Canada – United States

Air Quality Agreement

Progress Report 2018

The International Joint Commission Requests Your Comments on This Report

The Canada-U.S. Air Quality Agreement directs the International Joint Commission (IJC) to invite public comments on progress reports prepared by the Air Quality Committee and provide a synthesis of comments to the Governments of Canada and the United States in order to assist them with implementing the Agreement.

The IJC is interested in your views on the draft 2018 Progress Report reflecting the Governments' important work being carried out under the Agreement:

- *What do you think about the ongoing efforts of our two countries to address transboundary air quality?*
- *What issues do you think should have the highest priority?*
- *What do you think about the information provided in this report?*

The IJC invites you to send written comments on this draft progress report until June 30, 2021, using one of the following methods:

1. Online at www.ijc.org/en/what/engagement/consultations
2. Email at AirQuality@ottawa.ijc.org
3. Mail at:

Canadian Section
Secretary, Canadian Section
International Joint Commission
234 Laurier Avenue West, 22nd Floor
Ottawa, ON K1P 6K6

United States Section
Secretary, U.S. Section
International Joint Commission
1717 H Street NW, Suite 835
Washington, DC 20006

United States spelling is used throughout this report except when referring to Canadian titles.

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Environment and Climate Change Canada

Public Inquiries Centre
7th Floor, Fontaine Building
200 Sacré-Coeur Boulevard
Gatineau, QC K1A 0H3
Telephone: 819-997-2800
Toll Free: 1-800-668-6767 (in Canada only)
Email: ec.enviroinfo.ec@canada.ca

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INTRODUCTION

In 1991, the United States and Canada established an Air Quality Agreement (Agreement) to address transboundary air pollution. The Agreement initially focused on reducing levels of acid deposition, or acid rain, in each country, and in 2000, the Agreement was amended to also address ground-level ozone. A bilateral Air Quality Committee, established in the Agreement, is required to issue a report every two years, highlighting progress on the commitments included in the Agreement and describing the continued efforts by both countries to address transboundary air pollution. This is the 14th such progress report under the Agreement.

Working collaboratively under the Agreement, both countries have made remarkable progress in reducing acid rain and controlling ozone in the transboundary region, improving the environment and achieving better air quality for citizens in the United States and Canada. Significant reductions in emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs) have resulted from regulatory and non-regulatory programs—some of which are specifically designed to meet commitments set in the Agreement—implemented by both countries.

In addition, the Agreement has provided a mechanism, in the form of work plans, for cooperation on the development and implementation of harmonized regulations to reduce vehicle and engine emissions and for addressing emissions from the oil and gas sector.

ACID RAIN ANNEX

Acid deposition, more commonly known as acid rain, occurs when emissions of SO_2 and NO_x, from power plants, vehicles, and other sources, react in the atmosphere (with water, oxygen, and oxidants) to form various acidic compounds that exist in either a wet form (rain, snow, or fog) or a dry form (gases and particles). These acidic compounds can harm aquatic and terrestrial ecosystems (particularly forests); affect human health; impair visibility; and damage automotive finishes, buildings, bridges and monuments.

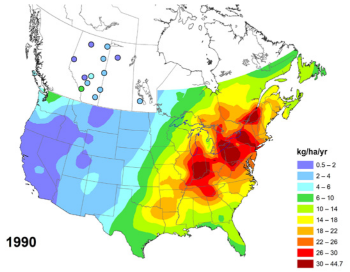
The Acid Rain Annex to the 1991 Agreement established commitments by both countries to reduce emissions of SO_2 and NO_x, the primary precursors to acid rain, from stationary and mobile sources. The Agreement also included provisions aimed at the prevention of air quality deterioration, protection of visibility, and continuous monitoring of emissions. Reductions in SO_2 and NO_x emissions in both Canada and the United States between 1990 and 2017 have led to major decreases in the wet deposition of sulfate and nitrate over the eastern half of the two countries. Implementation of various regulatory and non-regulatory actions for more than two decades in Canada has significantly reduced emissions of SO_2 and NO_x and ambient concentrations. Similar implementation, especially regulatory programs in the electric power sector, has significantly reduced emissions of SO_2 and NO_x and ambient concentrations in the United States as well.

ACID DEPOSITION TRENDS

Wet deposition of sulfate and nitrate is measured by precipitation chemistry monitoring networks in Canada and the United States. The measurement data, presented in kilograms per hectare per year (kg/ha/yr), are the basis for binational spatial wet deposition maps.

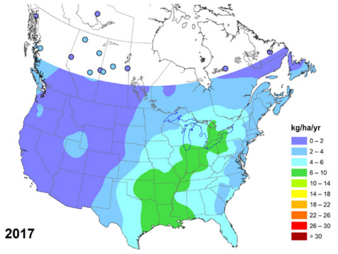
Figures 1 and 2 show the spatial patterns of annual wet sulfate deposition of non-sea-salt sulfate, which is measured sulfate with the contribution of sea salt sulfate removed, in 1990 and 2017, respectively, along with point values at sites in less densely measured regions. Figures 3 and 4 show the patterns of wet nitrate deposition for the same years. The lower Great Lakes region consistently received the highest wet deposition of both sulfate and nitrate in the 28-year period. Sulfate deposition in 1990 exceeded 26 kg/ha/yr over a large area of eastern North America, while in 2017, no areas in North America received more than 10 kg/ha/yr of sulfate. Similarly, nitrate deposition exceeded 19 kg/ha/yr in many parts of the northeastern United States and southern Ontario and Quebec in 1990, and in 2017, it falls below 13 kg/ha/yr throughout North America, except for a small area of eastern Lake Erie, which is still below 16 kg/ha/yr.

Figure 1. 1990 Annual Wet Sulfate Deposition



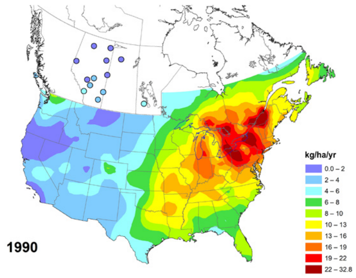
Sources: The Canadian National Atmospheric Chemistry Database and Analysis Facility (www.canada.ca/en/environment-climate-change/services/air-pollution/monitoring-networks-data/national-atmospheric-chemistry-database.html) and the United States National Atmospheric Deposition Program (http://nadp.slh.wisc.edu/).

Figure 2. 2017 Annual Wet Sulfate Deposition



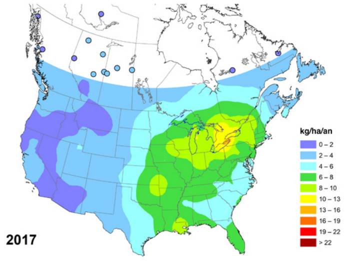
Sources: The Canadian National Atmospheric Chemistry Database and Analysis Facility (www.canada.ca/en/environment-climate-change/services/air-pollution/monitoring-networks-data/national-atmospheric-chemistry-database.html) and the United States National Atmospheric Deposition Program (http://nadp.slh.wisc.edu/).

Figure 3. 1990 Annual Wet Nitrate Deposition



Sources: The Canadian National Atmospheric Chemistry Database and Analysis Facility (www.canada.ca/en/environment-climate-change/services/air-pollution/monitoring-networks-data/national-atmospheric-chemistry-database.html) and the United States National Atmospheric Deposition Program (http://nadp.slh.wisc.edu/).

Figure 4. 2017 Annual Wet Nitrate Deposition



Sources: The Canadian National Atmospheric Chemistry Database and Analysis Facility (www.canada.ca/en/environment-climate-change/services/air-pollution/monitoring-networks-data/national-atmospheric-chemistry-database.html) and the United States National Atmospheric Deposition Program (http://nadp.slh.wisc.edu/).

ACID RAIN COMMITMENTS AND EMISSION REDUCTIONS

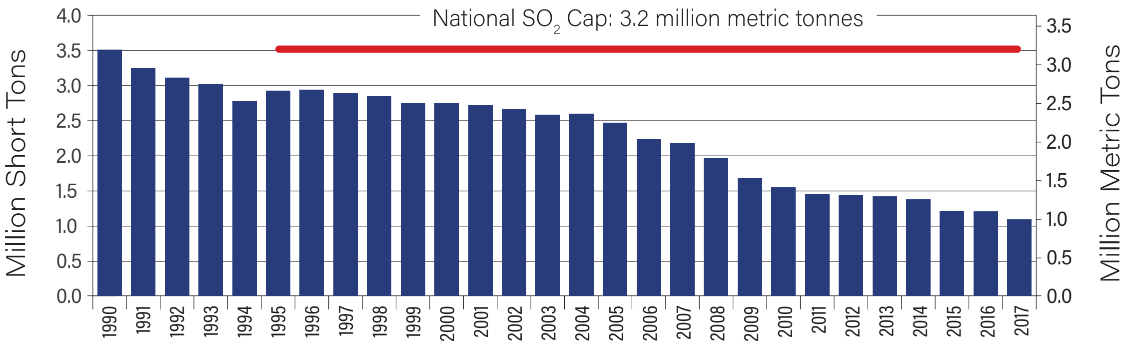
SO_2 Emission Reductions

CANADA

Actions driving SO_2 emission reductions include the implementation of the Canada-Wide Acid Rain Strategy for Post-2000, which serves as the framework for addressing the issues related to acid rain. The goal of the strategy is to ensure that the deposition of acidifying pollutants does not further deteriorate the environment in eastern Canada and that new acid rain problems do not occur elsewhere in Canada.

Canada has met its commitments to reduce SO_2 in the Agreement. In 2017, Canada's total SO_2 emissions were approximately 955 thousand metric tons (1.05 million short tons[1]), about 71 percent below the national cap of 3.2 million metric tons (3.5 million short tons). The 2017 emissions level also represents a 69 percent reduction from Canada's total SO_2 emissions of 3.1 million metric tons (3.4 million short tons) in 1990 (see Figure 5).

Figure 5. Total Canadian SO_2 Emissions, 1990-2017



Source: Environment and Climate Change Canada, 2019

The largest contribution of SO_2 emissions originates from three industrial sectors: non-ferrous smelting and refining; coal-fired electric power generation; and the upstream oil and gas, which includes the exploration and production of crude oil. These three sectors accounted for 75 percent of national SO_2 emissions in 2017. The majority of overall reductions in national SO_2 emission levels can be attributed to the SO_2 emission reduction actions undertaken by the province of Ontario, mainly from the permanent closure of coal-fired electric power generation facilities.

Although Canada has been successful in reducing these acidifying pollutants, many areas across Canada are still exposed to concentrations that exceed the capacity of the soils and surface waters to neutralize the acidic deposition, most notably in eastern Canada. A number of measures are being undertaken to reduce SO_2 and NO_x emissions from certain industrial sectors as part of Canada's Air Quality Management System (AQMS), which will also reduce the impact of acidifying pollutants on soils and surface waters.

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[1] One metric ton is equal to 1.1 short tons.

UNITED STATES

The United States has met its commitment to reduce SO_2 emissions. The national Acid Rain Program (ARP), the regional Clean Air Interstate Rule (CAIR), the Cross-State Air Pollution Rule (CSAPR), and the CSAPR Update were designed to reduce emissions of SO_2 and NO_x from the electric power sector. Since 1995, SO_2 emissions have fallen significantly under these programs. These reductions occurred while the demand for electricity remained relatively stable and were the result of continued increases in efficiency, installation of state-of-the-art pollution controls, and the switch to lower emitting fuels. Most of the power sector emission reductions since 2005 were from early reduction incentives and stricter emission cap levels under CAIR. The CAIR SO_2 program began on January 1, 2010, and was replaced by the Cross-State Air Pollution Rule (CSAPR) SO_2 program on January 1, 2015.[2] In May 2017, implementation of the CSAPR update began to further reduce seasonal NO_x emissions.[3]

Electric generating units in the ARP emitted 1.2 million short tons (1.1 million metric tons) of SO_2 in 2017, well below the ARP's statutory annual cap of 8.95 million short tons (8.1 million metric tons). ARP sources reduced emissions by 14.4 million short tons (13.1 million metric tons, or 92 percent) from 1990 levels and 16 million short tons (14.5 million metric tons, or 93 percent) from 1980 levels (see Figure 6).

In 2017, sources in the CSAPR SO_2 program and the ARP collectively reduced SO_2 emissions by 10.0 million short tons (9.1 million metric tons, or 89 percent) from 2000 levels, and 8.9 million short tons (8.1 million metric tons), or 87 percent from 2005 levels (before implementation of CAIR and CSAPR). All ARP and CSAPR sources emitted a total of 1.3 million short tons (1.2 million metric tons) of SO_2 in 2017.

Annual SO_2 emissions from sources in the regional CSAPR SO_2 program alone fell from 7.7 million short tons (7.0 million metric tons) in 2005 to 0.8 million short tons (0.7 million metric tons) in 2017, a 90 percent reduction. In 2017, SO_2 emissions were about 1.2 million short tons (1.1 million metric tons) below the regional CSAPR emission budget.

In addition to the electric power generation sector, emission reductions from other sources not affected by the ARP or CSAPR, including industrial and commercial boilers and refining, have contributed to an overall reduction in annual SO_2 emissions. National SO_2 emissions from all sources fell from 23.1 million short tons (20.9 million metric tons) in 1990 to 2.7 million short tons (2.4 million metric tons) in 2017, a reduction of 88 percent.

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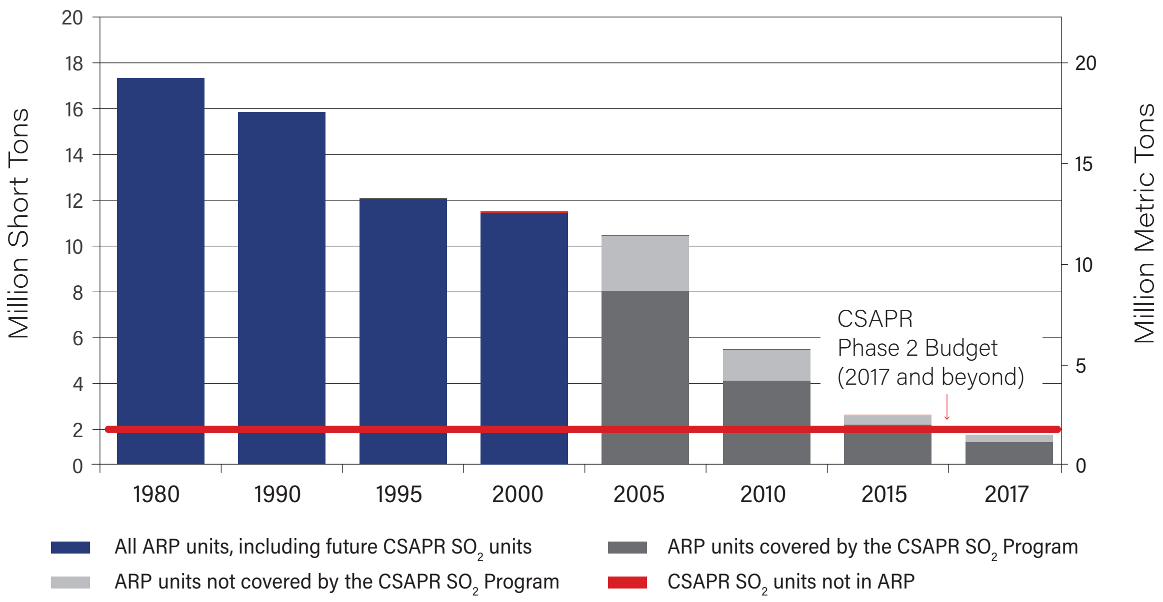
[2] See www.epa.gov/csapr for more information on the CSAPR program.

[3] See www.epa.gov/airmarkets/final-cross-state-air-pollution-rule-update for more information on the CSAPR Update.

Figure 6. SO_2 Emissions from CSAPR and ARP Sources, 1980-2017



Notes: For CSAPR units not in the ARP, the 2015 annual SO_2 emissions were applied retroactively for each pre-CSAPR year following the year in which the unit began operating. There are a small number of sources in CSAPR but not in ARP. Emissions from these sources comprise about 1 percent of total emissions and are not easily visible on the full chart.

Source: EPA, 2019

NO_X Emission Reductions

CANADA

Canada has met its commitment to reduce NO_x emissions from power plants, major combustion sources, and metal smelting operations by 100,000 metric tons (110,000 short tons) below the forecasted level of 970,000 metric tons (1.1 million short tons). This commitment is based on a 1985 forecast of 2005 NO_x emissions.

Emissions of NO_x from all industrial sources, including from electric power generation, totaled 772,474[4] metric tons (851,505 short tons) in 2017. Transportation sources contributed 52 percent of total Canadian NO_x emissions in 2017, with the remainder produced by the upstream petroleum industry (26 percent), electric power generation facilities (8 percent), and other sources. Canada continues to develop programs to further reduce NO_x emissions nationwide. In June 2016, Canada published the *Multi-sector Air Pollutants Regulations* to limit NO_x emissions from industrial boilers, heaters, and stationary gaseous fuel-fired engines; and NO_x and SO_2 emissions from cement manufacturing facilities. The regulations establish mandatory national air pollutant emissions standards for major industrial facilities. The regulations will significantly reduce emissions that contribute to acid rain and smog. ECCC analysis predicts that the regulations will result in a reduction of 2.0 million metric tons (2.2 million short tons) of NO_x emissions in the first 19 years (equivalent to taking all passenger cars and trucks off the road for about 12 years). These industrial emission requirements are a key element of Canada's AQMS.

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[4] Total includes NO_x emissions from the following sources: ore and mineral industries, oil and gas industry, electric power generation and manufacturing.

On January 2020, emission intensity limits for NO_x and SO_2 for cement manufacturing facilities entered into force. NO_x emission intensity limits for new stationary gaseous fuel-fired engines ($\geq$ 75 kW) came into force in 2016. Limits for existing stationary gaseous fuel-fired engines ($\geq$ 250 kW) will be phased-in starting in 2021, with final limits in force by 2026. The regulations provide multiple compliance options for regulatees to achieve the limit. Finally, regulated limits were established for new and existing industrial gaseous fuel-fired boilers and heaters ($\geq$ 10.5GJ/hour). As of June 2019, emission intensity limits are fully in force for modern and transitional boilers and heaters. Limits will be phased in for pre-existing boilers and heaters based on their current classification. These limits must be met by 2026 for Class 80 boilers and heaters and by 2036, for Class 70 boilers and heaters. Most regulatees have registered (engines, boilers and heaters) or completed the first reporting requirements (cement).

UNITED STATES

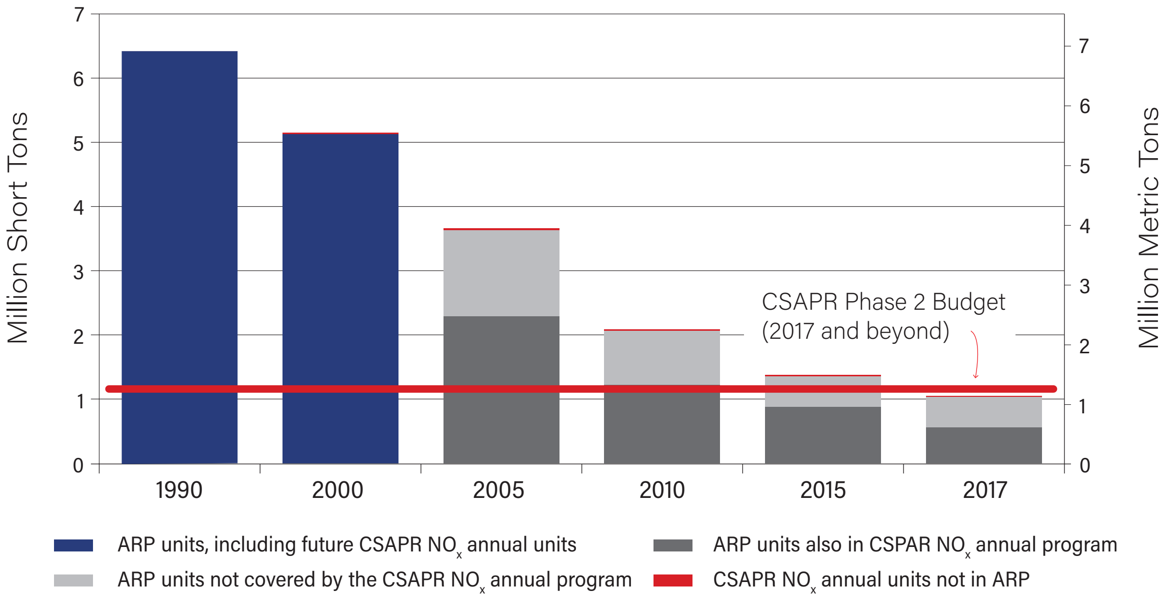
The United States has met its commitment to reduce NO_x emissions. To address NO_x emissions, the ARP NO_x program requires emission reductions through a rate-based approach on certain coal-fired power plants, while CSAPR achieves emission reductions through a market-based, emission trading program from fossil fuel-fired power plants. Overall, NO_x emissions have declined dramatically under the ARP, the former NO_x Budget Trading Program (NBP), the CAIR NO_x program, and the CSAPR program, with the majority of reductions coming from coal-fired units. Other programs—such as regional and state NO_x emission control programs—also contributed significantly to the annual NO_x emission reductions achieved by sources in 2017.

In 2017, sources in both the CSAPR NO_x program and the ARP reduced NO_x emissions by 5.4 million short tons (4.9 million metric tons) or 84 percent from 1990 levels, 4.1 million short tons (3.7 million metric tons) or 80 percent from 2000 levels, and 2.6 million short tons (2.4 million metric tons) or 72 percent from 2005 levels. Together, all ARP and CSAPR sources emitted a total of 1.1 million short tons of NO_x in 2017 (see Figure 7).

Annual NO_x emissions from sources in the CSAPR NO_x program alone fell from 2.3 million short tons (2.1 million metric tons) in 2005 to 580,000 short tons (530,000 metric tons) in 2017, a 75 percent reduction. For more detailed information on the United States NO_x programs, see www.epa.gov/airmarkets.

In addition to ARP and CSAPR, other NO_x ozone season and annual programs, as well as state NO_x emission control programs, contributed significantly to the NO_x reductions that sources achieved in 2017. Annual NO_x emissions from the power sector as well as all other sources fell from 25.2 million short tons (22.8 million metric tons) in 1990 to 10.7 million short tons (9.7 million metric tons) in 2017, a reduction of 58 percent.

Figure 7. Annual NO_x Emissions from CSAPR and ARP Sources, 1990-2017



Notes: For CSAPR units not in the ARP, the 2015 annual NO_x emissions were applied retroactively for each pre-CSAPR year following the year in which the unit began operating. There are a small number of sources in CSAPR but not in ARP. Emissions from these sources comprise about 1 percent of total emissions and are not easily visible on the full chart.

Source: EPA, 2019

Preventing Air Quality Deterioration and Protecting Visibility

Canada

Canada has continued to address the commitment to prevent air quality deterioration and ensure visibility protection by implementing the *Canadian Environmental Protection Act, 1999* (CEPA 1999) and the *Impact Assessment Act, 2019* and by following the principles of "continuous improvement" and "keeping clean areas clean". These principles underpin Canada's AQMS and the associated Canadian Ambient Air Quality Standards (CAAQS).

The British Columbia Visibility Coordinating Committee (BCVCC) continues to work towards developing a visibility management framework for the Lower Fraser Valley (LFV) in southwest British Columbia. Modeling work by Environment and Climate Change Canada (ECCC) has further strengthened scientific understanding of visual air quality, including the development of a statistical model to estimate light extinction from routine air quality measurements and investigations of the visibility impact of emission reduction scenarios. This modeling work has guided policy decisions to improve visual air quality.

The British Columbia Ministry of Environment and Climate Change Strategy partnered with Metro Vancouver to commission a Sustainability Scholar from the University of British Columbia to develop a research report regarding LFV visual air quality. The recently completed report synthesizes findings of the LFV Visual Air Quality Pilot Study, which also provides the basis for completing the final BCVCC report. Thorough data analysis will be conducted, and the final BCVCC report will be completed with overall findings and recommendations. A BCVCC meeting is planned for 2020, at which time the data analysis results will be presented and future activities will be discussed. The report for the pilot study can be found at: https://sustain.ubc.ca/sites/default/files/2019-37_Lower%20Fraser%20Valley%20Visual%20Air_RavaniCecato.pdf.

United States

The United States continues to address its commitment to air quality and visibility protection through several Clean Air Act programs, including New Source Review (NSR) and the Regional Haze Program. The NSR program requires that new or modified sources obtain pre-construction permits in areas that meet the National Ambient Air Quality Standards (NAAQS) (i.e., attainment areas) and in areas that exceed the NAAQS (i.e. nonattainment areas). Nonattainment area NSR permits for major sources require air pollution controls that represent the lowest achievable emission rate (LAER) and emissions offsets. Emissions offsets are actual emission reductions, generally obtained from sources in the vicinity of a proposed source or modification, that offset the proposed emissions increase and provide a net air quality benefit.

NSR permits for major sources in attainment areas are known as prevention of significant deterioration (PSD) permits and require air pollution controls that represent the best available control technology (BACT), as well as a demonstration that the project's emissions will not cause or contribute to a violation of any NAAQS or PSD increments. The PSD program also protects the air quality and visibility in Class I areas (i.e., national parks exceeding 6,000 acres and wilderness areas exceeding 5,000 acres). The NSR program also requires pre-construction permits for smaller sources of air pollution by way of the minor NSR program. Requirements for getting a minor NSR permit are generally less prescriptive than the requirements for a major NSR permit.

The *Clean Air Act* established the goal of improving visibility in the nation's 156 Class I areas and returning these areas to visibility conditions that existed before human-caused air pollution. In January 2017, EPA issued a final rule updating the Regional Haze Program, including revising portions of the visibility protection rule promulgated in 1980 and the Regional Haze Rule promulgated in 1999. The Regional Haze Program is divided into iterative 10-year implementation periods with the goal of achieving natural conditions by 2064. The CAA requires states to develop a long-term strategy for making "reasonable progress" toward the national visibility goal. The first required plans had to primarily address a one-time best available retrofit technology (BART) requirement that applied to certain older, larger stationary sources of visibility impairing pollutants. The first and subsequent plans must include measures necessary to make reasonable progress toward the national goal. Additional information on EPA's Regional Haze Program can be found at www.epa.gov/visibility.

Figures 8 and 9 show the annual average "standard visual range" (the farthest distance a large, dark object can be seen during daylight hours) within the United States for the period 2000-2004 and 2013-2017, respectively. This distance is calculated using fine and coarse particle data from the IMPROVE network. Increased particle pollution reduces the visual range. Between 2000-2004 and 2013-2017, the visual range increased throughout the United States with the largest increase occuring in the eastern United States. The visual range under naturally occurring conditions without human-caused pollution in the United States is typically 50–90 miles (80–140 kilometers [km]) in the east and 110–150 miles (180–240 km) in the west. Additional information on the IMPROVE program and visibility in U.S. National Parks can be found at http://vista.cira.colostate.edu/improve/.

Figure 8. Annual Average Standard Visual Range (km) 2000-2004

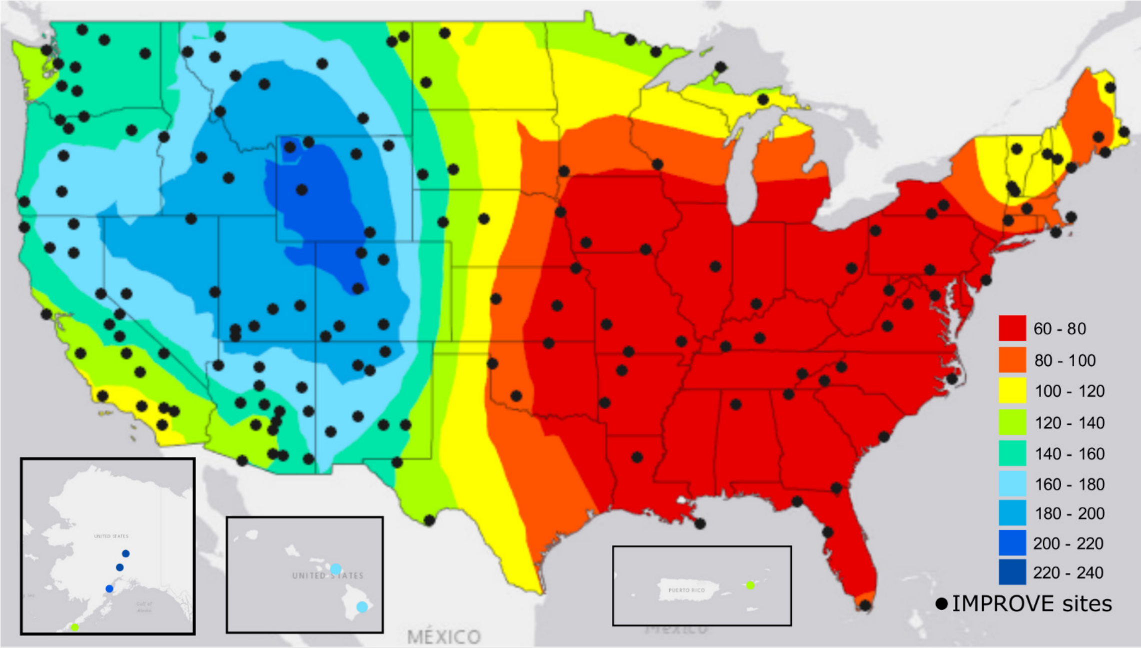
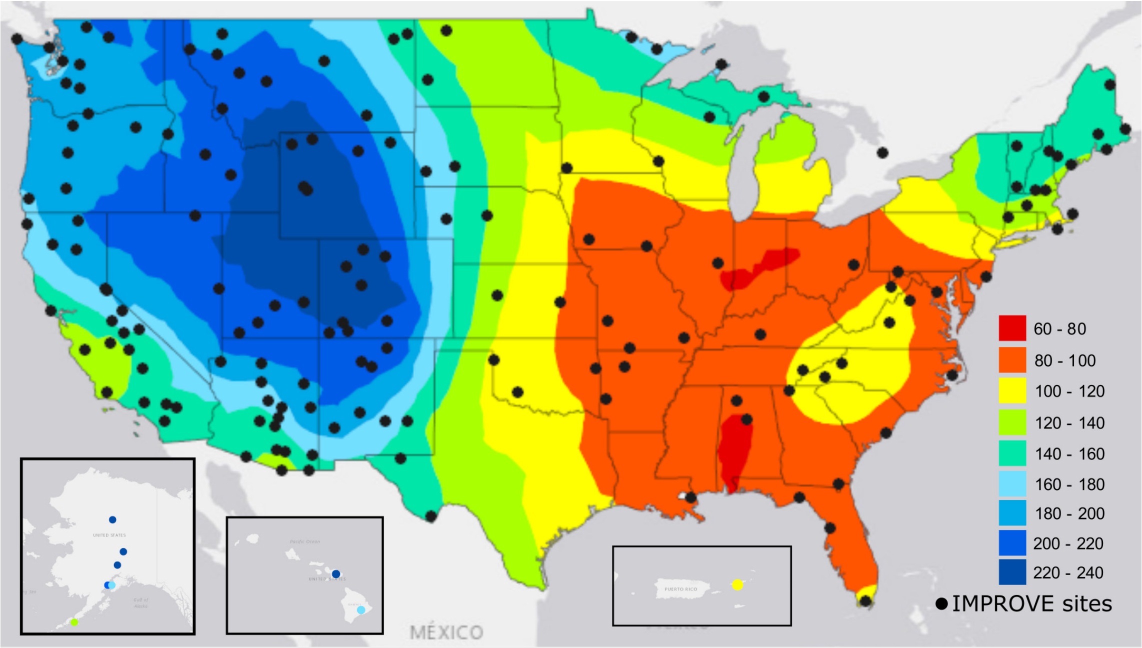


Figure 9. Annual Average Standard Visual Range (km) 2013-2017



Source: U.S. NPS, 2019 (data from IMPROVE website: http://vista.cira.colostate.edu/improve/

Emissions/Compliance Monitoring

Commitments in the Agreement require Canada and the United States to apply continuous emissions monitoring or methods of comparable effectiveness to certain electric utility units. Both countries meet these commitments by using continuous emissions monitoring systems (CEMS) and rigorous reporting programs. Canada and the United States each monitor more than 90 percent of eligible SO_2 emissions with CEMS.

Canada

Canada continues to meet its commitment to monitor and estimate emissions of NO_x and SO_2 from new and existing electric utility units with a capacity rating greater than 25 megawatts. CEMS, or other comparable monitoring methods, have had widespread use in Canada's electric utility sector since the late 1990s. Currently, most new and existing base-load fossil steam plants and natural gas turbines with high emission rates operate CEMS technology. Coal-fired facilities, the largest source of emissions from the sector, have SO_2 and NO_x CEMS installed at more than 93 percent of their total capacity. In addition, under Canada's National Pollutant Release Inventory, a mandatory reporting program, electric power generating facilities are required to report their air pollutant emissions (including NO_x and SO_2) annually. CEMS also serves as a monitoring approach to demonstrate compliance with several aspects of the *Multi-Sector Air Pollutants Regulations*.

United States

EPA has developed detailed procedures to ensure that sources monitor and report emissions with a high degree of precision, accuracy, reliability, and consistency. Most emissions of SO_2, carbon dioxide, and NO_x are measured with CEMS, which monitor important information such as the amount of pollution emitted from a smokestack (pollutant concentration) and how fast the emissions occur. In 2018, CEMS monitored over 99 percent of SO_2 emissions from CSAPR sources, including 100 percent from coal-fired units.

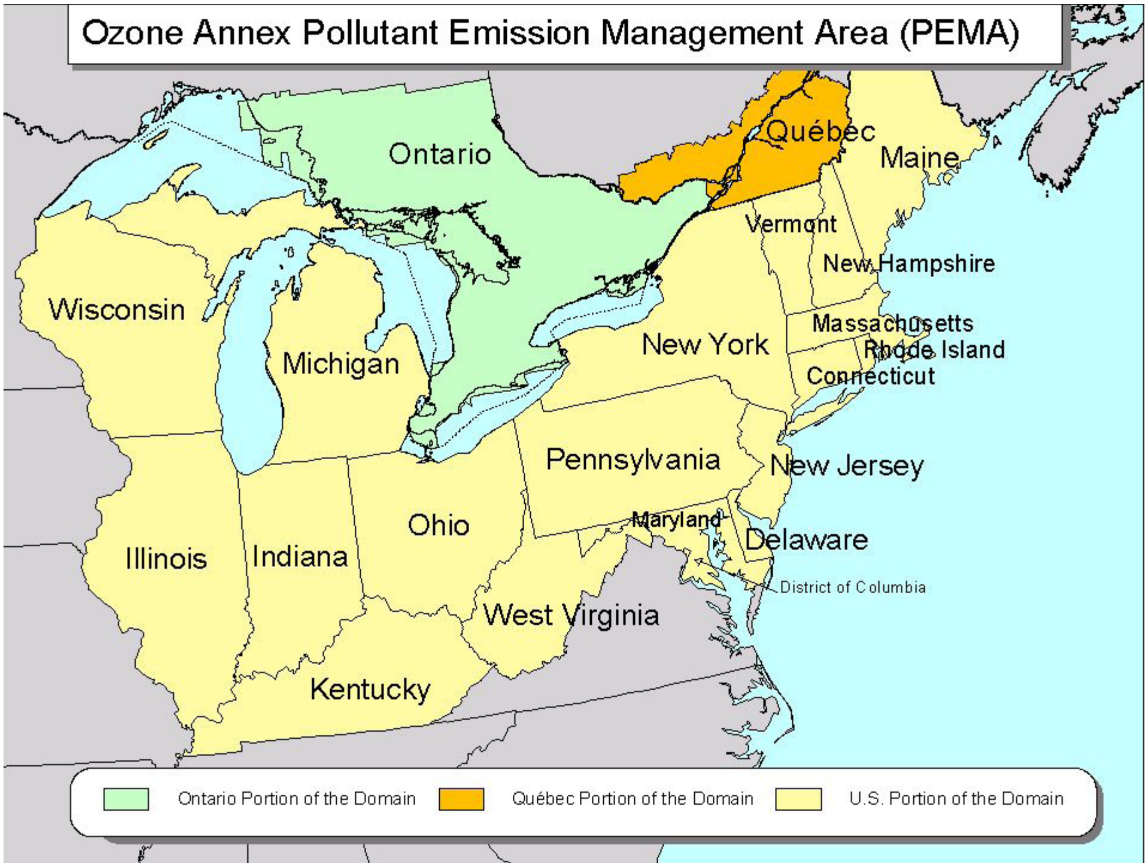
Additionally, other large emission sources that are equipped with pollution control devices are regulated under the Compliance Assurance Monitoring (CAM) rule. The CAM rule includes criteria that define the monitoring, reporting, and record keeping that should be conducted by a source to provide a reasonable assurance of compliance with emission limitations and standards. EPA rigorously checks the completeness, quality, and integrity of monitoring data. In addition to electronic audits, EPA conducts targeted field audits on sources that report suspect data.

OZONE ANNEX

Ground-level ozone is a pollutant that forms when emissions of NO_x and VOCs and other pollutants react in the atmosphere in the presence of sunlight. Cars, trucks, buses, engines, industries, power plants and products such as solvents and paints are among the major man-made sources of ozone-forming emissions. A key component of smog, ground-level ozone, can cause or exacerbate respiratory illnesses, and is especially harmful to young children, the elderly, and those suffering from chronic asthma and/or bronchitis. Exposure to ground-level ozone can damage vegetation, reduce growth, and have other harmful effects on plants and trees. This can make them more susceptible to attack from insects and diseases and reduce their ability to withstand droughts, windstorms, and man-made stresses such as acid rain.

The Ozone Annex, added to the Agreement in 2000, commits the United States and Canada to address transboundary ground-level ozone by reducing emissions of NO_x and VOCs, the precursors to ozone, from stationary and mobile sources and from solvents, paints, and consumer products. The commitments apply to a defined region in both countries known as the Pollutant Emission Management Area (PEMA), which includes central and southern Ontario, southern Quebec, 18 states, and the District of Columbia, where emission reductions are most important for reducing transboundary ozone (See Figure 10).

Figure 10. Ozone Annex Pollutant Emission Management Area (PEMA)

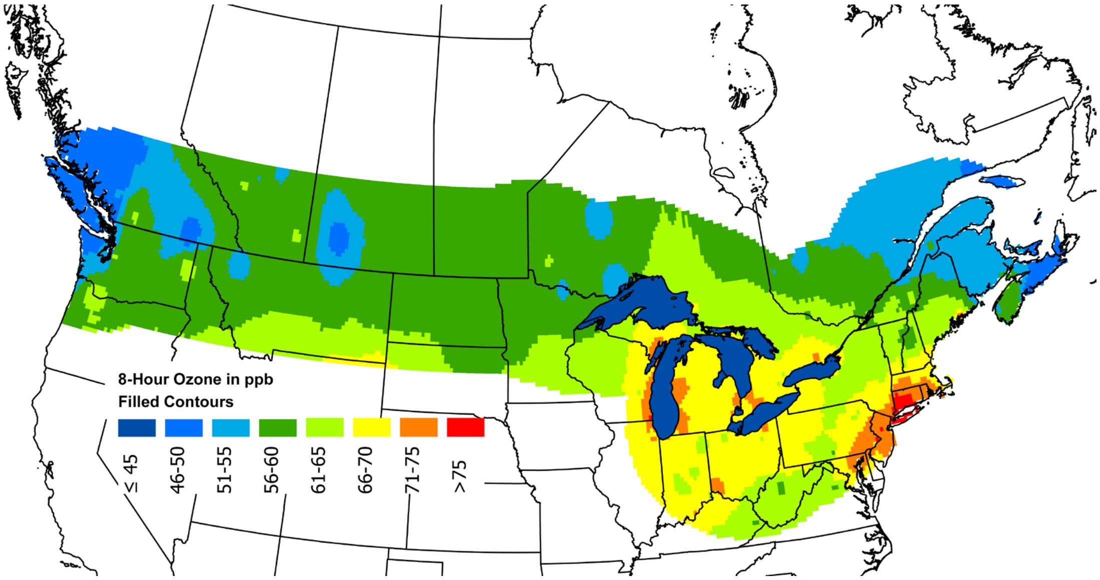


AMBIENT LEVELS OF OZONE IN THE BORDER REGION

Ozone concentrations, or ambient levels, in the PEMA have gradually decreased since 1995. Similarly decreasing trends in concentrations are found for both NO_x and VOCs. Regulatory and non-regulatory programs designed to meet emissions commitments in the Ozone Annex, as well as programs designed to meet program goals for Canada and the United States individually, have contributed to the reductions in ozone concentrations.

Figure 11 illustrates ozone concentrations in the border region—sites within 500 km (310 miles) of the United States–Canada border. The figure shows that higher ozone levels occur near the Great Lakes and along the United States eastern coast. The lowest values are generally found in western and eastern Canada. Levels are generally higher within and downwind of urban areas. The figure illustrates the regional pattern of ozone concentrations. Ozone is depicted in this figure as a 3-year average (2015-2017) of the annual fourth-highest daily maximum 8-hour concentration, in parts per billion (ppb), by volume. Only sites that met data completeness requirements (based upon 75 percent or more of all possible daily values during the EPA-designated ozone monitoring seasons) were used to develop this map.

Figure 11. Ozone Concentrations along the United States–Canada Border (Three-Year Average of the Fourth-highest Daily Maximum 8-hour Concentration), 2015-2017

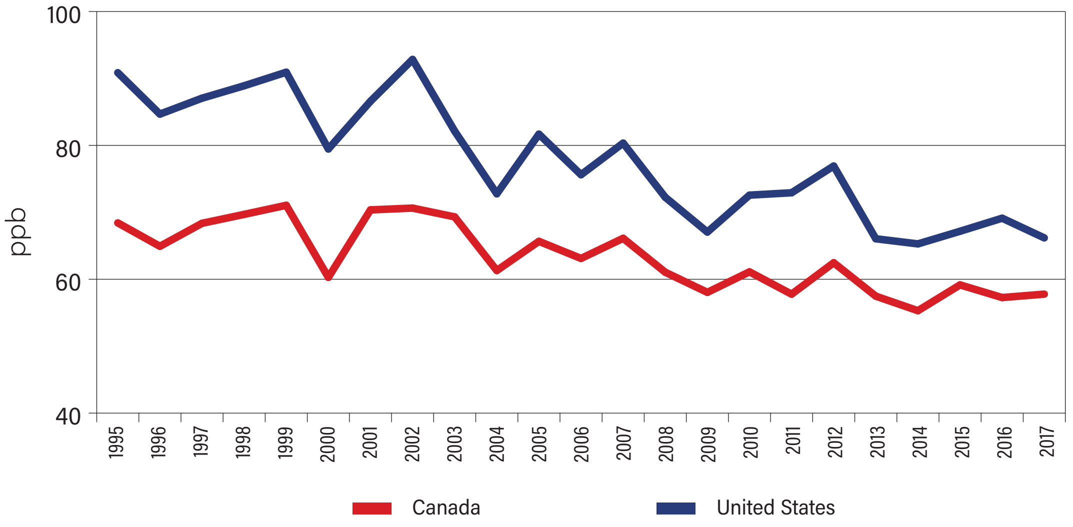


Notes: Data are the 2015-2017 averages of annual fourth-highest daily values, where the daily value is the highest running 8-hour average for the day.

Source: Environment and Climate Canada NAPS Network Canada-wide Database, 2019; (http://data.ec.gc.ca/data/air/monitor/national-air-pollution-surveillance-naps-program/). U.S. EPA Air Quality System (AQS) Data Mart (www.epa.gov/airdata).

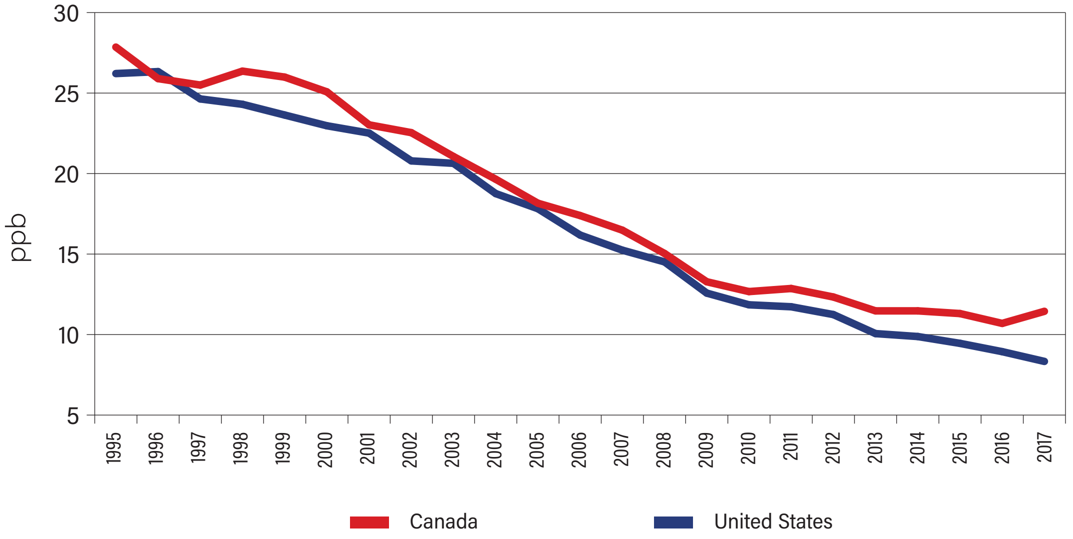
Figure 12 shows the trend of ozone concentrations reported as the annual average fourth-highest daily maximum 8-hour ozone concentration for sites within 500 km of the United States-Canada Border for 1995-2017. Trends of NO_x and VOC concentrations for the same time period are shown in Figures 13 and 14. Ambient concentrations of NO_x and VOCs reflect the significant reductions in emissions of these ozone precursors. Ozone concentrations reflect not only precursor concentrations, but also meteorological conditions for ozone formation. While some of the lowest ozone concentration levels are associated with cool, rainy summers (2004, 2009, 2014), ozone concentration levels are mainly due to the emission reductions programs described in this report.

Figure 12. Annual Average Fourth-Highest Daily Maximum 8-hour Ozone Concentration for Sites within 500 km of the United States-Canada Border, 1995-2017



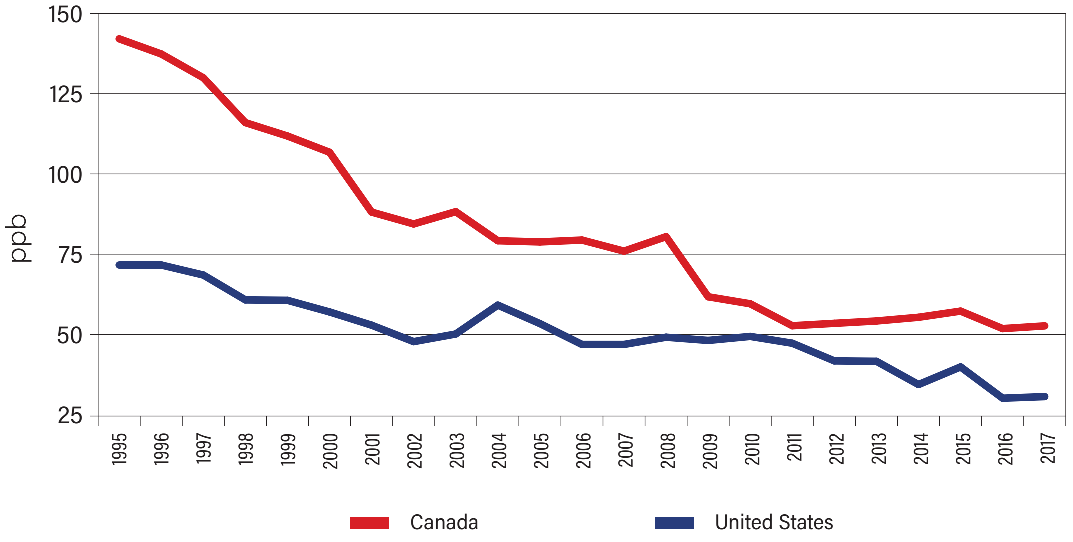
Source: U.S. EPA and Environment and Climate Change Canada, 2019

Figure 13. Average Ozone Season (May-September) 1-hour NO_x Concentrations for Sites within 500 km of the United States-Canada Border, 1995-2017



Source: U.S. EPA and Environment and Climate Change Canada, 2019

Figure 14. Average Ozone Season (May-September) 24-hour VOC Concentrations for Sites within 500 km of the United States-Canada Border, 1995-2017



Source: U.S. EPA and Environment and Climate Change Canada, 2019

EMISSIONS AND EMISSION TRENDS IN THE PEMA

Table 1 shows 2017 Canadian and United States emissions in the PEMA. In the Canadian PEMA, the sectors that contribute the most to the area's annual NO_x emissions are on-road and non-road transportation. The sectors that contribute the most to NO_x in both the Canadian PEMA and the United States PEMA are transportation and industrial sources. The predominant sectors that contribute to annual VOC emissions in the Canadian PEMA are solvent utilization processes and non-industrial fuel combustion. Transportation and solvent utilization are the predominant sectors for VOC emissions in the United States PEMA.

Table 1. PEMA Emissions, 2017

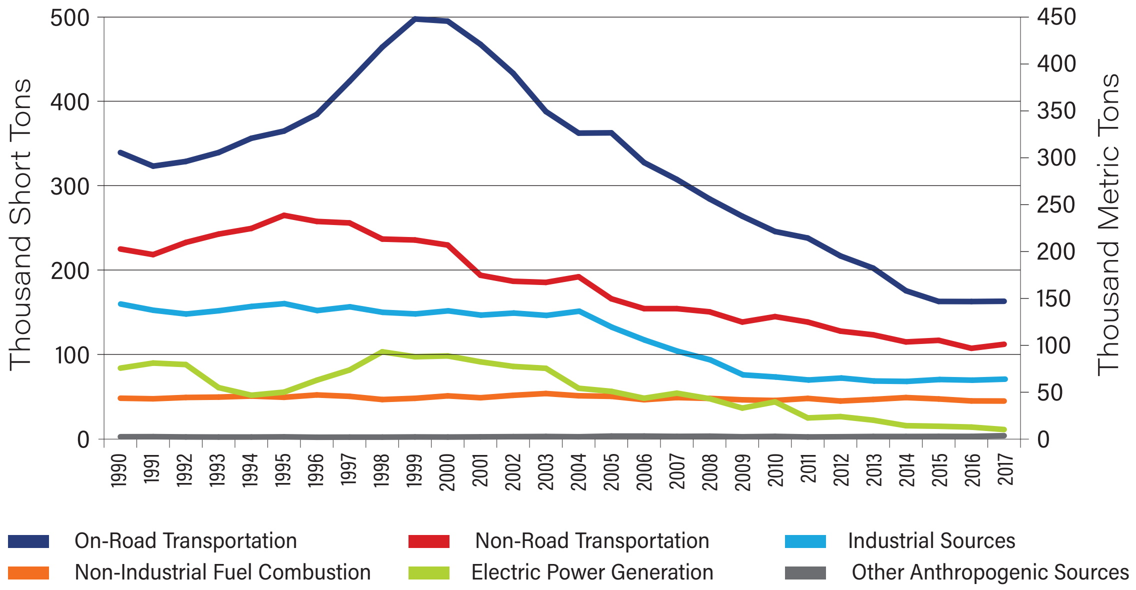
Emissions Category	2017 Annual				2017 Ozone Season			
	NO_x		VOCs		NO_x		VOCs	
	1000 Short Tons	1000 Metric Tons	1000 Short Tons	1000 Metric Tons	1000 Short Tons	1000 Metric Tons	1000 Short Tons	1000 Metric Tons
Canadian PEMA Region: Annual and Ozone Season Emissions								
Industrial Sources	69	63	58	52	30	27	24	22
Non-industrial Fuel Combustion	45	41	136	123	12	11	18	16
Electric Power Generation	11	10	0	0	4	4	0	0
On-road Transportation	162	147	61	55	64	58	25	22
Non-road Transportation	125	114	71	65	61	55	28	25
Solvent Utilization	0	0	197	179	0	0	84	76
Other Anthropogenic Sources	4	4	80	72	2	2	40	36
Forest Fires	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biogenic Emissions	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TOTALS	**416**	**378**	**603**	**547**	**172**	**156**	**218**	**198**
TOTALS without Forest Fires and Biogenics	**416**	**378**	**603**	**547**	**172**	**156**	**218**	**198**
U.S. PEMA States: Annual and Ozone Season Emissions								
Industrial Sources	530	481	496	450	221	200	207	188
Non-industrial Fuel Combustion	315	286	185	168	131	119	77	70
Electric Power Generation	337	306	13	12	141	128	5	5
On-road Transportation	1,041	944	534	484	434	394	223	202
Non-road Transportation	796	722	674	611	332	301	281	255
Solvent Utilization	0	0	1,160	1,052	0	0	484	439
Other Anthropogenic Sources	59	54	503	456	25	23	210	191
Forest Fires	6	6	109	99	3	3	45	41
Biogenic Emissions	145	132	4,671	4,237	60	54	1,948	1,767
TOTALS	**3,229**	**2,931**	**8,345**	**7,569**	**1,347**	**1,222**	**3,480**	**3,158**
TOTALS without Forest Fires and Biogenics	**3,078**	**2,793**	**3,565**	**3,233**	**1,284**	**1,165**	**1,487**	**1,350**

Notes: Short tons and metric tons are rounded to the nearest thousand. Totals in rows may not equal the sum of the individual columns.

Source: Environment and Climate Change Canada and U.S. EPA, 2019.

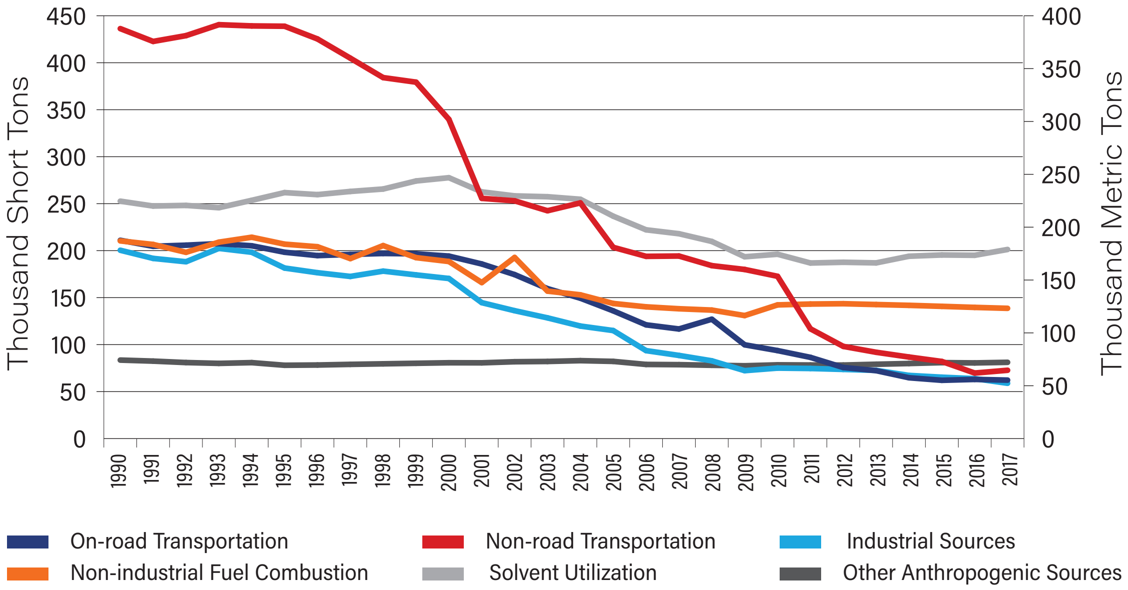
Figures 15 and 16 show Canadian NO_x and VOC PEMA emission trends for the years 1990 through 2017. For NO_x, nearly all source categories show an overall decrease in emissions with the greatest reductions originating from electric power generation. Over the same time period, each category of VOC sources shows an overall decrease with most of the reductions coming from non-road transportation sources, industrial sources and on-road transportation sources. The percent decrease in emissions from 1990 to 2017 for NO_x is 51 percent and for VOCs is 56 percent. The sharp increase in NO_x emissions for on-road transportation in 2002 is due to a different estimation method beginning with that year.

Figure 15. Canada NO_x Emission Trends in the PEMA Region, 1990 -2017



Source: Environment and Climate Change Canada, 2019

Figure 16. Canada VOC Emission Trends in the PEMA Region, 1990-2017

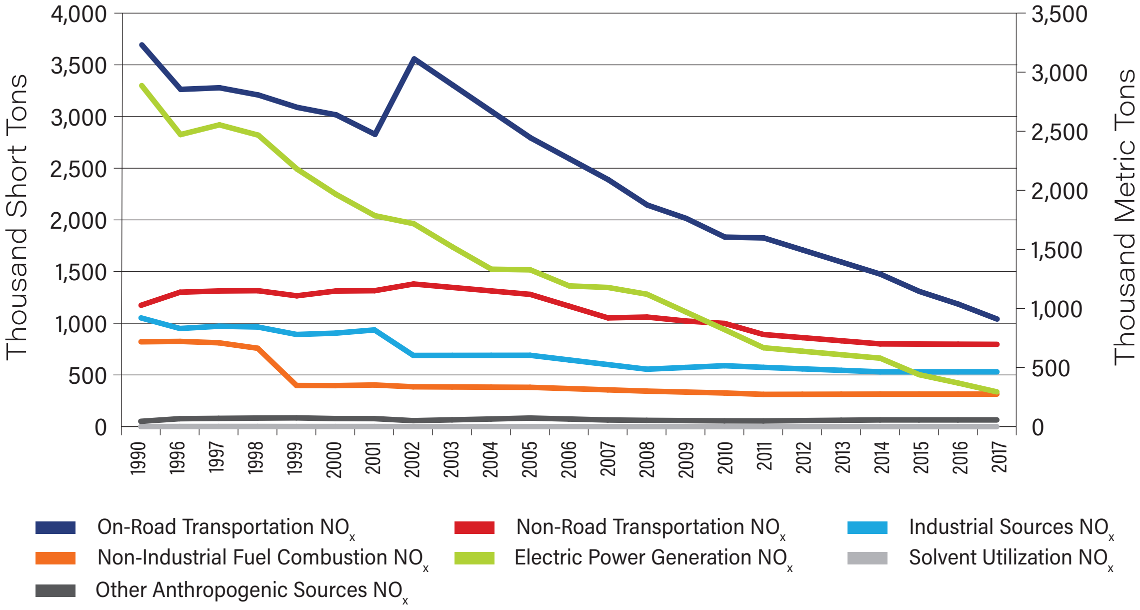


Source: Environment and Climate Change Canada, 2019

Figures 17 and 18 show United States PEMA emission trends for 1990 through 2017. There has been an overall trend of emission reductions for NO_x and VOCs. The percent decrease in emissions from 1990 to 2017 for NO_x is 69 percent and for VOCs is 60 percent. For NO_x emissions, the on-road and non-road transportation sources account for the greatest portion of the emissions in 2017, followed by fuel combustion for electrical power generation and industrial and non-industrial boilers. The largest NO_x emission reductions from these sources have occurred over the last 15 years. The sharp increase in NO_x emissions for on-road transportation in 2002 is due to a different estimation method beginning with that year.

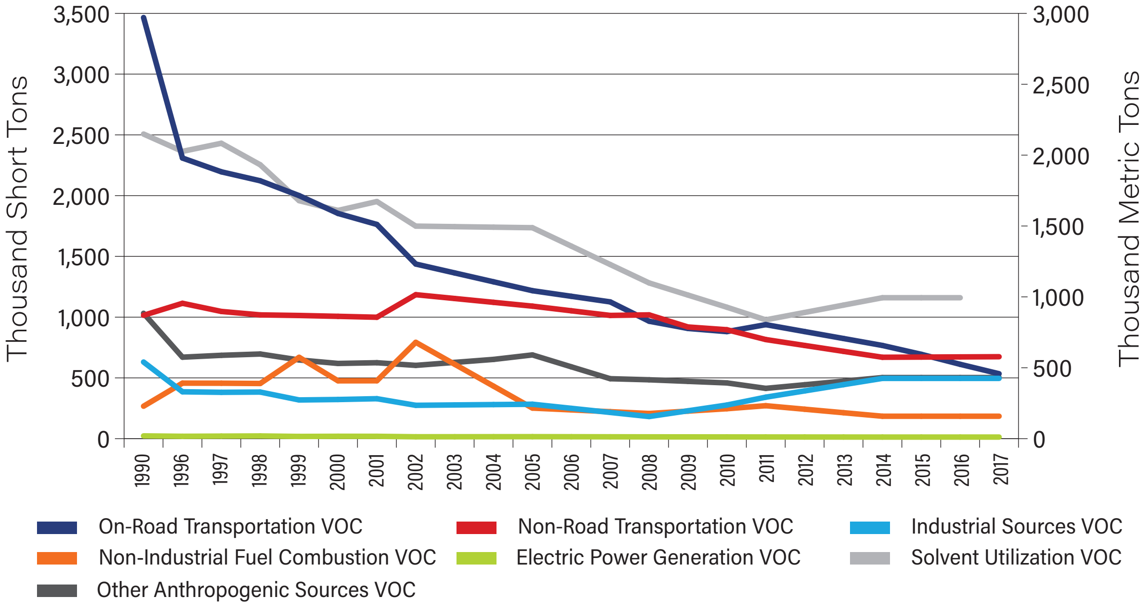
The greatest contributions of VOC emissions since 2012 are predominantly from solvent utilization and transportation sources. Over the period shown in Figure 18, the largest VOC emission reductions have occurred in on-road mobile sources and solvent utilization. While there is an overall decrease in VOC emissions, there have been increases for petroleum and related industries, including oil and gas production, and for prescribed fires. Emission estimation methods and reporting for these sources have also improved significantly in recent years.

Figure 17. U.S. NO_x Emission Trends in PEMA States, 1990-2017



Source: U.S. EPA, 2019

Figure 18. U.S. VOC Emission Trends in PEMA States, 1990-2017



Source: U.S. EPA, 2019

ACTIONS TO ADDRESS OZONE

Canada and the United States continue to implement programs designed to reduce emissions of NO_x and VOCs. Emissions from power plants and from vehicles remain a focus of these programs.

Canada

Canada is implementing a series of regulations to align Canadian emission standards for vehicles, engines, and fuels with corresponding standards in the United States.

Four regulations which set emission performance standards on on-road and off-road vehicles are in effect. They include: *On-Road Vehicle and Engine Emission Regulations*; *Off-Road Small Spark-Ignition Engine Emission Regulations*; *Off-Road Compression-Ignition Engine Emission Regulations*; and *Marine Spark-Ignition Engine, Vessel, and Off-Road Recreational Vehicle Emission Regulations*. Regulations that have been subject to recent amendments are set out below.

Regulatory initiatives for gasoline include *Sulphur in Gasoline Regulations* and *Benzene in Gasoline Regulations*, which have limited the level of sulfur and benzene content in gasoline. In addition, *Sulphur in Diesel Fuel Regulations* set maximum limits for sulfur in diesel fuels. Sulfur in gasoline impairs the effectiveness of emission control systems and contributes to air pollution. Reducing the sulfur content in gasoline enables advanced emission controls and reduces air pollution.

In July 2015, ECCC published final *Regulations Amending the Sulphur in Gasoline Regulations* (SiGR Amendments), which introduced lower limits on the sulfur content of gasoline from an average of 30 milligrams per kilogram (mg/kg) to 10 mg/kg, in alignment with the EPA Tier 3 fuel standards. The SiGR Amendments were published with *Regulations Amending the On-Road Vehicle and Engine Emission Regulations* and *Other Regulations Made Under the Canadian Environmental Protection Act, 1999* (ORVEER). The ORVEER Amendments introduce stricter limits on air pollutant emissions from new passenger cars, light-duty trucks, and certain heavy-duty vehicles beginning with the 2017 model year in alignment with the EPA Tier 3 vehicle standards. These two regulatory initiatives work in concert to reduce vehicle air pollutant emissions.

In October 2017, ECCC published amendments to the *Off-Road Small Spark-Ignition Engine Emission Regulations*. These amendments apply to small spark-ignition (SSI) engines found in lawn and garden machines, light-duty industrial machines, and light-duty logging machines. The amendments incorporate the more stringent EPA Phase 3 exhaust emission standards and include new evaporative emission standards for engines that have complete fuel systems attached. The amendments introduced tighter air pollutant emission standards for the 2019 and later model year SSI engines in Canada. Canada continues to work synergistically with the United States on administering, verifying and enforcing its vehicle and engine emission regulations.

The federal government also continues to address VOC emissions through various regulations. The *Tetrachloroethylene (Use in Dry Cleaning and Reporting Requirements) Regulations* were published in March 2003 with the goal of reducing PERC use in dry cleaning in Canada to less than 1,600 metric tons per year. In 2017, dry cleaners reporting under the regulations used less than 380 metric tons (419 short tons) of PERC.

The *Solvent Degreasing Regulations,* which took effect in July 2003, required a 65 percent reduction in annual consumption of trichloroethylene (TCE) and PERC from affected facilities by 2007. This usage has continued to decline. Under the regulations, ECCC issues annual allowances (consumption units) for use of PERC or TCE to qualifying facilities. Consumption units issued for 2018 represented a reduction of 88 percent respectively, for both TCE and PERC relative to the baseline.

ECCC has taken action to reduce VOC emissions from consumer and commercial products. The *Volatile Organic Compound (VOC) Concentration Limits for Automotive Refinishing Products Regulation*s and the *Volatile Organic Compound (VOC) Concentration Limits for Architectural Coatings Regulations* were published in 2009. By 2016, these two regulations had contributed to an estimated reduction in VOC emissions from surface coatings of 43 percent, compared to 2004 levels.

In June 2019, the department proposed *Volatile Organic Compound (VOC) Concentration Limits for Certain Products Regulations* to establish concentration limits for VOCs for about 130 product and sub-categories, including personal care, automotive, and household maintenance products; adhesives, adhesive removers, sealants, and caulks. It is estimated that between 2023 and 2030, the proposed regulations could result in 200 metric kilotons of VOC emission reductions.

The *Code of Practice for the Reduction of Volatile Organic Compound (VOC) Emissions from Cutback and Emulsified Asphalt* came into effect in February 2017. The main objective of the Code is to encourage the use of low VOC-emitting asphalt products. It is anticipated that compliance with the Code would result in annual VOC emission reductions of up to 5,000 metric kilotons from the use of asphalt.

ECCC has taken action to put in place requirements to limit VOC emissions from industrial facilities. In April 2018, ECCC published *Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas)* which came into effect in January 2020. These regulations introduce operating and maintenance standards for the upstream oil and gas industry, ensuring that fugitive and venting emissions of hydrocarbon gas will be reduced across the oil and gas sector. ECCC proposed Regulations Respecting the Reduction in the Release of Volatile Organic Compounds (Petroleum Sector) in 2017, which would reduce emissions of VOCs from refineries, upgraders and certain petrochemical facilities

New Canadian ambient air quality standards (CAAQS) for fine particulate matter ($PM_{2.5}$) and ground-level ozone were established as objectives under the CEPA 1999, by the federal government in 2013, having been approved by federal, provincial, and territorial Ministers of the Environment. In 2017 new standards were established for SO_2 and NO_2. These health- and environment-based standards are regularly reviewed to ensure they are set at the appropriate level, reflecting the latest scientific information and technological advances. A review of the 2020 ozone standard was completed in 2019 resulting in a more stringent standard for 2025 being established in June 2019. A review of the $PM_{2.5}$ standards was initiated in 2018. The CAAQS are objectives underpinned by four air quality management levels with thresholds that require increasingly more stringent action as the air quality in a given air zone approaches the level of the standard.

★ United States

The U.S. EPA has established National Ambient Air Quality Standards (NAAQS) for six principal pollutants shown to be harmful to public health and the environment, including ground-level ozone. In 2015, EPA revised the level of ozone NAAQS from 0.075 ppm to 0.070 ppm. When EPA establishes a new or revised NAAQS, the *Clean Air Act* directs EPA to designate all areas in the country as attainment (meeting the standard), nonattainment (not meeting the standard or contributing to a nearby area that is not meeting the standard), or unclassifiable (insufficient information to support a nonattainment or attainment designation). EPA completed designations for the revised NAAQS in 2018, with 52 areas designated as nonattainment. Nineteen of these nonattainment areas are fully or partially located in the ozone PEMA.

Ozone nonattainment areas are subject to planning and emission reduction requirements as specified in the *Clean Air Act*. The requirements and attainment dates vary according to the severity of the air quality levels in each area. State plans must provide for expeditious attainment of the NAAQS, taking into account existing national emission reduction programs (e.g., since 2000 EPA has finalized numerous emissions and fuel standards for cars, trucks, and nonroad engines); adoption of reasonably available control measures on local sources in the area; and regional emission reductions from programs designed to address interstate transport of air pollution that affects the ability of downwind states to meet and maintain the NAAQS.

EPA has addressed interstate transport of air pollution contributing to ozone nonattainment pursuant to three successive multi-state programs: the NBP in 2000, CAIR in 2005, and CSAPR in 2012 (with 2016 update). The EPA implemented the NBP under the NO_x State Implementation Plan Call from 2003 to 2008 to reduce ozone season NO_x emissions in eastern states. Starting in 2009, the NO_x annual and ozone season programs under EPA's CAIR took effect. These programs addressed regional interstate transport of fine particulate matter and ozone by requiring 28 eastern states to make reductions in SO_2 and NO_x emissions that contribute to fine particle and ozone pollution in downwind states. All affected states chose to meet their emission reduction requirements by controlling power plant emissions through the CAIR NO_x annual trading program and the CAIR NO_x ozone season trading program. In addition to the CAIR NO_x ozone season program and the former NBP, prior programs, such as the Ozone Transport Commission's NO_x Budget Program, and current regional and state NO_x emission control programs (i.e., CSAPR) have contributed significantly to the ozone season NO_x reductions.

From 2015 to 2018, ozone season NO_x emissions from sources in the CAIR NO_x ozone season program decreased by 92,000 short tons (83,500 metric tons) or 24 percent. NO_x ozone season program emissions decreased from 1.5 million short tons (1.4 million metric tons) in 2000 to 297,000 short tons (269,000 metric tons) in 2018, a decrease of 76 percent. CSAPR replaced CAIR on January 1, 2015. For more information on the CAIR and CSAPR NO_x programs, see www.epa.gov/airmarkets. In May 2017, implementation of the CSAPR Update program began.

In addition to implementing existing United States vehicle, non-road engine, and fuel quality rules to achieve both VOC and NO_x reductions, EPA continues implementation and updating of New Source Performance Standards to achieve VOC and NO_x reductions from new and modified existing sources. Reductions of NO_x emissions are also being achieved through rules on solid waste incineration units and guidelines that impact new and existing incineration units.

SCIENTIFIC AND TECHNICAL COOPERATION AND RESEARCH

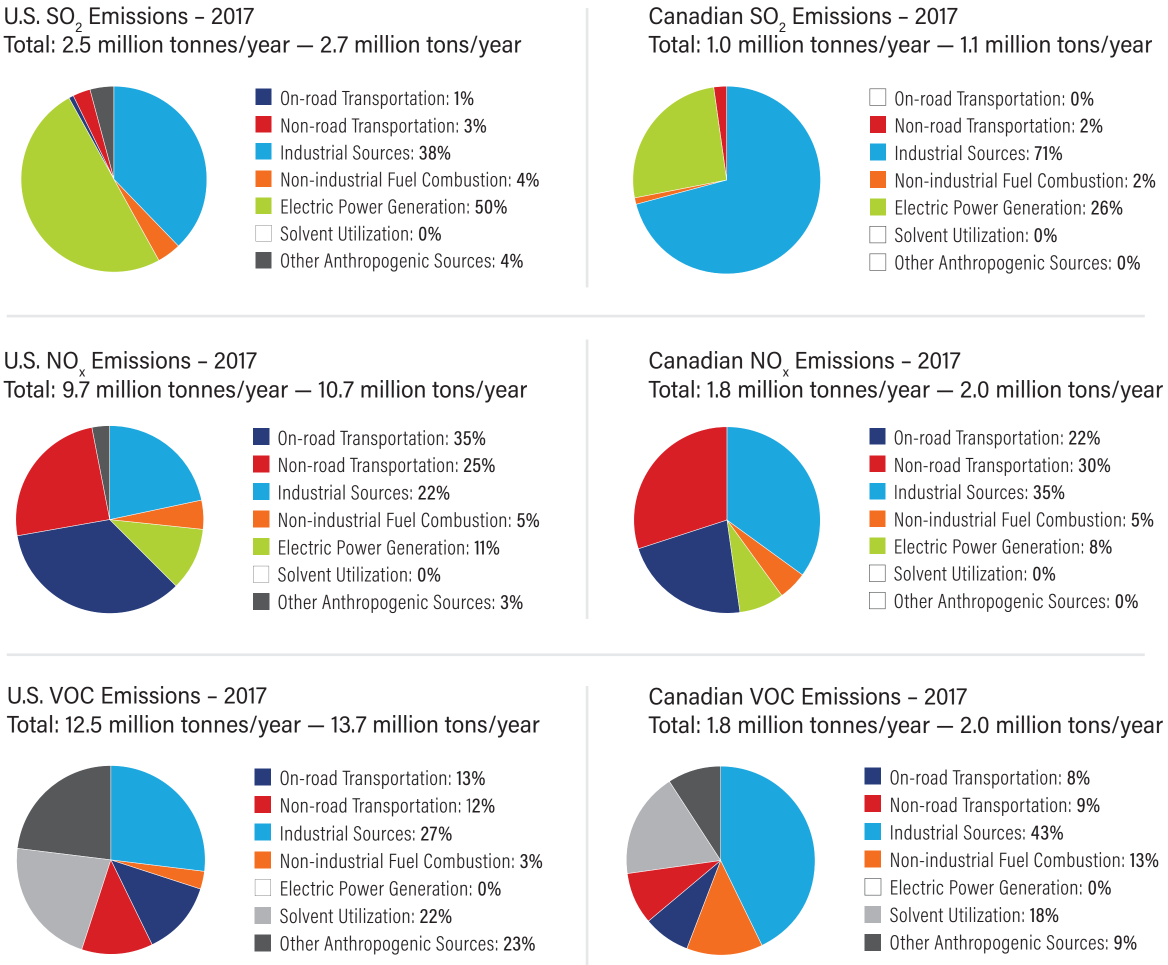
EMISSION INVENTORIES AND TRENDS

The United States and Canada have updated and improved their emission inventories and projections for a number of important pollutants, including particulate matter less than or equal to 10 microns (PM_{10}), $PM_{2.5}$, VOCs, NO_x, and SO_2, to reflect the latest information available. In Canada, the emissions inventory data are for the year 2017, as published in Canada's 2019 Air Pollutant Emissions Inventory. The United States emissions data are based on national and state-level trend information from the 2017 National Emission Inventory (https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data).

Figure 19 shows the distribution of emissions by source category grouping for SO_2, NO_x, and VOCs. The following observations can be made:

- Canadian SO_2 emissions originate mostly from the non-ferrous smelting and refining industry, upstream petroleum industry, and coal-fired electric power generation. The relative contribution from electric power generation utilities is lower in Canada due to the large hydroelectric and nuclear capacity in place.
- SO_2 emissions in the United States originate primarily from coal-fired combustion in the electric power sector and from industrial boilers.
- In Canada, non-road and on-road vehicles account for the greatest portion of NO_x emissions, followed by the upstream petroleum industry.
- Similarly, in the United States non-road and on-road vehicles account for the greatest portion of NO_x emissions, followed by industrial sources.
- Solvent utilization and industrial sources contribute more than half the total VOC emissions in both Canada and the United States.

Figure 19. U.S. and Canadian National Emissions by Sector for Selected Pollutants, 2017



U.S. SO_2 Emissions – 2017
Total: 2.5 million tonnes/year — 2.7 million tons/year

Canadian SO_2 Emissions – 2017
Total: 1.0 million tonnes/year — 1.1 million tons/year

U.S. NO_x Emissions – 2017
Total: 9.7 million tonnes/year — 10.7 million tons/year

Canadian NO_x Emissions – 2017
Total: 1.8 million tonnes/year — 2.0 million tons/year

U.S. VOC Emissions – 2017
Total: 12.5 million tonnes/year — 13.7 million tons/year

Canadian VOC Emissions – 2017
Total: 1.8 million tonnes/year — 2.0 million tons/year

Notes: Emissions exclude natural sources (biogenics and forest fires). Percentages may not add up to 100 due to rounding.

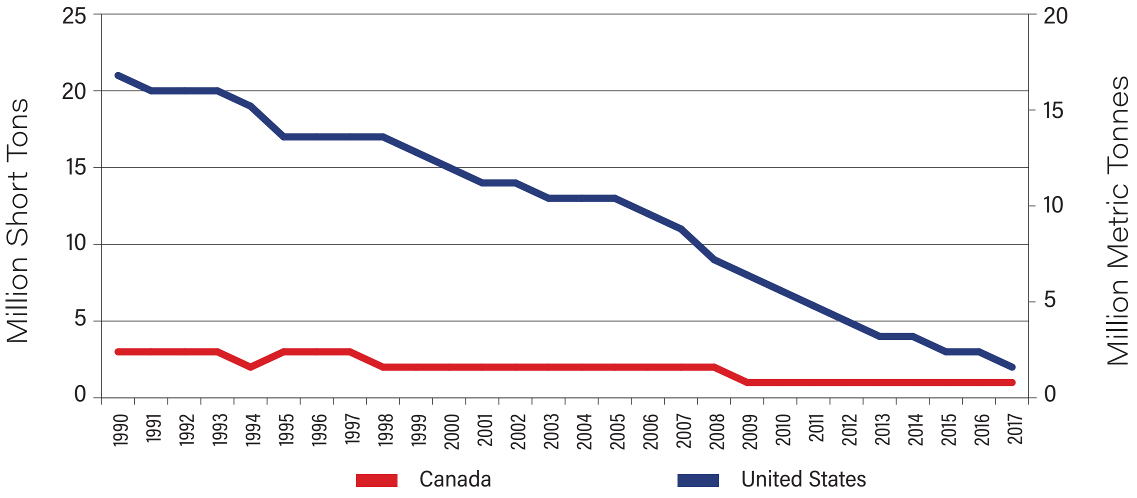
Sources: Environment and Climate Change Canada, 2019; EPA, 2019

Figures 20, 21, and 22 show emissions trends from 1990 through 2017 in Canada and the United States, for SO_2, NO_x, and VOCs, respectively. Both countries have seen major reductions in emissions.

In Canada, the reductions in SO_2 emissions came from the non-ferrous smelting and refining industry, coal-fired electric power generation, and the upstream petroleum industry. For NO_x, the reductions were from coal-fired electric power generation and transportation-related sources. The VOC reductions came from transportation-related sources such as off-road and on-road vehicles.

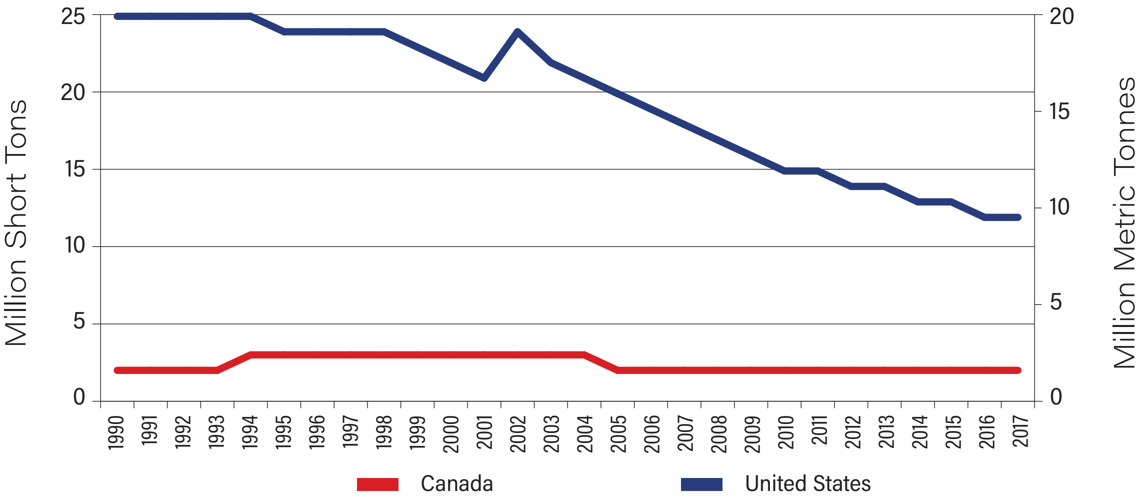
In the United States, the reductions in SO_2 emissions came mostly from electric power generation and industrial sources. Reductions in NO_x emissions came from on-road and off-road transportation, and from electric power generation. Reductions in VOC emissions came from on-road and off-road transportation as well as from other anthropogenic sources.

Figure 20. National SO_2 Emissions in the United States and Canada from All Sources, 1990-2017



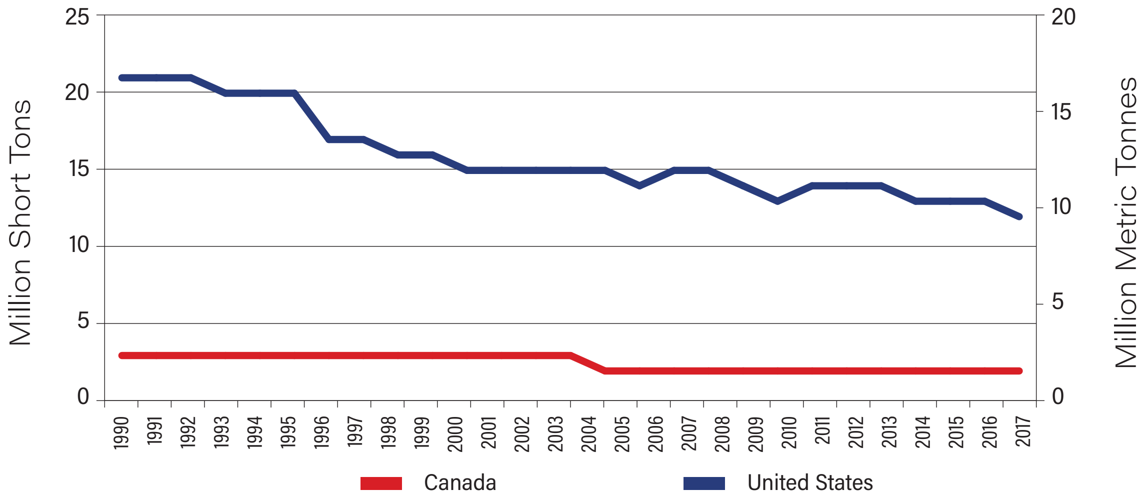
Source: U.S. EPA and Environment and Climate Change Canada, 2019

Figure 21. National NO_x Emissions in the United States and Canada from All Sources, 1990- 2017



Source: U.S. EPA and Environment and Climate Change Canada, 2019

Figure 22. National VOC Emissions in the United States and Canada from All Sources, 1990- 2017



Source: U.S. EPA and Environment and Climate Change Canada, 2019

SCIENTIFIC COOPERATION

Air Quality Model Evaluation International Initiative

Since its start in 2008, the Air Quality Model Evaluation International Initiative (AQMEII) has been coordinated by the European-Commission Joint Research Center (JRC) and the EPA. The primary goal of this project is to promote the collaboration of the European and North American regional scale air quality modeling communities on evaluation of air quality models. The key elements driving the AQMEII process are regular, dedicated workshops; the organization of international model evaluation studies; and the dissemination of findings from these studies in the peer-reviewed literature.

To date, AQMEII has completed three phases of collaborative model evaluation and intercomparison activities and is currently and the fourth phase is currently underway. These collaborations involved a total of 37 groups from 17 countries. Besides co-chairing AQMEII with the JRC, EPA also contributes Community Multiscale Air Quality Modeling (CMAQ) simulations to these collaborative activities, allowing comparison of various aspects of CMAQ to other state-of-science regional air quality models used by the North American and European modeling communities. ECCC has contributed simulations using its AURAMS (AQMEII-1) and GEM-MACH models (AQMEII-2, AQMEII-4), as well as contributing to the design of the study protocols through participation in the AQMEII steering committees.

In the first phase of AQMEII (2010-2012), chemical transport models were applied by different groups over the North American and European continents and extensively evaluated based on the comprehensive model evaluation framework presented by Dennis et al. (2010). This framework promotes a gradual and fit-for-purpose multi-stage evaluation process that includes operational, diagnostic, dynamic and probabilistic (i.e., uncertainty) evaluation. While all these model evaluation modes were employed in Phase 1, most of the contributions focused on operational and probabilistic evaluation as noted in Schere et al. (2012), who reflected on lessons learned from that activity.

Phase 2 of AQMEII (2012-2014) focused on applying and evaluating on-line coupled or integrated chemistry transport models and meteorological models. Such modeling systems attempt to close some or all of the feedback loops that exist between atmospheric dynamics and composition. A key feature of AQMEII-2 was a detailed evaluation of the impacts of air pollution on weather and the skill of fully coupled models on weather forecasts (Makar et al., 2015a,b[5]). The model evaluation framework presented by Dennis et al. (2010) also formed the basis for the work under AQMEII Phase 2. Compared to Phase 1, contributions covered a fuller range of this framework, most notably diagnostic evaluation as well as some aspects of dynamic and probabilistic evaluation.

Some of the key findings from Phase 2 of AQMEII included:

- It is important to include interactions between meteorology and chemistry (especially aerosols and ozone) in online coupled models;
- Aerosol indirect and direct effects often counteract each other - direct effects are weaker on the annual scale;
- The aerosol indirect effect (cloud microphysics implementation) is a prime cause of model differences;
- The representation of aerosol indirect effects needs to be further developed and improved in online coupled models; and
- Inter-model variability typically is greater than the feedback effects simulated with a given model. This last finding implies that factors other than feedback effects such as emissions, boundary conditions, and process representations of chemistry and/or transport remain the key determinants for overall model performance.

Phase 3 of AQMEII (2014-2018) was aimed at applying and comparing modeling techniques to provide information on the impact of long-range transport on regional air quality. Modeling this phenomenon requires representing relevant processes at hemispheric-to-regional scales, either by using global or linked global-regional scale modeling systems. AQMEII contributed to coordinated modeling exercises to apply and intercompare these modeling approaches in partnership with the Task Force on Hemispheric Transport of Air Pollution (HTAP) and the Model Intercomparison Study for Asia (MICS-Asia). Results were published in the journal Atmospheric Chemistry and Physics in a special issue entitled "Global and regional assessment of intercontinental transport of air pollution: results from HTAP, AQMEII and MICS".[6] The special issue contains publications that investigate various aspects of modeling intercontinental transport of air pollution such as publications evaluating the joint HTAP, AQMEII and MICS modeling experiments, publications developing new methodologies to assess intercontinental transport or air pollution, and publications describing and evaluating observational and emission data sets used to study intercontinental transport.

Phase 4 of AQMEII focuses on performing systematic intercomparisons of atmospheric deposition estimates from a variety of modeling systems used in the U.S. and Europe. A Steering Committee was formed in 2018 and has conducted an analysis of the aspects to be considered in the planned evaluation activities. The Steering Committee included representatives from ECCC and EPA. The analysis performed by the Steering Committee included a harmonization of the nomenclatures (for example, making sure that a specific definition of a resistance or conductance would comprise the same processes across different models, since no common nomenclature exists in general and across schemes), a harmonization of the reported land use categories to make sure that sophisticated land descriptions

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[5] Makar, P.A., Gong, W., Milbrandt, J., Hogrefe, C., Zhang, Y., Curci, G., Zabkar, R., Im, U., Balzarini, A., Baro, R., Bianconi, R., Cheung, P., Forkel, R., Gravel, S., Hirtl, H., Honzak, L., Hou, A., Jimenez-Guerrero, P., Langer, M., Moran, M.D., Pabla, B., Perez, J.L., Pirovano,G., San Jose,R., Tuccella, P., Werhahn, J., Zhang, J., Galmarini, S , Feedbacks between air pollution and weather, part 1: Effects on weather. Atmospheric Environment, 115, 442-469, 2015a.
Makar, P.A., Gong, W., Hogrefe, C., Zhang, Y., Curci, G., Zabkar, R., Milbrandt, J., Im, U., Balzarini, A., Baro, R., Bianconi, R., Cheung, P., Forkel, R., Gravel, S., Hirtl, H., Honzak, L., Hou, A., Jimenez-Guerrero, P., Langer, M., Moran, M.D., Pabla, B., Perez, J.L., Pirovano,G., San Jose,R., Tuccella, P., Werhahn, J., Zhang, J., Galmarini, S.
Feedbacks between air pollution and weather, part 2: Effects on chemistry. Atmospheric Environment, 115, 499-526, 2015b.

[6] Available at www.atmos-chem-phys.net/special issue390.html.

could be comparable with less sophisticated ones, and a determination of variables and parameters which can be used to represent equivalent deposition-related pathways across models with different deposition formulations. Study protocols were released in the summer of 2019, with model runs expected to be completed in early 2020 and data analysis completed in fall 2020. It is anticipated that results from this activity will help more robustly characterize the uncertainties in current estimates of deposition fluxes, identify key knowledge gaps, and study implications for the use of these estimates for ecological assessments.

Collaborative Projects on Nitrogen and Sulfur Deposition

The atmospheric deposition of nitrogen, sulfur and other chemical species to underlying surfaces is an important exposure pathway that can contribute or lead to the degradation of air, land and water quality as well as reductions in the benefits humans may derive from ecosystems. Understanding the processes and outcomes associated with atmospheric deposition is needed to characterize progress toward meeting targeted reductions in deposition in the US and Canada.

Scientists at the US EPA and ECCC actively participate in the National Atmospheric Deposition Program's (NADP) Total Deposition (TDep) Science Committee. The mission of TDep is to improve estimates of atmospheric deposition by advancing the science of measuring and modeling atmospheric wet, dry, and total deposition of species such as sulfur, nitrogen, and mercury. TDep provides a forum for the exchange of information on current and emerging issues within a broad multi-organization context including atmospheric scientists, ecosystem scientists, resource managers, and policy makers. One of the goals of the NADP's TDEp Science Committee is to provide estimates of total sulfur and nitrogen deposition for use in critical loads and other ecological assessments.

In 2019, TDep members and collaborators issued a white paper – *Science Needs for Continued Development of Total Nitrogen Deposition Budgets in the United States*. This document describes the current state of the science and remaining knowledge and data gaps related to improving measurements and models of reactive nitrogen deposition and better understanding sources of reactive nitrogen to support review of the U.S. secondary national ambient air quality standards (NAAQS) and further develop critical loads[7] as a framework for managing deposition of nutrients and acidity. Though focused on the U.S., this document can serve as a roadmap for researchers and policy makers across North America.

EPA and ECC scientists are continuing to collaborate on projects that combine network measurement data and air quality models to estimate total deposition. A comparison of the US product from TDep with the first results from the Canadian project ADAGIO (Atmospheric Deposition Analysis Generated by optimal Interpolation from Observations) is underway. This comparison will support the goal of combining the results from the two approaches to obtain one set of deposition maps for North America. The measurement-model fusion approaches used by the US and Canada, as well as Sweden, are now leading the way for the use of measurement-model fusion on a global scale; scientists from the TDep and ADAGIO projects are members of the recently-formed leadership team for a Measurement-Model Fusion for Global Total Atmospheric Deposition initiative sponsored by the World Meteorological Organization.

Much of the collaborative work discussed above was summarized in an article titled, *Ongoing U.S.-Canada Collaboration on Nitrogen and Sulfur Deposition* in the Air and Waste Management Association's magazine for environmental managers. This article, co-authored by Canadian and US scientists, was included in the June 2019 special issue describing cross-border environmental issues. It provided an overview of the past, current and planned activities related to deposition, such as monitoring network and modelling intercomparison studies, cooperation on measurement-model fusion projects as described above, and sharing data to improve satellite estimates of reactive nitrogen dry deposition.

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[7] Critical loads are used to quantify the amount of atmospheric deposition (load) that can be tolerated by ecosystems without significant harm or change occuring.

CONCLUSION

Canada and the United States continue to meet their commitments in the 1991 Agreement. Since the establishment of the Agreement, both countries have made significant progress in reducing acid rain and controlling ozone in the transboundary region.

Despite the results achieved under the Agreement, the pollutants covered by the Agreement (SO_2, NO_x, VOCs) remain a concern and continue to have significant impacts on human health and the environment in both countries. Continued bilateral efforts are needed to reduce the transboundary impact of these pollutants and to ensure that transboundary air pollution does not affect each country's ability to attain and maintain its national ambient air quality standards for pollutants such as ozone and $PM_{2.5}$, or to protect the health and environment of its citizens.

The Agreement provides a formal and yet flexible vehicle for addressing transboundary air pollution and as such provides a framework under which the two countries continue to cooperate to address ongoing, emerging and future air quality issues.

APPENDIX A: LIST OF ABBREVIATIONS AND ACRONYMS

ARP	Acid Rain Program
Agreement	Air Quality Agreement
AQMS	(Canada) Air Quality Management System
AQS	(EPA) Air Quality System
BACT	Best Available Control Technology
BART	Best Available Retrofit Technology
BCVCC	British Columbia Visibility Coordinating Committee
CAA	*Clean Air Act*
CAM	Compliance Assurance Monitoring
CAAQS	Canadian Ambient Air Quality Standards
CAIR	Clean Air Interstate Rule
CAPMon	Canadian Air and Precipitation Monitoring Network
CASTNET	Clean Air Status and Trends Network
CEM	Continuous Emissions Monitoring
CEPA 1999	*Canadian Environmental Protection Act, 1999*
CFR	Code of Federal Regulations
CI	Continuous Improvement
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSAPR	Cross-State Air Pollution Rule
CSN	PM2.5 Chemical Speciation Network
CWS	Canada-wide Standards
D.C.	District of Columbia
DOT	Department of Transportation
ECA	Emission Control Area
EGU	Electric Generating Unit
EPA	Environmental Protection Agency
Eq/ha/yr	equivalents per hectare per year
FIPs	Federal Implementation Plans
GHG	greenhouse gas
HNO_3	Nitric Acid
IMPROVE	Interagency Monitoring of Protected Visual Environments
ISA	Integrated Science Assessment
KCAC	Keeping Clean Areas Clean
kg/ha/yr	kilograms per hectare per year
kW	Kilowatts
LAER	Lowest Achievable Emission Rate
LFV	Lower Fraser Valley
mg/kg	Milligrams per kilogram
MW	Megawatt
NAA	Non-Attainment Area
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NAPS	National Air Pollution Surveillance
NatChem	National Atmospheric Chemistry Database
NBP	NO_x Budget Trading Program
NCore	National Core Monitoring Network
NEI	National Emissions Inventory
NO	Nitrogen Monoxide
NO_2	Nitrogen Dioxide
NO_3	Nitrate
NO_x	Nitrogen Oxides
NOy	total reactive nitrogen
NOAA	National Oceanic and Atmospheric Administration
NPRI	National Pollutant Release Inventory
NPS	National Park Service
NSPS	New Source Performance Standards
NSR	New Source Review
NTN	National Trends Network
O_3	ground-level ozone
OTC	Ozone Transport Commission
Pb	Lead
PEMA	Pollutant Emission Management Area
PERC	Tetrachloroethylene
pH	measure of the activity of the solvated hydrogen ion

ORVEER	*Regulations Amending the On-Road Vehicle and Engine Emission Regulations and Other Regulations Made Under the Canadian Environmental Protection Act, 1999*
$PM_{2.5}$	Particulate matter less than or equal to 2.5 microns, known as fine particles
PM_{10}	Particulate matter less than or equal to 10 microns
ppb	parts per billion
ppm	parts per million
PSD	Prevention of Significant Deterioration
SiGR	*Regulations Amending the Sulphur in Gasoline Regulations*
SIP	State Implementation Plan
SO_X	Sulfur Oxides
SO_2	Sulfur Dioxide
SO_4^{2-}	Sulfate
TCE	Trichloroethylene
ueq/L	micro-equivalents per liter
ug/m^3	micrograms per cubic meter
VOCs	Volatile Organic Compounds