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Air and Atmosphere

Ground-level Ozone

Key Findings

- Ground-level ozone—unlike ozone in the stratosphere—damages human health, vegetation and materials. Ozone and its precursor chemicals travel across both North American and continental boundaries.
- Humans contribute to the formation of ground-level ozone primarily through burning fossil fuels in the transportation, industrial and electricity generation sectors. Evaporation of liquid fuels and solvents also adds to ozone formation.
- In certain areas of North America, levels of ground-level ozone exceed national standards for the protection of human health.
- Since 1990, total emissions of ozone precursor chemicals have declined in North America, but the trend in human exposure across the three countries is mixed, reflecting differences in location conditions and reporting methods.

Ground-level ozone **is a colorless, highly irritating gas created by photochemical reactions between nitrogen oxides and volatile organic compounds produced largely by fuel combustion, gasoline vapors and chemical solvents.**

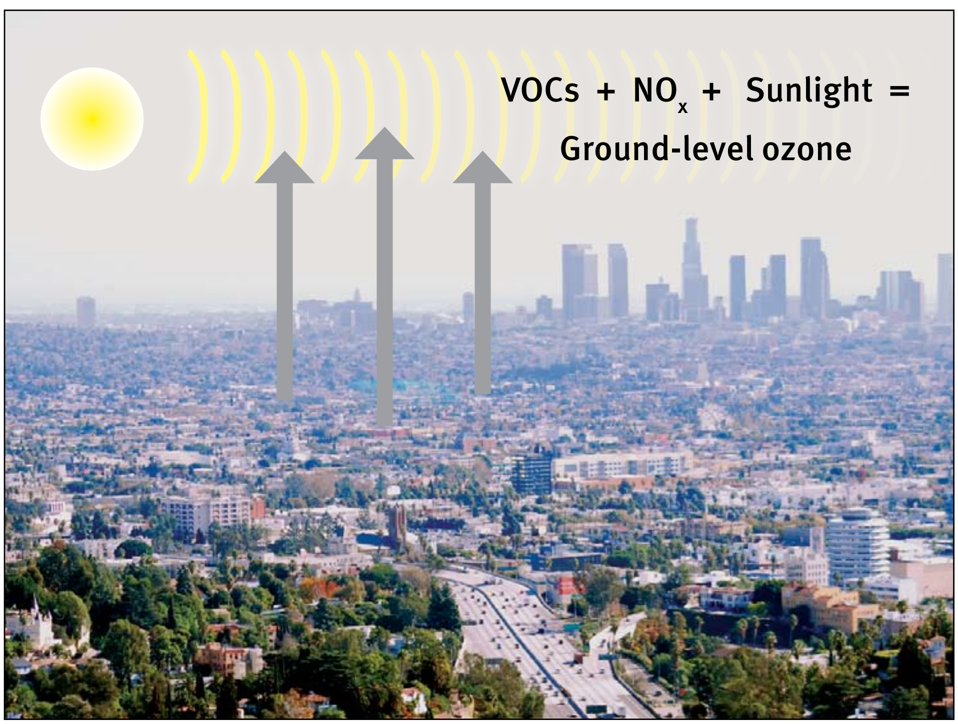
What Is the Environmental Issue?

Ozone (O_3) is a gas found in different parts of the atmosphere. Ozone in the upper atmosphere, or stratosphere, is an essential gas that helps to protect the earth from the sun's harmful ultraviolet rays. By contrast, the ozone found near the ground in the troposphere harms both human health and the environment. For this reason, ozone is often described as being "good up high and bad nearby."

Ground-level ozone is produced when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) react through photochemical processes in sunlight (see figure). Power plants, motor vehicle exhaust, industrial facilities, gasoline vapors, and chemical solvents are the major sources of these emissions.

Ozone is also formed at ground level from natural emissions of VOCs, NO_x and carbon monoxide, as well as stratospheric ozone that occasionally migrates down to the earth's surface. Natural sources of ozone precursors include emissions from plants and soils, forest fires, and lightning. High ozone concentrations are observed at many remote mid-latitude sites in late winter and spring, especially at high elevations. However, long-range transport and the winter buildup of O_3 precursors also contribute to these springtime levels, so it is not possible to attribute these high levels solely to natural sources.

How ground-level ozone is formed



Levels of ground-level ozone are often higher during hot summer days or downwind of the heavily populated areas that are emitting the necessary precursors. In the Northern Hemisphere, ozone levels are typically highest during the afternoon hours of the months in which temperatures are warm and the influence of direct sunlight is the greatest.

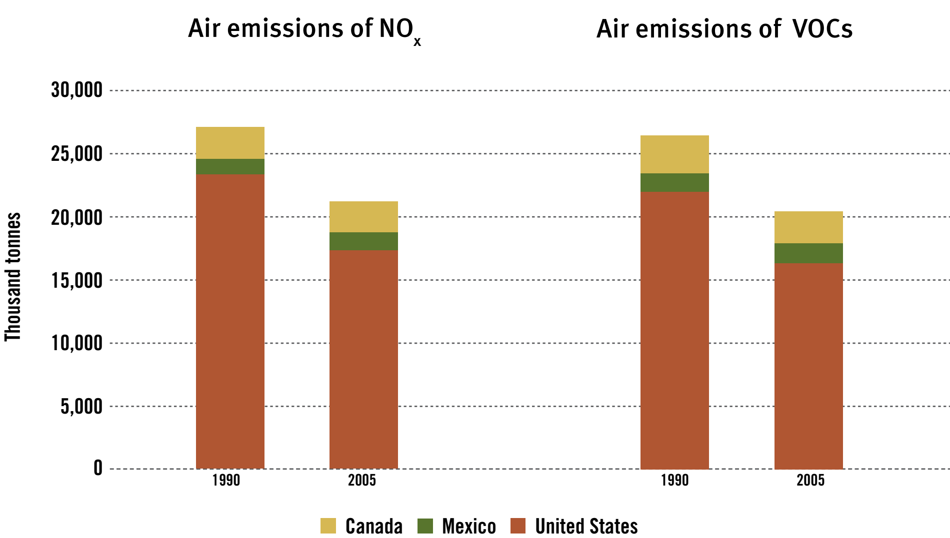
Why Is This Issue Important to North America?

Ground-level ozone has deleterious effects on human and animal health and the environment. Despite reduction efforts by the three countries, it still exceeds national air quality standards in some areas of North America.

Effects of Ground-level Ozone

Ground-level ozone, a key component of smog, is considered a "nonthreshold" problem because even very small amounts in the air have deleterious effects on human health, especially the cardiovascular and respiratory systems. Exposure to ozone has been linked to premature mortality and a range of morbidity outcomes that include hospital admissions and asthma symptoms. After analyzing the air pollution and mortality data of eight major Canadian cities, Health Canada estimated that in these cities almost 6,000 deaths a year could be attributed to air pollution of which ground-level ozone is a major component. According to the Ontario Medical Association, air pollution costs Ontario citizens more than C$1 billion a year in hospital admissions, emergency room visits and absenteeism. In the United States, studies of 95 major urban areas by researchers at Yale and Johns Hopkins revealed that an increase in daily ozone levels was associated with more than 3,700 deaths each year from cardiovascular and respiratory illnesses.

Vegetation, crop productivity, flowers, shrubs and forests are also damaged by ground-level ozone. Moreover, it can deteriorate cotton and synthetic materials, produce cracks in rubber and accelerate the fading of dyes, paints and coatings.



Sources: Environment Canada, *Instituto Nacional de Ecología* (latest data from Mexico from 2002, not 2005), US Environmental Protection Agency.

Reducing Emissions

The 1970s saw the beginning of attempts to mitigate ground-level ozone concentrations across North America through directed reductions in precursor emissions. In response, both NO_x and VOC emissions in the United States fell substantially, despite significant economic growth. In Canada, VOC emissions have decreased, but the trend in NO_x emissions has been almost flat since 1990. Mexico has experienced reductions in emissions from vehicles, but increases in those from fixed or stationary sources for both NO_x and VOCs. Overall, air emissions of ground-level ozone precursors in North America have declined since 1990, with releases of both NO_x and VOCs falling over 20 percent (see graphs).

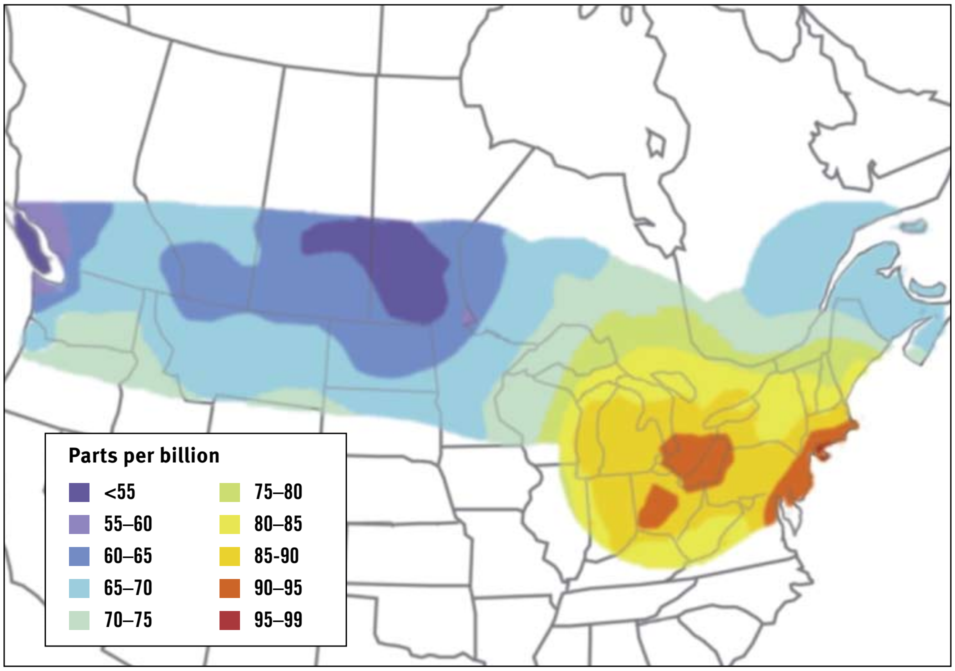
In all three countries, fuel combustion by mobile sources is a major source of both NO_x and VOC emissions, with fossil fuel–fired power plants adding significantly to NO_x emissions in the United States and Mexico. In Canada, upstream oil and gas production is the largest industrial contributor of NO_x. In addition to fuels in the transportation sector, solvents are a major source of emissions of VOCs in all three countries, but oil and gas production is also a large contributor in Canada.

Monitoring Ozone Trends

At present, considerable ozone data for North America are available from various networks. Characterization of North American trends and patterns is limited, however, by the lack of consistency in these data sets and by the inconsistent methods for preparing and reporting results. It is also difficult to derive meaningful North American trends because conditions vary greatly on a regional basis. Nevertheless, existing monitoring reveals that ambient levels of ozone exceed national standards in certain areas of all three countries.

In Canada, trends for ambient ozone based on the Canada-wide Standard (CWS) remained largely unchanged over the 15 years ending in 2005. However, the Canadian indicator for human exposure to ozone rose by an average of 0.8 percent a year, for a total increase of 12 percent between 1990 and 2005. The national ozone exposure indicator for Canada, which is weighted by population, is driven primarily by the ozone concentrations and populations in Ontario and southern

Ozone concentrations along the Canada-US border (2002–2004)



Source: Bilateral Air Quality Committee.

Quebec. In 2005, communities in these areas recorded the highest ground-level ozone concentrations for both the CWS and seasonal averages. Many stations in Alberta also reported high seasonal average concentrations. In 2005, at least 40 percent of Canadians lived in communities with ozone concentrations above the ambient CWS target.

In Mexico, the frequency of days on which ground-level ozone concentrations exceed the standard has remained constant over time in most monitored cities. However, in Mexico City and Guadalajara, ground-level ozone remains a serious air quality problem. In 2005 at least 27.7 percent of Mexicans lived in municipalities in which ozone concentrations were above the national standard at least one day a year.

In the United States, national ozone concentrations averaged over one hour and eight hours fell by 12 percent and 8 percent, respectively, in the period between 1990 and 2005. Despite the decrease, in 2005, more than 10 percent of Americans lived in counties with air quality concentrations above the ozone one-hour National Ambient Air Quality Standard, and at least 33 percent lived in counties with concentrations above the eight-hour standard.

Transboundary Flows

Both field studies and computer models confirm that the ozone problem in various regions of North America is a result of the complex interactions between meteorological processes on various scales and precursor emissions and their chemistry. At times, ozone levels are predominantly the result of local emissions, with only minor contributions from upwind sources. And at other times, local ozone levels are dominated by the transport of ozone and its precursors from upwind sources.

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Analyses of ozone levels within 500 kilometers of the Canada-US border found higher ozone levels in the lower Great Lakes–Ohio Valley region and along the US East Coast (see map). The lowest ozone values are largely found in the west and in Atlantic Canada. Levels are generally higher downwind of urban areas, such as in the western portions of lower Michigan. The locally higher levels in the complex terrain of the Georgia Basin–Puget Sound area of British Columbia–Washington State are not well resolved in the map shown, although they are lower than in the east. Between 1995 and 2004, there was a decrease in annual ozone levels within this border region, with trend lines on either side of the border tracking similarly.

Ozone concentrations in the US-Mexico border region remain a concern in some areas. Although in the Rio Grande Valley no days in 2005 exceeded the binational eight-hour ozone standard, other monitoring locations in border sister-city pairs demonstrated exceedances, including Ambos Nogales (1 day), Ciudad Juárez/El Paso (6 days), Tijuana/San Diego (11 days), and Mexicali/Imperial Valley (24 days). Although overall compliance with the ozone standard is generally improving, Mexicali/Imperial Valley and Tijuana/San Diego consistently remained above the applicable standard from 2001 to 2005.

Transport of ozone and precursor emissions extends beyond North America's borders. North America is a source of ground-level ozone for Europe just as Asia is for North America. More widely, ground-level ozone levels are rising across the planet and have created "background" ozone concentrations, even in remote areas that are not directly affected by human influence. Retrospective analysis of eighteenth-century data from Europe suggests that ozone concentrations in the Northern Hemisphere may have doubled over the past century in response to the massive industrialization that has taken place. Current "background" ozone concentrations in North America are about 30–40 parts per billion.

What Are the Linkages to Other North American Environmental Issues?

Ozone and its precursor pollutants are linked to particulate matter (PM), another component of smog, and to acidification, eutrophication and climate change.

Particulate Matter

When nitrate, an oxidation product of nitrogen dioxide (NO_2), is combined with other compounds in the atmosphere, such as ammonia, it becomes an important contributor to the secondary formation of fine particulate matter ($PM_{2.5}$). VOCs are also a precursor pollutant to the secondary formation of $PM_{2.5}$. Ozone and PM have some common precursor gases, and reductions in any one of these precursors can have complex, and at times negative, results for concentrations of ozone or PM. Efforts to address and reduce concentrations of ozone and PM are often integrated in air quality management programs to avoid negative air quality results.

Acidification

Nitrogen oxides are formed primarily from the nitrogen liberated during combustion processes. Nitrogen oxide emitted during combustion quickly oxidizes to NO_2 in the atmosphere. The NO_2 then dissolves in water vapor in the air to form nitric acid (HNO_3), and interacts with other gases and particles in the air to form particles known as nitrates and other products that may be harmful to people and their environment. Both NO_2 in its untransformed state and the acid and transformation products of NO_2 can have adverse effects on human health and the environment, harming vegetation, buildings and materials, and contributing to the acidification of aquatic and terrestrial ecosystems.

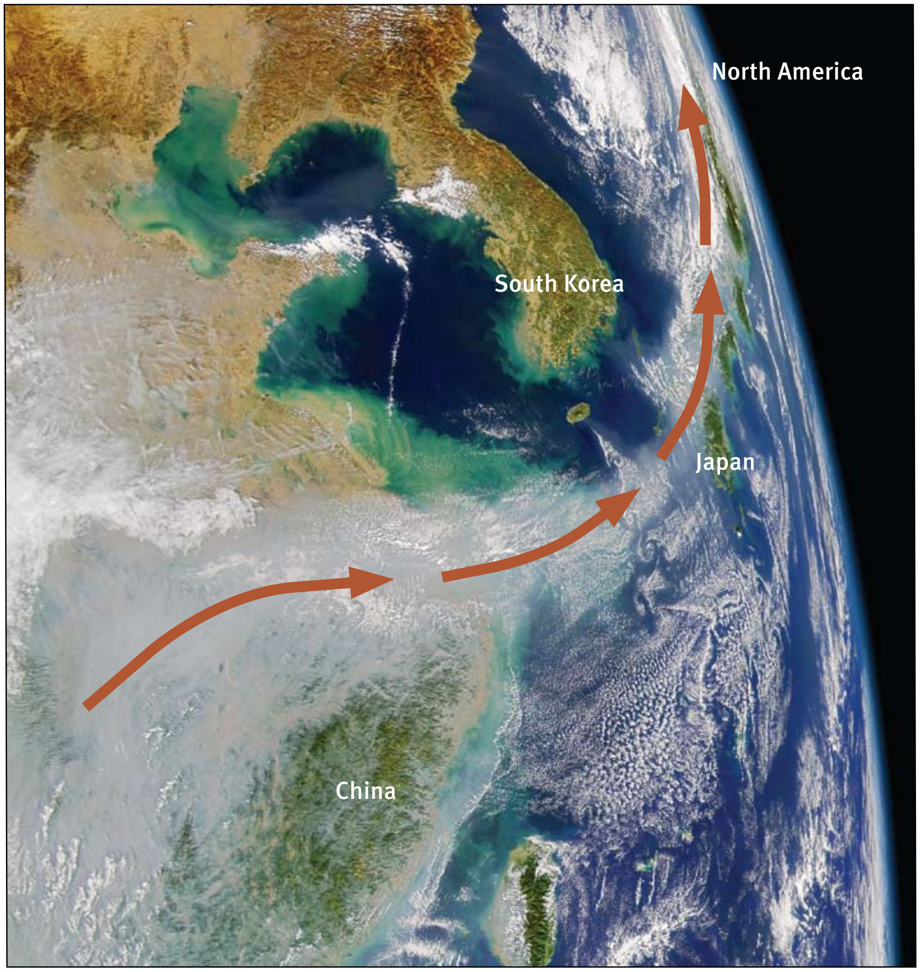
Eutrophication

Nitrogen releases not only contribute to the formation of acid depositions, but also can act as a nutrient in ecosystems, resulting in eutrophication or overenrichment of soils and waters.

Climate Change

When present in the upper troposphere, ozone is a very effective greenhouse gas. Strategies that reduce ozone concentrations on urban and regional scales probably help to limit the contribution of ground-level ozone to the greenhouse effect and global warming.

Case Study – Transporting Asian Pollution to North America



Source: NASA

A recent study suggests that the transpacific transport of pollution from Asia influences North America's air quality during the spring and summer. Even small quantities of Asian emissions over North America during the summer can have significant implications for air quality management.

In the summertime, emissions from Asia and Europe contribute 4–7 parts per billion by volume (ppbv) to afternoon ozone concentrations in the surface air over the United States, instigating violations of the air quality standard. If Asian anthropogenic emissions triple from 1985 to 2010 as expected, surface ozone in the United States could increase by 1–5 ppbv during the summer.

The long-range transport of Asian pollution across the Pacific reaches a maximum in the spring because of the active cyclonic activity and strong westerly winds. The strongest Asian outflow occurs in the middle troposphere; it can be transported across the Pacific in 5–10 days. During the summer, the export of Asian pollution by convection competes with the export of mid-latitude cyclones. Transpacific transport occurs primarily in the middle and upper troposphere, with an average transpacific transport time of 6–10 days.

According to the analysis, the Asian air masses contained elevated levels of carbon monoxide, ozone, particulate matter, and other chemicals consistent with the dominant influence of combustion emissions over East Asia. High levels of methanol and acetone indicated that natural emissions were combining with the polluted outflow.