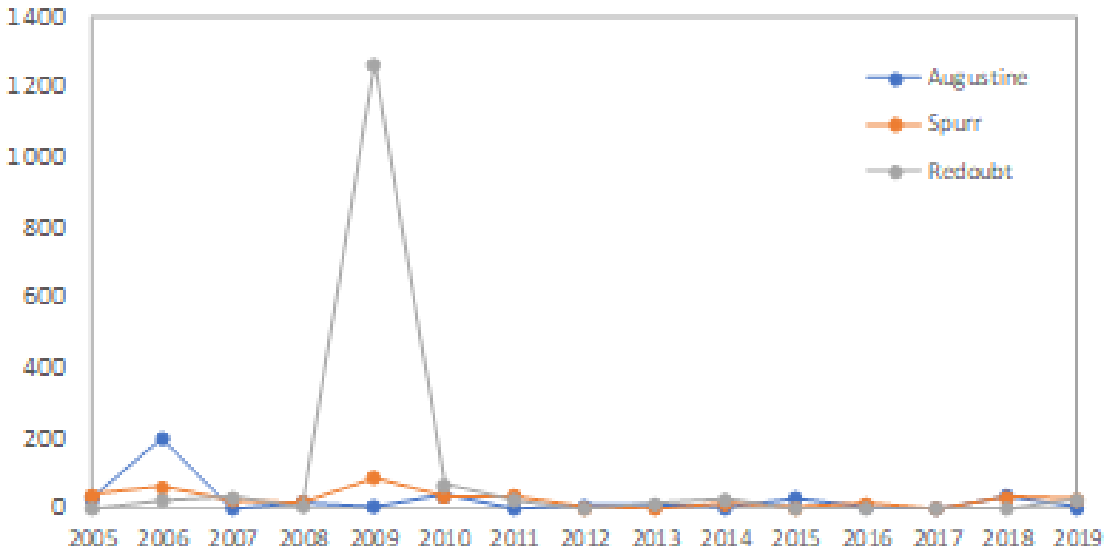
sensor located on NASA's Aura satellite (Fioletov et al., 2019)[19]. This top-down method combines all qualified daily OMI measurements (e.g., cloud free) during a particular year to provide a single cumulative rate of annual VSO_2 emissions for each volcano.

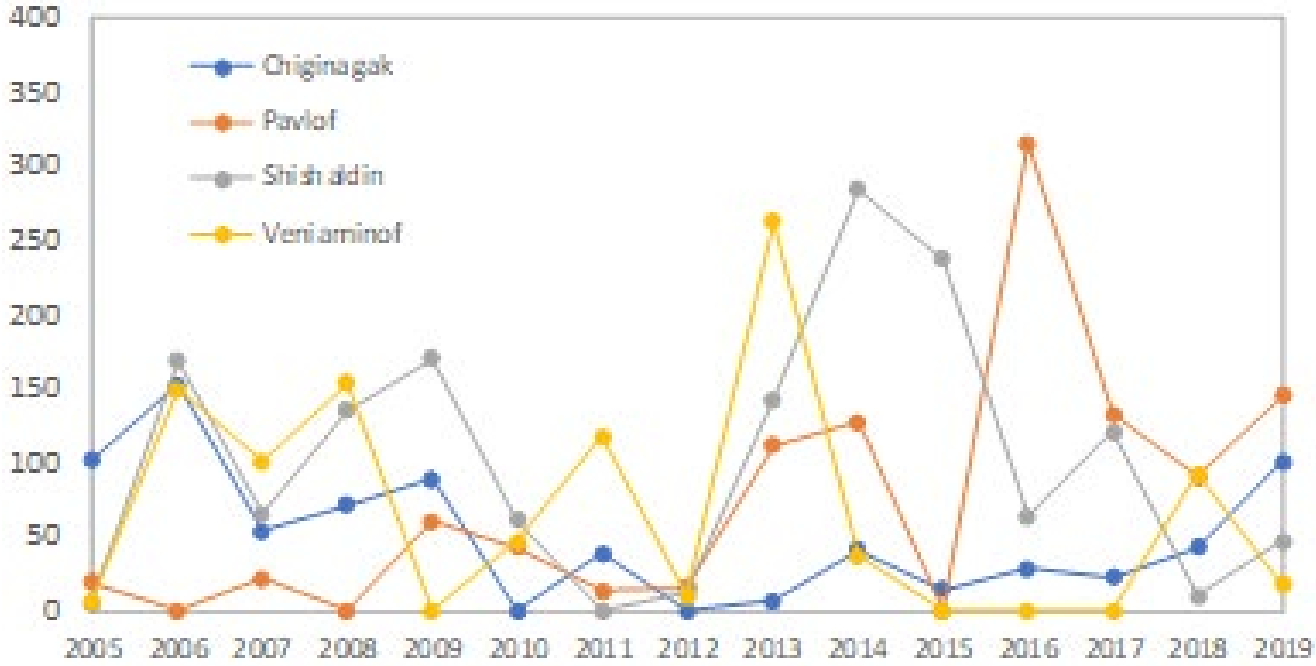
According to the NASA inventory, VSO_2 emissions in Alaska exhibit significant inter-annual variability ranging from 133 thousand tons (year 2012) to 1,957 thousand tons (year 2009) (Figure III.K.13.E-10). In 2016, VSO_2 alone is estimated to contribute 51% of total SO_2 emissions within the CMAQ 27-km grid resolution domain. Multiple volcanoes are located near the Alaska IMPROVE sites and can influence the measured $(NH_4)_2SO_4$ concentrations at these sites. Figure III.K.13.E-11 shows an example comparison of annual VSO_2 emissions and sulfate extinctions on the MID at the SIME IMPROVE site.

The higher VSO_2 emissions in 2009 include emissions from the eruption of the Redoubt volcano in southern Alaska that is located between Tuxedni and Anchorage that started March 15, 2009, and appears to be reflected in the SIME sulfate measurements on the 2009 MID. The eruptive emissions are estimated to make up less than 10% of total VSO_2 in Alaska; the rest is due to passive degassing that can last multiple days or months. For example, during 2014 to 2015, AVO classified volcano activity at Shishaldan as orange category (e.g., small-moderate eruptions, increased seismic activity) for 24 months continuously. Such variability in magnitude, frequency and temporal distribution makes it challenging to account for VSO_2 in the visibility projection and visibility glidepath. If emissions activity over the years has resulted in current year (e.g., 2014-2018) $(NH_4)_2SO_4$ levels being higher than the baseline years (2000-2004), the 2028 projections would be starting at a higher level than the baseline. When combined with small anthropogenic emission contributions, it may be impossible for the 2028 visibility projection to achieve the glidepath (see Section III.K.13.I-4).

[19] Fioletov, V., McLinden, C., Krotkov, N., Li, C., Leonard, P., Joiner, J., Carn, S.A., 2019. Multi-Satellite Air Quality Sulfur Dioxide (SO2) Database Long-Term L4 Global V1, Edited by Peter Leonard, Greenbelt, MD, USA, Goddard Earth Science Data and Information Services Center (GES DISC), Accessed on November 2, 2020, 10.5067/MEASURES/SO2/DATA403

Figure III.K.13.E-10. Satellite-derived annual VSO_2 emissions (ktons per year). 2000-2004 data is not available.




Chiginagak
Pavlof
Shishaldin
Veniaminof
400
350
300
250
200
150
100
50
0
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

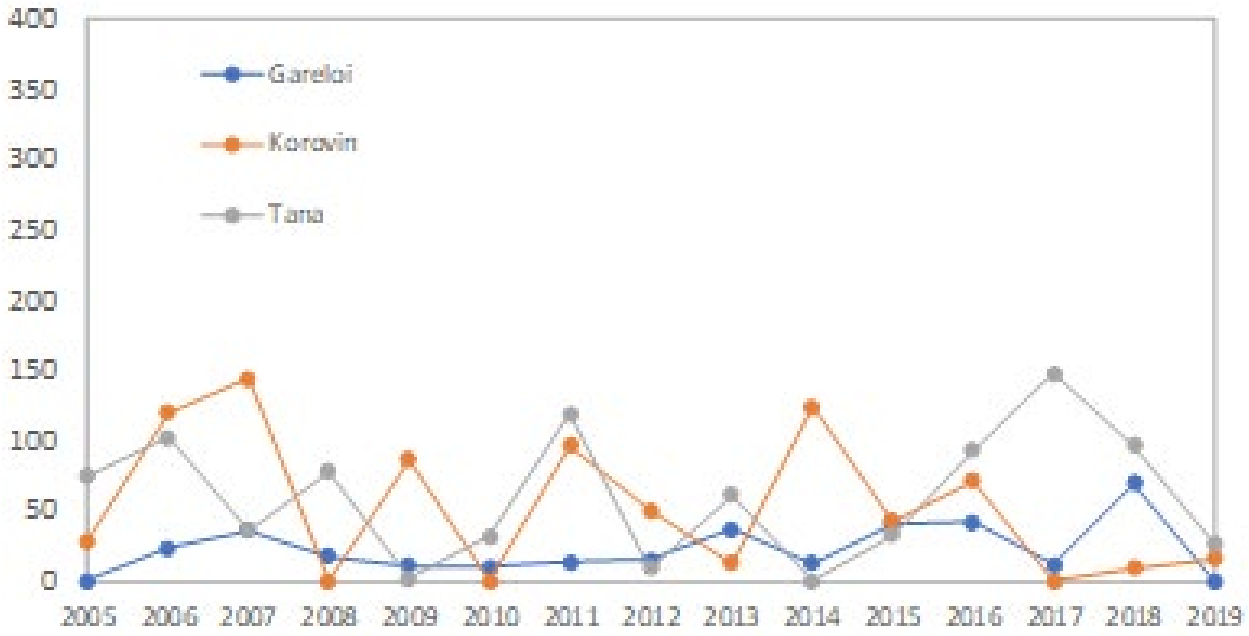
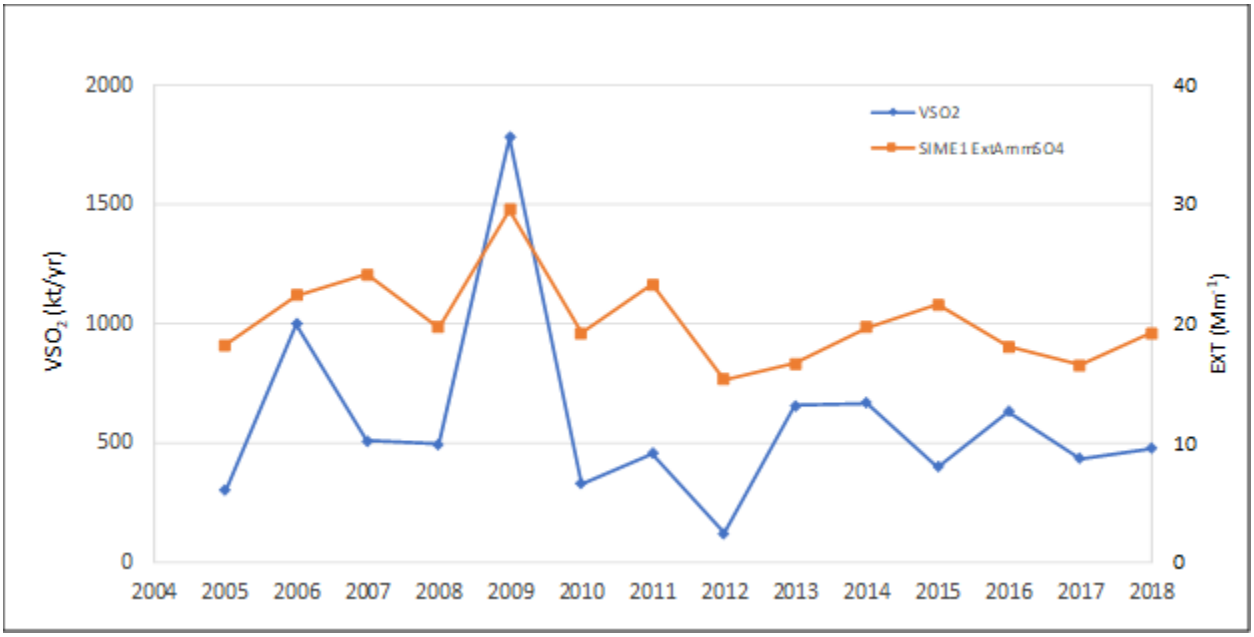

Gareloi
Korovin
Tana
400
350
300
250
200
150
100
50
0
2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019

Figure III.K.13.E-11. Annual volcanic SO_2 emissions in Alaska and $(NH_4)_2SO_4$ extinction at Simeonof IMPROVE site.



5. INTERNATIONAL TRANSPORTED EMISSIONS

Several studies, such as Polisar, et al. (2001)[20], have been conducted that attributed atmospheric aerosols measured in Alaska to contributions from upwind regions as far away as portions of Asia and Russia based on back trajectory analysis and identification of unique chemical source signatures of anthropogenic sources from these regions. Dust generated by the Gobi and Taklimakan Deserts in Central Asia can also be transported to the Arctic airshed by seasonal cycles. Though this constitutes a natural source of pollution, rapid industrialization in the People's Republic of China has led to an extended period of deforestation, desertification, and heavy industrial pollution in these areas, creating conditions whereby industrially-generated heavy metals are transported to Arctic airsheds along with desert dust particles. Arctic haze and Asian dust are described in more details below.

One of the most significant sources of human-caused impairment is from maritime vessels engaged in trans-Pacific trade between East Asia and North America. Several large trade routes run south of the state, causing pollution transport to coastal and interior Class I areas. This is an uncontrollable source of pollution, as the state has no ability to regulate or control these maritime emissions outside of state waters.

The state also receives impairment from large wildfires burning in Canada, the Russian Far East, and Siberia, which have grown in size and severity over the last decade from Arctic climate

[20] Polissar, A.V., Hopke, P.K. and Harris, J.M., 2001. Source regions for atmospheric aerosol measured at Barrow, Alaska. *Environmental science & technology*, *35*(21), pp.4214-4226.

changes. These wildfire impacts have been recorded on several occasions at Class I areas as causing noticeable degradation of visibility quality and clarity at IMPROVE monitors.

A. Arctic Haze

Arctic haze is a regional air quality process whereby during winter months the Arctic atmosphere becomes saturated with anthropogenic pollution. Most of these pollutants are not created locally but instead originate in Europe, Russia, and East Asia. They are transported to the high Arctic by air currents and other atmospheric processes. Arctic atmospheric process differences due to local weather patterns in winter result in greatly reduced normal photochemical oxidation of SO_2 and other chemicals. With Arctic sunrise, photochemical oxidation is stepped up and gaseous pollutants are broken down into aerosols, causing an increase in aerosol pollution in March and April. Thus, haze periods are broken down into two periods: gaseous haze in January and February, and aerosol haze in March and April.

Haze is composed of particles no larger than 2 μm ($PM_{2.5}$), as these particles have a low settling velocity. They are capable of remaining suspended in the atmosphere for weeks at a time. This allows these particles to travel from distant emissions locations into the Arctic air shed. Because these particles are roughly the same size as the visible sunlight wavelength, the haze can more effectively scatter light and diminish visibility at ground level.

Arctic haze is often layered as a result of the small thermal lapse rate of the Arctic atmosphere in winter. This shallow lapse rate dampens vertical mixing, allowing pollution to spread horizontally rather than vertically.

During spring and summer, in the absence of haze and wildfires, Arctic visual range is quite high. Utqiagvik (formerly known as Barrow) averages around 270 kilometers of visual range in June. Average values for March, during high aerosol haze, are reduced to 143 kilometers and usually much lower. Haze instances often can drive visual range down below 30 kilometers in the high Arctic.

B. Asian Dust

Like the above Arctic haze, Asian dust is a seasonal process taking place in the spring where air masses from Asia are transported across the North Pacific to the high Arctic. Large amounts of dust are lofted from the Gobi and Taklimakan Deserts due to high winds and weather fronts which start during the end of winter. The localized impact of these dust lofting events is well recorded in neighboring Japan and Korea, where the seasonal dust events have been given their own names to describe the event. The dust fall is known as “Kosa” in Japan and as “Whangsa” on the Korean Peninsula. Along with being a period of active dust lofting from China and Mongolia, it is also a period of high activity for atmospheric transport and exchange from East Asia to the Pacific Ocean.

Geological evidence suggests global transport of Asian dust is a long-running natural process. Chemical analysis of Greenland ice cores and Hawaiian soil studies both showed the chemical and radiological fingerprints of deposited dust consistent with the composition of Asian dust

sources in the Gobi and Taklimakan Deserts. It should be noted there is a similar process of dust transport from the Saharan Desert east across the Atlantic Ocean to the rainforests of the Amazon in South America. This process is believed to assist in fertilizing the rainforest and is associated with forest health.

Studies conducted in the late 1970s showed little pollution accompanying the dust during atmospheric exchange. However, more recent analyses of the dust showed an increase in anthropogenic pollution concurrent with Asian dust transport and more general Asian atmospheric exchange over the Pacific Ocean. Due to China's rapid industrialization and the associated expansion of both the Gobi and Taklimakan Deserts (related to both industrial policy and more general deforestation starting in the 1980s), it is likely dust amounts will increase in the future. This dust has been measured as containing elevated levels of heavy metals and other pollutants associated with industrial manufacturing and coal-fired power generation. This process could be reversed with recent efforts in China to begin aggressive reforestation and reseeding efforts in the western provinces, as well as parallel efforts in Mongolia. As these are relatively recent policies that have only taken effect in the last decade, it will be some time before results can be determined. Future studies inside and outside of China will demonstrate long-term results of this approach to pollution levels within the dust plumes

6. POTENTIAL SOURCE CONTRIBUTIONS AT ALASKA IMPROVE SITES

As described above, visibility impacts at Alaska IMPROVE sites are a combination of sources within and in the immediate vicinity of Alaska as well as long-range transport from other continents (e.g., Russia and China). Emission contributions from these sources can be quantified through global simulations. This section provides an initial summary of the source of sulfur emissions within and near Alaska based on a 2014 GEOS-Chem simulation. Sulfur emitting sources are focused here because sulfate is the main component contributing to visibility impairment on MID at Alaska IMPROVE sites.

GEOS-Chem includes various inventories[21] and provides sulfur (and other species) emissions rates from worldwide anthropogenic emissions, shipping emissions, biomass burning, volcanic degassing/leakage, and oceanic DMS. The Western Air Quality Study (WAQS) 2014 GEOS-Chem simulation used global anthropogenic emissions, including emissions from shipping sources, from the Community Emissions Data System (CEDS) inventory[22], biomass burning emissions from the Global Fire Emissions Database Version 4 (GFED4) inventory[23], volcanic degassing emissions of SO_2 from the AeroCom inventory, and oceanic DMS emissions from the DMS ocean exchange inventory. Table III.K.13.E-7 and Figure III.K.13.E-12 show the contributions of reactive sulfur emissions or the following regions: (1) an Alaska region; (2) the contiguous United States (CONUS); and (3) global world-wide. Figure III.K.13.E-13 shows the Alaska (dark pink) and CONUS (lighter pink) emission extraction domains on the GEOS-Chem 2 x 2.5 degree domain. The Alaska emission extraction domain was defined to roughly correspond to the EPA's 27-km grid resolution CMAQ modeling domain.

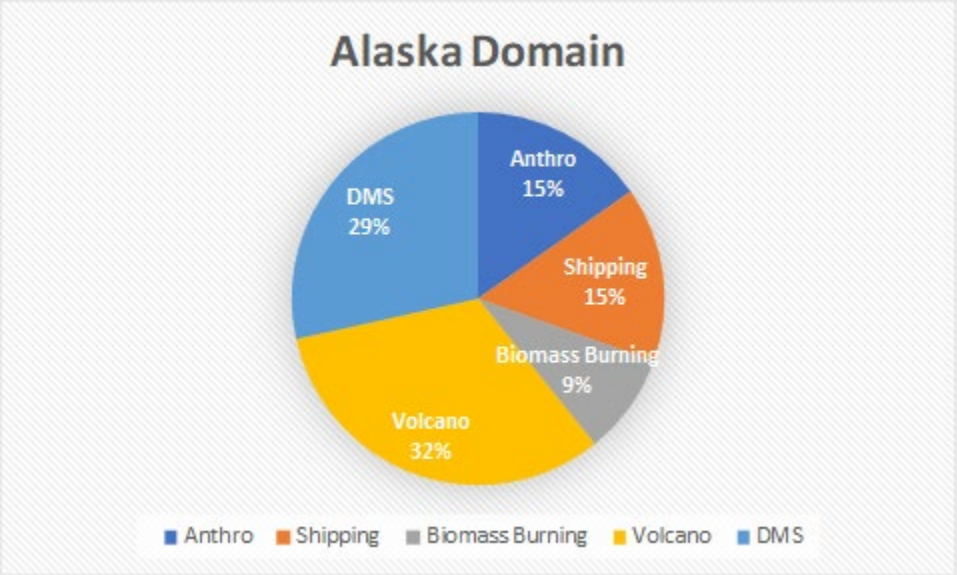
[21] wiki.seas.harvard.edu/geos-chem/index.php/HEMCO_data_directories
[22] http://wiki.seas.harvard.edu/geos-chem/index.php/CEDS_anthropogenic_emissions
[23] https://daac.ornl.gov/VEGETATION/guides/fire_emissions_v4_R1.html

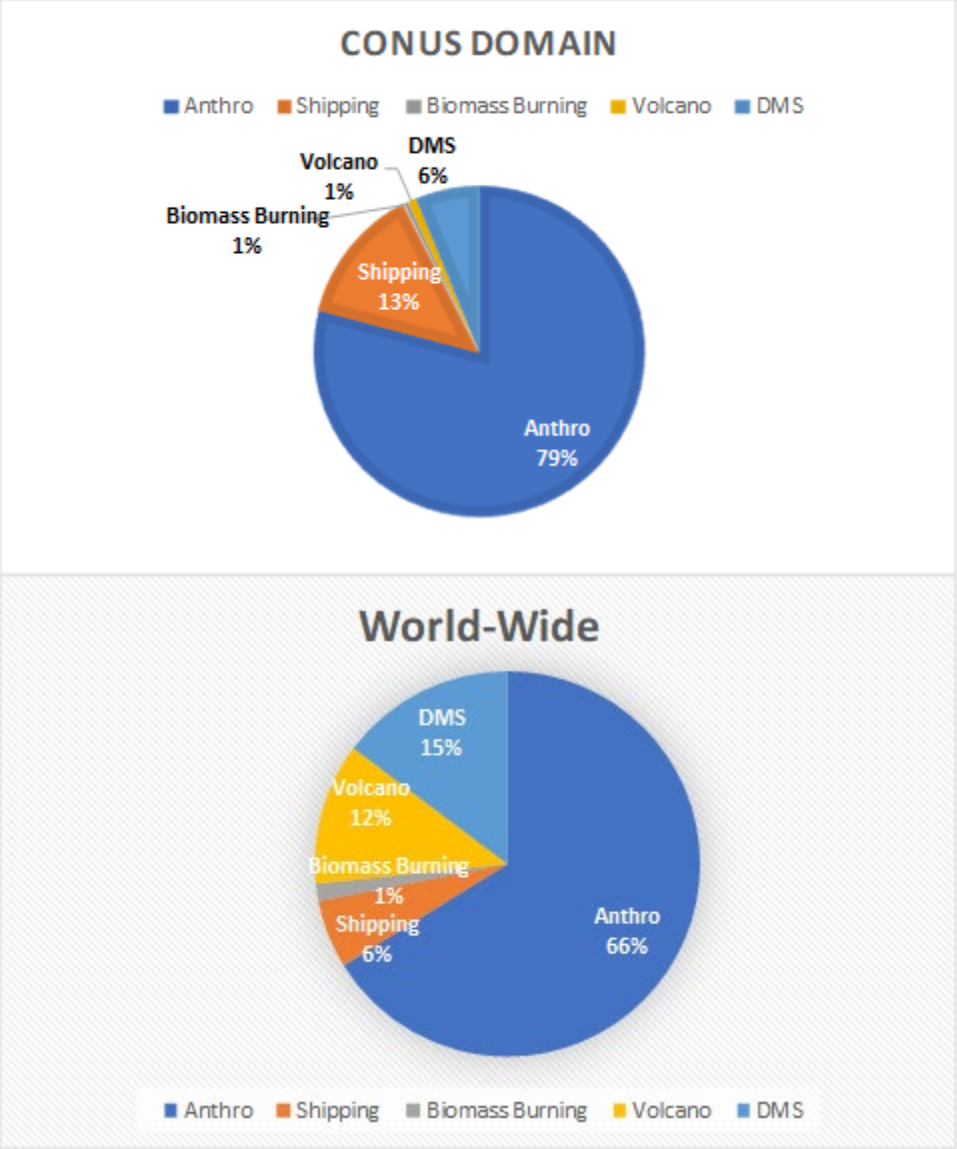
Table III.K.13.E-7. Emissions of SO_2 (Mt/year) in 2014. Data comes from the inventories in the GEOS-Chem global model

Source	Alaska Domain		CONUS Domain		World-Wide Domain	
	(M tons/yr)	(%)	(M tons/yr)	(%)	(M tons/yr)	(%)
Anthropogenic	0.39	15%	5.46	79%	102.8	66%
Shipping	0.39	15%	0.92	13%	8.90	6%
Biomass Burning	0.22	9%	0.031	0%	2.25	1%
Volcano degassing	0.82	32%	0.06	1%	18.5	12%
Oceanic DMS*	0.73	28%	0.43	6%	22.9	15%
Total	2.6		6.9		155.3	

*a DMS-to-SO_2 conversion of 0.6 applied

Figure III.K.13.E-12. Relative importance of reactive sulfur emissions from the GEOS-Chem for 2014 of three emission extraction domains: Alaska, CONUS, and World-Wide





The volcano degassing SO_2 emissions account for 32% of the reactive sulfur emissions in the Alaska domain, with DMS accounting for another 28%24. Anthropogenic and shipping emissions account for 15% each. Biomass burning (e.g., wildfires) account for 9% of the reactive sulfur emissions, but fire emissions are very episodic and have a lot of year-to-year variability; 2014 was not a high wildfire year in Alaska. In contrast to the Alaska domain, where only 30% of the reactive sulfur emissions were from anthropogenic sources and shipping, almost 90% of the reactive emissions are anthropogenic and shipping in the CONUS domain. And world-wide, 72% of the reactive sulfur emissions are anthropogenic and shipping.

[24] In the EPA Alaska 9-km CMAQ modeling domain, volcano degassing accounts for 46% and DMS accounts for 20% of total SO_2 emissions.

Figure III.K.13.E-13. Map of the EPA Alaska 27-km CMAQ modeling domain (green) overlaid over the GEOS-Chem 2x2.5 degree grid Alaska emission extraction domain (dark pink) and CONUS emission extraction domain (lighter pink).