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Background Ozone: Challenges in Science and Policy

Updated January 31, 2019

Congressional Research Service
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R45482

CRS REPORT
Prepared for Members and
Committees of Congress

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SUMMARY

R45482

January 31, 2019

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Background Ozone: Challenges in Science and Policy

Exposure to ozone, a common air pollutant, has been linked to early death, plant and crop damage, and damage to property. The U.S. Environmental Protection Agency (EPA) sets National Ambient Air Quality Standards (NAAQS) for ground-level ozone to protect human health and welfare with, by law, a "margin of safety." States that contain areas with ozone concentrations above these standards must develop plans to reduce emissions and improve air quality. However, states have direct control only over emission sources located within their borders.

The Clean Air Act (CAA) requires EPA to re-evaluate the NAAQS every five years to include the latest science and technological advancements. Studies reporting the human health impacts of ozone increasingly suggest that ozone exposure may not be completely safe at any level. With the potential for a NAAQS re-evaluation leading to science-based recommendations for a tighter standard, some stakeholders have expressed increasing concern that future—and even current—ozone standards could be difficult to meet due to the contribution of "background ozone," which arises from a variety of sources described in this report. In some areas of the United States, background ozone may be approaching 70 parts per billion (ppb) on some days, the current level of the NAAQS.

Some Members of Congress have expressed interest in adverse health effects that occur at or below the current standard, challenges some nonattainment areas may have in meeting current standards, and particularly the responsibilities for meeting the health standard, given interstate and international transport. EPA's review of the ozone NAAQS is underway and set to be completed in 2020, with background ozone contributions suggested as a topic to be addressed. Congress may have an interest in better understanding scientific capabilities, needs, and efforts to improve understanding of contributions from background sources, as well as options for regulatory responses.

Defining Background Ozone

Three terms are used for different types of background ozone, and distinguishing among them can be important for regulatory purposes.

1. **Natural background.** Ozone concentrations that would be present without any human influence or contribution from anywhere on the globe. Natural background includes contributions from wildfires, vegetation, lightning, ozone in the stratosphere, and global methane concentrations. Contributions to background ozone from wildfires and methane have been increasing over the past several decades.
2. **North American background.** Ozone concentrations absent human-caused emissions from North America. North American background includes all sources in natural background plus ozone from international sources outside North America. Studies suggest that Asian emissions may be contributing to ozone in the United States, especially in Western states, but that those contributions may be beginning to decrease.
3. **United States background.** Ozone concentrations absent human-caused emissions from the United States. U.S. background includes all sources in North American background plus ozone formed from emission sources in Mexico and Canada.

Challenges in Estimating Background Ozone

The CAA provides alternative regulatory options for areas that successfully demonstrate significant influence from some specific sources of natural background ozone on ozone exceedences. However, such demonstrations may be difficult to conduct and reliably assess, given data and analytical challenges:

- **Emissions inventories.** Current understanding of the amount, location, and type of pollutant emissions from many types of sources is insufficient. Therefore inventories typically provide estimations, which may not be precise enough for apportioning contributions.
- **Weather data.** Meteorological data (i.e., wind speed, wind direction, temperature, cloud cover, humidity, etc.) are not currently measured at a fine enough spatial scale to adequately represent relevant weather processes.
- **Ambient air quality measurements.** Data on pollutant concentrations are limited, which increases the challenge of understanding ozone formation and movement. Fine spatial and temporal measurements are needed both horizontally across the surface and vertically to higher levels of the atmosphere.
- **Source contribution variability.** Background ozone source contributions change by year, season, day, and hour and from location to location. This makes it difficult to project future contributions, including when contributions will be relevant to attainment status.

This report provides information on sources of background ozone, presents key challenges in addressing these sources, and discusses potential options to overcome these challenges.

Contents

Introduction 1
Defining Background Ozone 3
Different Types of Background Ozone 5
Natural Background (NB) 6
North American Background (NAB) 7
U.S. Background (USB) 8
Challenges in Estimating Background Ozone 8
Trends in Background Ozone Contributions 9
Regulatory Relief Options for Some "Natural Sources" 11
Issues for Congress 11

Figures

Figure 1. NAAQS Ozone Nonattainment Areas 4
Figure 2. Atmospheric Transport Processes for Ozone 5
Figure 3. Area Burned and Annual Count of Wildfires Larger Than 1,000 Acres, 1984-2015 10

Contacts

Author Information 13

Introduction

Exposure to ozone (often referred to as "smog"), regardless of where that ozone originates, has been linked to negative human health effects, including respiratory ailments and premature death.[1] Children, the elderly, and persons with respiratory illnesses are particularly susceptible to adverse health impacts from ozone exposure. EPA estimates that ozone exposure was responsible for more than 15,000 premature deaths in the United States in 2007 based on 2006-2008 average ambient ozone concentrations.[2] Ozone has also been linked to plant damage and decreases in crop yield.[3]

Concentrations of ozone at the ground level, originally considered a local issue, is increasingly recognized as a global challenge. Ozone is not emitted directly but is formed in the atmosphere from chemical reactions of nitrogen oxides (NO_x) with volatile organic compounds (VOCs, a type of hydrocarbon) in the presence of sunlight. NO_x and VOCs are known as "precursor" emissions, and their relative contributions to the formation of ozone depends on a number of factors, including weather conditions and concentrations of other pollutants. The lifetime of ozone in the atmosphere ranges from hours to weeks, providing time—under the right conditions—for pollution emitted in one location to affect the health and welfare of populations far downwind (see **Figure 2**).

While local emissions of ozone precursors are still the dominant source of ozone in many areas, state and local air quality agencies face ozone pollution arising from sources outside of their jurisdictional control ("background ozone"). As will be described and discussed in this report, potential long-range transport of air pollutants presents a challenge to downwind communities. It can also be an opportunity for cooperation among localities, states, and countries.

The Clean Air Act (CAA) directs the U.S. Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards (NAAQS) to protect public health (primary standards) and welfare (secondary standards). The law directs that "the attainment and maintenance of [primary standards] are requisite to protect the public health."[4] While the standards are set to limit adverse impacts, EPA acknowledges that these standards do not suggest that concentrations below these levels present zero risk.[5] The NAAQS set limits for the concentrations in ambient air of six common "criteria" pollutants: lead, nitrogen oxides, sulfur dioxide, carbon monoxide, particulate matter, and ozone.[6] There is no evidence of a safe level of ozone exposure below which no

[1] The Environmental Protection Agency (EPA) evaluated the extensive body of published literature and published its findings in an Integrated Science Assessment (ISA). See EPA, Office of Research and Development, *Integrated Science Assessment for Ozone and Related Photochemical Oxidants*, 2013, pp. 2-49, https://www.epa.gov/isa/integrated-science-assessment-isa-ozone-and-related-photochemical-oxidants. The report concluded, "The current body of evidence indicates that there is likely to be a causal relationship between short-term exposure to O_3 and total mortality [and] respiratory effects."

[2] EPA, *Health Risk and Exposure Assessment for Ozone*, August 2014, Section 8.1.2, https://www.epa.gov/naaqs/ozone-o3-standards-risk-and-exposure-assessments-review-completed-2015.

[3] J. Reilly et al., "Global Economic Effects of Changes in Crops, Pasture, and Forests Due to Changing Climate, Carbon Dioxide, and Ozone," *Energy Policy*, vol. 35, no. 11 (2007), pp. 5370-5383.

[4] According to Section 109(b)(1) of the CAA, the NAAQS "shall be ambient air quality standards the attainment and maintenance of which in the judgment of the Administrator, based on such criteria and allowing an adequate margin of safety, are requisite to protect the public health. Such primary standards may be revised in the same manner as promulgated."

[5] EPA, *Integrated Science Assessment for Ozone and Related Photochemical Oxidants*, p. lxxvi: "The CAA does not require the Administrator to establish a primary NAAQS at a zero-risk level or at background concentration levels."

[6] Criteria pollutants are those that EPA has determined "may reasonably be anticipated to endanger public health or

adverse health effects occur. However, uncertainty between exposure and health response increases at very low ozone concentrations—that is, below 20 parts per billion (ppb).[7]

Air quality monitoring stations in the United States measure concentrations of the six criteria pollutants, and these measurements are used to determine whether locations meet the NAAQS. If a monitor measures concentrations above the standard for any of those six pollutants for an averaging time specified in the NAAQS,[8] the area around that monitor may face a "nonattainment" designation for that pollutant. Once designated nonattainment, the state containing that area must propose a plan to bring the area into attainment of the NAAQS. These State Implementation Plans (SIPs) require approval by EPA.[9]

State air quality regulators develop SIPs to attain NAAQS for ambient air in their states, and they have jurisdiction only over the sources of emissions within their borders. The levels of pollution flowing into nonattainment regions, generally referred to as "background pollution," may be making it more difficult for some areas of the United States to meet attainment. Congress recognized this challenge when it enacted the original CAA, adding the "good neighbor provision," which addressed interstate transport of human-caused air pollution that contributes to nonattainment. For detailed information about domestic air transport, see CRS Report R45299, *The Clean Air Act's Good Neighbor Provision: Overview of Interstate Air Pollution Control*, by Kate C. Shouse.

The CAA also mandates EPA to review the NAAQS every five years and revise them as appropriate.[10] EPA completed its most recent review of the ozone standard in 2015, when it lowered the standard from 75 ppb to 70 ppb.[11] EPA reported that it has begun the next ozone NAAQS review and that it intends to complete it by 2020.[12] The procedure for reviewing and setting the NAAQS explicitly does not consider what sources contribute to total ozone, including background sources.

In 2018, EPA announced plans to streamline the NAAQS review process and obtain Clean Air Scientific Advisory Committee advice regarding background pollution and potential adverse effects from NAAQS compliance strategies.[13] EPA's "Back-to-Basics" memorandum described

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welfare" and whose presence in "ambient air results from numerous or diverse mobile or stationary sources." CAA §108(a)(1), codified at 42 U.S.C. §7408(a)(1). EPA determined that the following pollutants meet the Section 108 criteria: (1) carbon monoxide, (2) lead, (3) nitrogen dioxide, (4) ground-level ozone, (5) particulate matter, and (6) sulfur dioxide.

[7] National Research Council, *Estimating Mortality Risk Reduction and Economic Benefits from Controlling Ozone Air Pollution* (Washington, DC: National Academies Press, 2008), https://doi.org/10.17226/12198.

[8] Pollutant measurement averaging time for attainment determination depends on NAAQS, which depends on the pollutant being measured and the health response of interest (i.e., human acute health, human long-term impacts, ecological impacts). See "Pollution Exposure Averaging Metrics" text box on page 10 for more discussion on pollution averaging time. A single detection of an ambient air concentration exceeding a NAAQS number does not indicate a "non-attainment" situation.

[9] For more information about the NAAQS, nonattainment requirements, and SIPs, see the corresponding sections of CRS Report RL30853, *Clean Air Act: A Summary of the Act and Its Major Requirements*, by James E. McCarthy.

[10] CAA §109(d); 42 U.S.C. §7409(d).

[11] EPA, "National Ambient Air Quality Standards for Ozone: Final Rule," October 1, 2015, http://www3.epa.gov/ozonepollution/actions.html. The rule appeared in the *Federal Register* on October 26, 2015, at 80 *Federal Register* 65292.

[12] Respondent EPA's Final Status Report at 4, Murray Energy Corp. v. EPA, No. 15-1385 (D.C. Cir. Aug. 1, 2018).

[13] E. Scott Pruitt, EPA Administrator, "Back-to-Basics Process for Reviewing National Ambient Air Quality Standards," memorandum to EPA assistant administrators, May 9, 2018, https://www.epa.gov/sites/production/files/2018-05/documents/image2018-05-09-173219.pdf.

concerns that background levels of pollution pose a challenge to meeting NAAQS standards. The memorandum noted a call from certain state regulators for advice on how to treat background ozone, stating that "state environmental agencies have sought this advice, citing the 'absolute need for a valid source of information about background concentrations.'" Additionally, EPA created a task force to develop "additional flexibilities for states to comply with the ozone standard."[14]

Much of the focus of ozone transport and control has historically been on upwind domestic sources. Members of Congress may have an interest in better understanding background ozone from natural and international sources, particularly as EPA reviews the 2015 ozone standard. Contributions from sources of background ozone may become important as states with nonattainment areas develop SIPs that attempt to quantify these contributions and consider ways to address them. To assist Congress in understanding these issues, this report defines *background ozone*, focusing on natural and international sources, and describes what is currently known about these sources. The report then goes on to discuss the limitations in the scientific community's understanding and options for deepening that understanding.

Defining Background Ozone

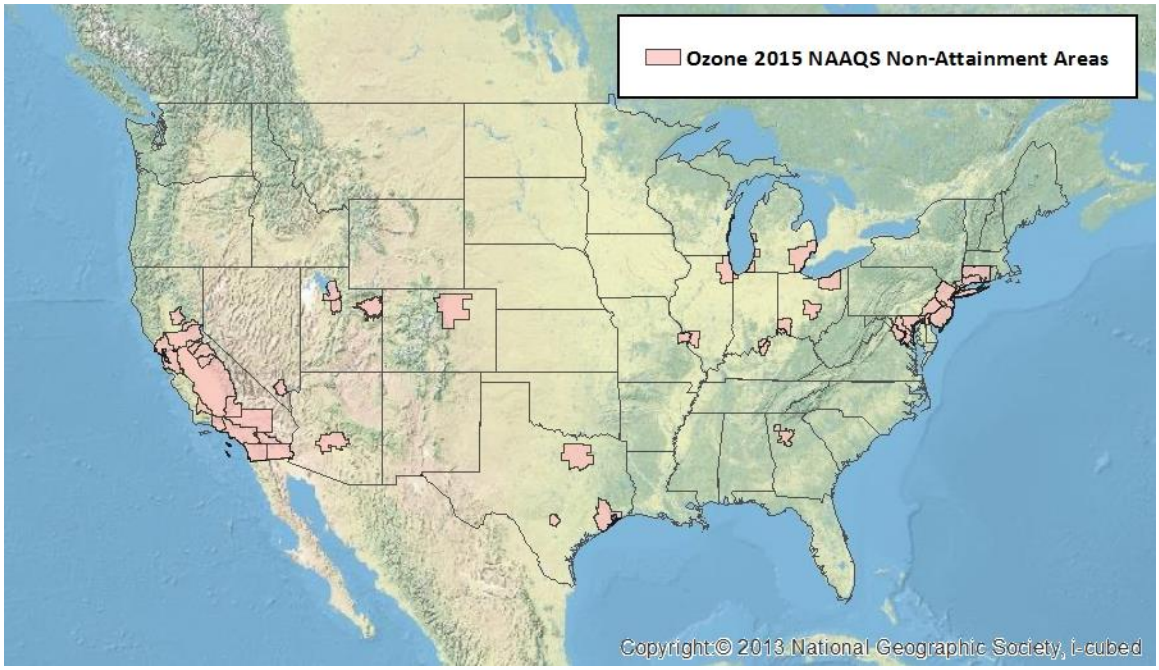
This report will discuss background air pollution primarily in the context of ground-level ozone. As of 2018, with the 2015 ozone standard set at 70 ppb, there are 52 areas in the United States designated "nonattainment" for ozone (see **Figure 1**). Current research suggests that natural sources and sources outside the United States may contribute to total ozone in those areas at certain times.[15] Many of the issues discussed here are not unique to ozone, however, and may apply to other pollutants covered by NAAQS, and any potential actions taken to understand or reduce background ozone may also reduce background concentrations of other pollutants.

[14] EPA, "Final Report on Review of Agency Actions That Potentially Burden the Safe, Efficient Development of Domestic Energy Resources Under Executive Order 13783," October 25, 2017, https://www.epa.gov/sites/production/files/2017-10/documents/eo-13783-final-report-10-25-2017.pdf.

[15] For example, See D. A. Jaffe et al., "Scientific Assessment of Background Ozone over the U.S.: Implications for Air Quality Management," *Elementa Science of the Anthropocene*, vol. 6, no. 56 (2018).

Figure 1. NAAQS Ozone Nonattainment Areas

8-hour* Ozone (2015 Standard: 70 ppb)



Source: EPA Green Book GIS Download: https://www.epa.gov/green-book/green-book-gis-download.

Notes: NAAQS, ozone nonattainment updated as of September 26, 2018. Alaska and Hawaii do not contain any areas of ozone nonattainment. *Ozone nonattainment designations are determined using the three-year average of the fourth-highest daily maximum eight-hour averaged ozone concentration measured at a regulatory air quality monitor. See "Pollution Exposure Averaging Metrics" on page 10 for more details.

This report deals exclusively with ozone measured at ground level and its adverse health and material effects.[16] Ozone Transport 101 and **Figure 2** provide additional information about ozone in different layers of the atmosphere and how each layer may interact with, or contribute to, ozone at ground level.

Ozone Transport 101

Three layers of the atmosphere are relevant to ozone formation and transport. The well-mixed layer adjacent to the ground is called the planetary boundary layer (PBL) and is part of the lower troposphere. Above the PBL and distinct from it, but still part of the troposphere, is another well-mixed layer called the "free troposphere." Finally, the stratosphere is the atmospheric layer above the troposphere. Ozone concentrations in the PBL are the primary concern of this report and the focus of regulation because that is where people live and breathe. However, two other important paths of contribution to ozone in the PBL should also be discussed: (1) Long-range transport of ozone can occur in the free troposphere, and (2) ozone concentrations in the stratosphere are naturally two orders of magnitude larger than at ground level and can sometimes mix down.

Ozone forms in the PBL from energy-induced (i.e., sunlight) chemical reactions in the atmosphere of precursor chemicals, including both natural and human-caused emissions of NO_x and volatile organic compounds VOCs.

The two largest processes through which ozone is removed from the atmosphere are deposition to the ground, and chemical destruction of ozone by freshly emitted NO_x. Ozone found in the free troposphere arrives there largely from the layers above and below. These two removal processes are generally not available in the free troposphere, and so ozone lifetime is extended, allowing for long-range transport (e.g., across the Pacific ocean).

The PBL height can change throughout the day as the sun heats up the earth's surface, adding heat and energy to the air in contact with it and pushing the boundary of the PBL higher (sometimes up to five kilometers above the

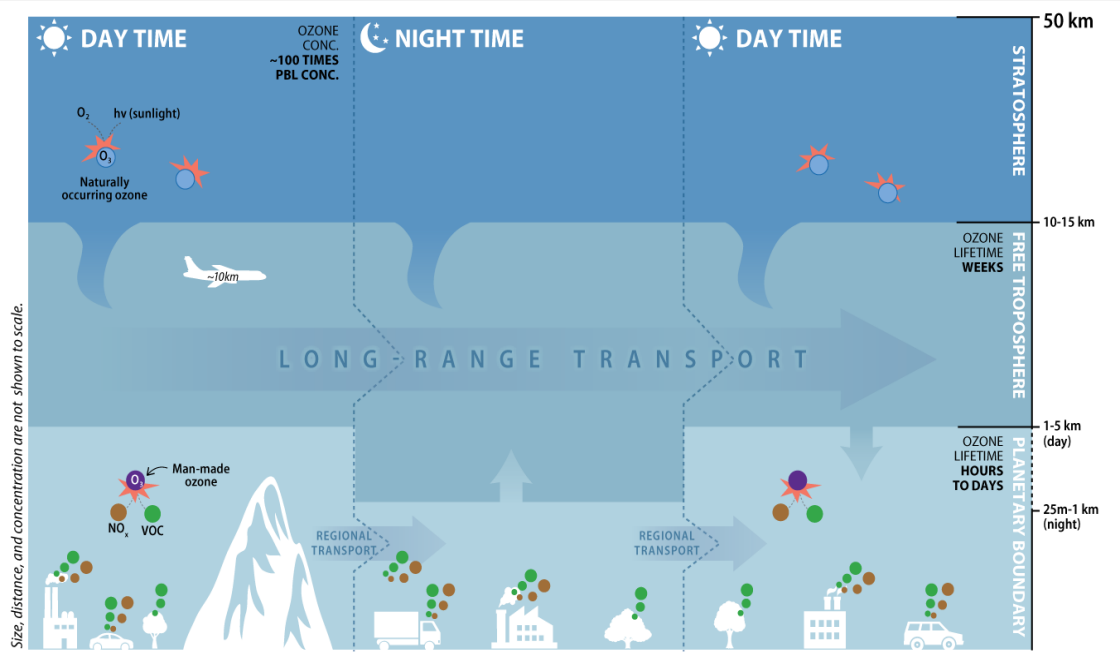
[16] The ground-level ozone for which the NAAQS is established should not be confused with stratospheric ozone.

surface). When that happens, air in the free troposphere—the layer above the PBL—can be mixed in. Similarly, when the sun goes down and the earth's surface cools, the PBL also cools and begins to descend (as low as 25 meters on very calm, cold nights), thus pushing air from the PBL into the free troposphere. This is a daily pathway for air exchange between the PBL and the free troposphere. Large storms can also cross the boundary between the PBL and free troposphere and cause air from the two layers to mix.

Ozone in the stratosphere is naturally present at very high concentrations (~400 parts per million) due to enhanced photochemical reactions of oxygen molecules. Ozone in the stratosphere is beneficial because it absorbs and filters out ultraviolet radiation. Periodically, behind large frontal weather systems, stratospheric air can be brought down and mixed with tropospheric air. These "stratospheric intrusions" can bring high levels of ozone with them.

Finally, since there is no solid barrier between levels of the atmosphere, air from the lower stratosphere can slowly mix with air from the free troposphere, potentially elevating ozone levels in the upper troposphere where air may be more likely to reach the ground. This pathway for stratospheric contribution is more difficult to identify because it does not occur with a large weather system, and metrics that may be used to differentiate stratospheric air (from, say, international transport) are tempered by dilution with tropospheric air.

Figure 2. Atmospheric Transport Processes for Ozone



Source: Congressional Research Service.

Different Types of Background Ozone

EPA defined *natural background* (NB) and *U.S. background* (USB) in the final 2015 ozone rule (the chemical notation of ozone is O_3):

> NB is defined as the O_3 that would exist in the absence of any manmade precursor emissions. USB is defined as that O_3 that would exist in the absence of any manmade emissions inside the U.S. This includes anthropogenic emissions outside the U.S. as well as naturally occurring ozone.[17]

[17] 80 *Federal Register* 65327, note 84.

A third term, *North American background*, is also defined in this report for added clarity. Each is explained in more detail below.

Natural Background (NB)

Natural background ozone is what the average concentration of ground-level ozone would be without any human influence. Ozone forms naturally in the lower levels of the atmosphere due to natural emissions of precursors from sources including lightning, vegetation, wildfires, and methane. Transport of ozone vertically from the stratosphere to the atmospheric layer at ground level (called stratospheric intrusions) is a fifth major source. No air pollution monitors today are able measure true present day NB because human contributions to the formation of ozone are so widespread globally. The only way to estimate NB is with global scale atmospheric chemistry simulation models with inputs representing conditions without human influence.

The remainder of this section summarizes the five major contributors to NB. A key point is that *the estimated contributions presented are uncertain and are very dependent on both location and timing*. The "Challenges in Estimating Background Ozone" section discusses specific challenges and uncertainties associated with the data and the modeling projects.

1. **Lightning (NO_x).** Lightning flashes cause naturally occurring nitrogen and oxygen in the atmosphere to react and generate NO_x molecules. Lightning and the resulting emissions occur primarily during the warmer months and are released in the free troposphere, which is above the well-mixed ground layer (see **Figure 2**). There is data to suggest that lightning contributes to daily, as well as seasonal average, ozone concentrations in high impact areas.[18]
2. **Vegetation (VOCs).** Trees release VOCs as a byproduct of photosynthesis. Biogenic VOCs from vegetation are the largest emissions source of VOCs in the United States, making up about 70% of the total inventory.[19] Vegetation emissions are largest during the spring and summer, when plants are actively growing. For plants and trees that have leaves only seasonally, emissions decline as leaves drop and photosynthesis ends.
3. **Wildfires (VOCs and NO_x).** Wildfires release both NOx and VOCs (as well as fine particles), but the amount and the reactivity of the polluting emissions depend on the type of fuel that is burning and how quickly and how hot the fire burns. Controlled/prescribed fires tend to burn cooler and release fewer pollutants. Current research suggests that active fires contribute to daily as well as seasonal average ozone concentrations.[20] Research to improve emissions inventories from fire events is ongoing.
4. **Stratospheric intrusions.** Ozone occurs naturally in the stratosphere at very high concentrations and can occasionally be transported down to lower atmospheric levels during certain weather events (see text box "Ozone Transport 101" for more information about atmospheric layers and vertical transport of ozone). Stratospheric intrusions are more likely to affect ground-level concentrations at

[18] Jaffe et al., "Scientific Assessment of Background Ozone over the U.S."; S. F. Mueller and J. W. Mallard, "Contributions of Natural Emissions to Ozone and PM2.5 as Simulated by the Community Multiscale Air Quality (CMAQ) Model," *Environmental Science and Technology*, vol. 45 (2011), pp. 4817-4823.

[19] EPA, "Profile of Version 1 of the 2014 National Emissions Inventory," 2017, pp. 3-5, https://www.epa.gov/sites/production/files/2017-04/documents/2014neiv1_profile_final_april182017.pdf.

[20] L. Zhang et al., "Sources Contributing to Background Surface Ozone in the US Intermountain West," *Atmospheric Chemistry and Physics*, vol. 14 (2014), pp. 5295-5309.

high elevation sites in the western United States, simply because these areas are closer to the stratosphere. These events are more common in winter and spring months because the large storms that cause them are more likely to occur in late winter and spring.

5. **Methane.** Methane has not been traditionally considered an ozone precursor because it does not react quickly to produce ozone. Nonetheless, it will over time react and contribute to background ozone. Methane's atmospheric lifetime is on the order of a decade, compared to a timescale of months to days for other VOCs, and so it is considered well-mixed globally by the time it contributes to the formation of ozone. It is accumulating in the atmosphere as well, raising background ozone concentrations. This ozone contribution is considered approximately spatially uniform and is increasing as methane concentrations increase.[21] The major source contributors to global methane are natural production by bacteria in anaerobic (oxygen-free) conditions in natural wetlands or in agriculture, fossil fuel emissions leaking or venting either naturally or from energy development, and incomplete combustion of biomass or carbon.[22]

North American Background (NAB)

North American background (NAB) is the estimated concentration of ozone that excludes the effects of all human-caused emissions in North America. NAB includes all NB sources as well as human-caused sources of emissions from countries outside of North America.[23] Air quality monitors located at sites on the western coast of the United States are not consistently reliable measures of NAB for two reasons: (1) Air circulation can bring continental air over the Pacific Ocean and then back into North America. (2) If meteorological conditions are favorable, ozone pollution formed from emissions in North America can have a long enough lifetime to travel all the way around the globe and re-enter North America from the west. Therefore, like NB, modeling is the best way to estimate NAB.

Human-caused sources outside of North America are currently dominated by Asian emissions. Estimates of Asian contribution to background ozone in the United States are highly time- and location-specific. Asian precursor emissions, and resulting ozone, travel across the Pacific Ocean in the free troposphere (see **Figure 2**). However, because this pollution is traveling at higher elevations, it is more likely to impact cities and locations in the western United States located at higher elevations.

These upper-level air flows from areas in Asia are also more likely to affect the United States in the late winter, spring, and early summer due to seasonal variability in hemisphere-scale circulation patterns. Asian emissions begin to taper off in late winter, and a July/August monsoon season in eastern China reduces formation of ozone in late summer.[24] These features suggest that the maximum impact from Asian pollution would likely occur in late winter/early spring.

[21] A. M. Fiore et al., "Characterizing the Tropospheric Ozone Response to Methane Emission Controls and the Benefits to Climate and Air Quality," *Journal of Geophysical Research: Atmospheres*, vol. 113, no. D8 (2008).

[22] S. Kirschke et al., "Three Decades of Global Methane Sources and Sinks," *Nature Geoscience*, vol. 6 (2013), pp. 813-823.

[23] Prior to the analysis conducted for the 2015 ozone NAAQS review, EPA referred to what they called "Policy-Relevant Background," which is equivalent by definition to NAB. The term is no longer used.

[24] M. Lin et al., "Multi-Scale Model Analysis of Boundary Layer Ozone over East Asia," *Atmospheric Chemistry and Physics*, vol. 9, no. 10 (2009).

U.S. Background (USB)

U.S. background (USB) includes all contributions from NB and NAB plus all human-caused emissions from Mexico and Canada. In the publication of the most recent NAAQS for ozone, EPA generically defined *background ozone* as USB:

> The term "background" O_3 is often used to refer to O_3 that originates from natural sources of O_3 (e.g., wildfires and stratospheric O_3 intrusions) and O_3 precursors, as well as from man-made international emissions of O_3 precursors. Using the term generically, however, can lead to confusion as to what sources of O_3 are being considered. Relevant to the O_3 implementation provisions of the CAA, we define background O_3 the same way the EPA defines USB: O_3 that would exist in the absence of any man-made emissions inside the U.S.[25]

Mexican and Canadian emissions primarily impact locations on the borders of those two countries, with maximum contribution estimates from one study of about 30 ppb to border cities.[26] Model estimates of the contribution of USB to total ozone range from 25 ppb to 50 ppb, with the highest values in the inter-mountain West, based on an EPA review of model data.[27]

Challenges in Estimating Background Ozone

The contribution of background ozone to total local ozone concentrations varies from location to location, day to day, and even hour to hour. These variations are driven both by changes in pollutant emissions from sources and by changing weather patterns that influence the chemistry and physical transport of the pollutants. There is also uncertainty associated with measuring or estimating these driving forces behind background ozone contributions.

As mentioned, estimates of source contributions to background ozone rely on computer models that simulate atmospheric chemistry and transport and the resulting pollution. These models rely on large datasets of emissions inventories and meteorological data, both with detailed hourly and location-specific data. These input data are often not available at the temporal and spatial resolution needed, and so estimates and/or simplifications must be made, which increases uncertainty. Atmospheric measurements of ozone concentrations are then compared to model output to evaluate how well the model is performing. However, measurement data of the pollutants being modeled are also limited, which increases the challenge associated with evaluating the performance of the model in capturing ozone formation and movement.

Modeling studies estimating background ozone and source attribution often present results as seasonal averages or represent time periods that may not be of specific use to regulators. See text box "Pollution Exposure Averaging Metrics" for additional information about averaging metrics.

Retrospective studies face all the challenges mentioned. Forecasting studies face the additional challenge of attempting to model the future based on historical patterns and current conditions, adding another level of uncertainty.

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[25] 80 *Federal Register* 65327, https://www.federalregister.gov/d/2015-26594/p-1320.

[26] H. Wang et al., "Surface Ozone Background in the United States: Canadian and Mexican Pollution Influences," *Atmospheric Environment*, vol. 43, no. 6 (2009), pp. 1310-1319; A. M. Fiore et al., "Estimating North American Background Ozone in U.S. Surface Air with Two Independent Global Models: Variability, Uncertainties, and Recommendations," *Atmospheric Environment*, vol. 96 (2014), pp. 284-300.

[27] EPA, "Implementation of the 2015 Primary Ozone NAAQS: Issues Associated with Background Ozone," https://www.epa.gov/ozone-pollution/background-ozone-workshop-and-information.

Pollution Exposure Averaging Metrics

The NAAQS for ozone is currently set at 70 ppb. "Attainment" of this NAAQS, however, is based on the three-year average of the fourth-highest daily maximum eight-hour ozone concentration measured at regulatory air quality monitors. Using the fourth-highest annual value may help protect areas from being penalized by high ozone conditions that are uncommon. Calculating the three-year average allows for a buffer against years with meteorological conditions that may be especially conducive to ozone. Daily maximum eight-hour averages represent both average short-term exposure and a source or cause that is consistent throughout the day.

As mentioned, ozone concentrations change by year, day, and hour and from location to location. Background ozone source contributions in any location can have a similarly high level of variability. Also, studies have found no correlation between high total ozone days and days with high background ozone contributions.[28] These issues make it difficult to extrapolate historical background ozone impacts in a way that is informative to forecasting the future impacts of background ozone on attainment. One way of addressing temporal variability and contribution uncertainty is to average estimated ozone contributions across time. For this reason, many background ozone analyses present impacts as monthly or "seasonal" average impacts: the total contribution from a particular background source averaged over the months of the year that represent meteorological conditions conducive to ozone formation (warm, sunny, clear skies and low wind), also referred to as an ozone season. However, while seasonal average contribution may provide information about the relative total contributions and trends from various sources—and therefore which sources might be of more interest for research attention—seasonal average contributions do not provide information about how a particular source may impact the specific days with high ozone that determine attainment.

Trends in Background Ozone Contributions

According to EPA, NO_x emissions from electricity generating units have decreased 81% nationally compared to 1990 levels due in part to the acid rain program and ozone transport rules.[29] While these reductions have resulted in total ozone decreases across most of the United States, models suggest that temperature increases in many areas of the United States during that same time frame have negated what would have been additional ozone benefits.[30]

Decreasing trends in total ozone concentrations measured at regulatory monitors between 1990 and 2010 generally occur in the eastern United States.[31] Many western monitors do not show similar trends in total ozone over the same time period despite similar reductions in NO_x from the power sector and individual personal vehicles. The lack of a decreasing ozone trend at many monitors in the West could be due to a number of causes: increasing seasonal average temperatures, an increase in incidents of fire since 1986, emissions from oil and gas development, increasing contributions from international transport of air pollution, and increasing global methane concentrations.[32]

[28] EPA, "Implementation of the 2015 Primary Ozone NAAQS."

[29] According to summaries available at EPA, "2016 Program Progress—Cross-State Air Pollution Rule and Acid Rain Program," https://www3.epa.gov/airmarkets/progress/reports/index.html; EPA, "2016 Progress Report: Cross-State Air Pollution Rule and Acid Rain Program," 2016, pp. 7-8, "Program Basics," https://www3.epa.gov/airmarkets/progress/reports/pdfs/2016_full_report.pdf.

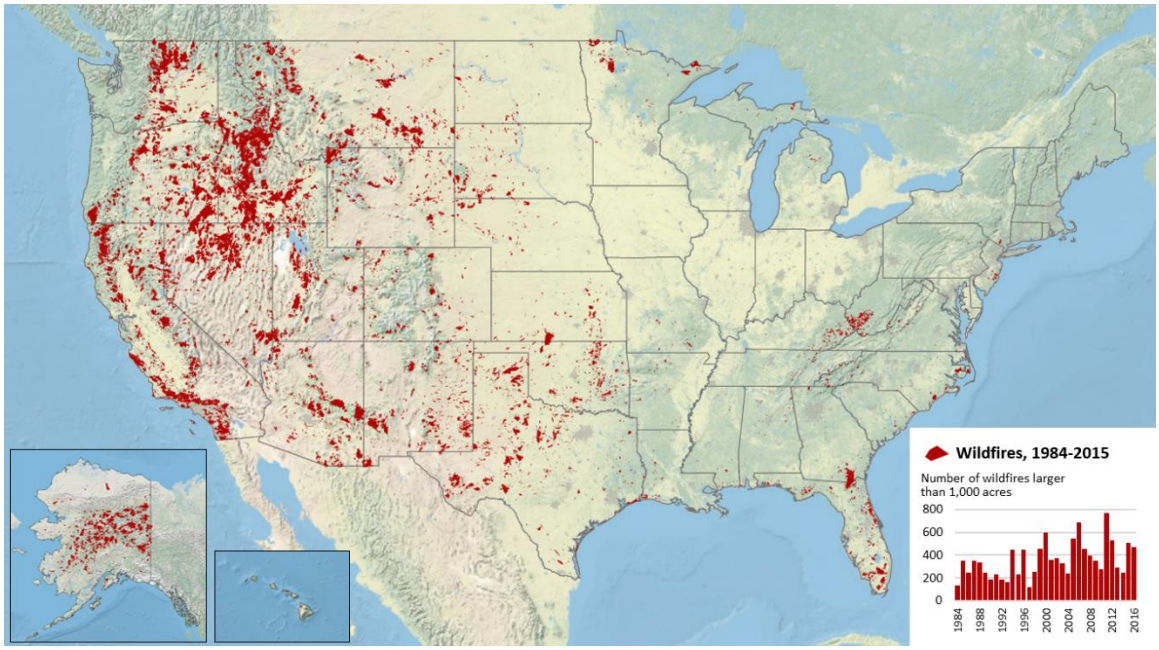
[30] J. L. Gamble (ed.) et al., "Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems," EPA, 2008, https://www.globalchange.gov/browse/reports/sap-46-analyses-effects-global-change-human-health-and-welfare-and-human-systems; M. Lin et al., "U.S. Surface Ozone Trends and Extremes from 1980 to 2014: Quantifying the Roles of Rising Asian Emissions, Domestic Controls, Wildfires, and Climate," *Atmospheric Chemistry and Physics*, vol. 17 (2017), pp. 2943-2970.

[31] O. R. Cooper et al., "Long-Term Ozone Trends at Rural Ozone Monitoring Sites Across the United States, 1990-2010," *Journal of Geophysical Research: Atmospheres*, vol. 117, no. D22 (2012).

[32] Cooper et al., "Long-Term Ozone Trends at Rural Ozone Monitoring Sites Across the United States;" Lin et al.,

According to the 2017 U.S. National Climate Assessment,[33] on average since 1986 in the United States, the number of wildfires and the burn duration have both quadrupled. The number of acres burned has increased six-fold, compared to 1970 to 1986. The report also indicates that total NO_x emissions from fire events are expected to increase with fire temperature, duration, and area burned. **Figure 3** shows the annual count, and total area burned of all wildfires larger than 1,000 acres from 1984 through 2015.

Figure 3. Area Burned and Annual Count of Wildfires Larger Than 1,000 Acres, 1984-2015



Source: J. Eidenshink et al., "A Project for Monitoring Trends in Burn Severity," *Fire Ecology*, vol. 3, no. 1 (2007), pp. 3-21.

While emission inventories from Asia are highly uncertain—and outdated in some modeling cases—several sources of data suggest that Asian emissions, and potentially their impact on U.S. air quality, have peaked. Projections of fossil fuel combustion in Asian countries suggest uncertainty about peaking, although the Chinese government recently announced a target of a 15% reduction in NO_x emissions by 2020 compared to 2015 emissions.[34] A review of measurements of baseline ozone[35] taken at monitors along the western coast of North America show that, after two decades of increasing trends, ozone flowing into the continental United States from the west stopped increasing in the mid-2000s and has begun to decrease.[36] However,

"U.S. Surface Ozone Trends and Extremes from 1980 to 2014," pp. 2943-2970.

[33] M. F. Wehner et al., "Droughts, Floods, and Wildfires," in *Climate Science Special Report: Fourth National Climate Assessment*, U.S. Global Change Research Program, vol. 1 (2017), pp. 231-256, https://science2017.globalchange.gov/chapter/8/.https://science2017.globalchange.gov/chapter/8/.

[34] State Council, "Three-Year Action Plan for Winning the Blue Sky War" (Guo Fa [2018] No. 22, June 27, 2018) (in Chinese), http://www.gov.cn/zhengce/content/2018-07/03/content_5303158.htm. See related LOC document at http://www.loc.gov/law/foreign-news/article/china-2020-air-pollution-action-plan-released/.

[35] *Baseline ozone* is a term used more generally to describe measured ozone in locations where there is no direct influence of local emissions.

[36] D. D. Parrish et al., "Reversal of Long-Term Trends in Baseline Ozone Concentrations at the North American West

since about 2000, ozone levels measured at a rural site in Alaska have been increasing, with the source suspected in part to be transport of East Asian air.[37]

Regulatory Relief Options for Some "Natural Sources"

Demonstrations of high ozone directly related to wildfires and stratospheric intrusions may be eligible for exclusion from an ozone attainment calculation under the Exceptional Event Rule of the CAA.[38] In order to facilitate successful demonstrations of exceptional events, EPA released a final guidance document in 2016 for preparations of exceptional events demonstrations for wildfires.[39] A draft guidance document was released in August 2018 covering the preparation of exceptional events demonstrations for stratospheric ozone intrusions. These documents outline expectations, but they do not provide the specific modeling platforms or tools required to conduct the successful demonstrations.

State, local, and tribal co-regulators recommended to EPA that the agency develop a similar guidance document for international emissions.[40] Under Section 179B of the CAA, a demonstration of contribution by international sources may reduce attainment demonstration requirements in SIPs but does not provide regulatory relief from a potential nonattainment designation.[41]

Issues for Congress

Several issues may arise for congressional deliberations with regard to background ozone pollution. Stakeholders suggest challenges with meeting the NAAQS, in part due to the difficulty of reducing ozone in areas with potentially large contributions from background sources and in part due to lack of data availability to conduct demonstrations of those background contributions. Congress may seek to understand the progress of research on background ozone as EPA revisits the NAAQS for ozone.

EPA released a state of the science background ozone white paper to stakeholders and requested feedback on major issues.[42] The House Committee on Science, Space and Technology revisited the issue when its Subcommittee on Environment held a hearing on background ozone on June 21, 2018.[43] The following four points summarize the opinions and policy and scientific challenges

Coast," *Geophysical Research Letters*, vol. 44 (2017), pp. 10,675-10,681.

[37] D. F. McGlynn et al., "Understanding Long-Term Variations in Surface Ozone in United States National Parks," *Atmosphere*, vol. 9, no. 125 (2018).

[38] "Treatment of Air Quality Monitoring Data influenced by Exceptional Events," 40 CFR 50.14(b)(6).

[39] EPA, "Guidance on the Preparation of Exceptional Events Demonstrations for Wildfire Events That May Influence Ozone Concentrations," 2016, https://www.epa.gov/sites/production/files/2016-09/documents/exceptional_events_guidance_9-16-16_final.pdf.

[40] Many state and regional level air quality policy leaders and interested parties provided feedback to the white paper, and those comments were summarized by EPA and are available at https://www.epa.gov/sites/production/files/2016-03/documents/bgo3-high-level-summary.pdf. Additional written comments from stakeholders can be found in a separate EPA docket available at http://www.regulations.gov (Docket ID No. EPA-HQ-OAR-2016-0097).

[41] 42 U.S.C. 7509a.

[42] EPA, "Implementation of the 2015 Primary Ozone NAAQS."

[43] See U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Environment, *State Perspectives on Regulating Background Ozone*, 115th Cong., 2nd sess., June 21, 2018.

brought forth both by stakeholder responses to the EPA white paper[44] and by the testimony from invited stakeholders at the recent background ozone hearing:

1. Some states, especially states in the western United States, have asserted that natural and non-U.S. sources of ozone and precursors have increased the ozone concentrations in their states.
2. Current statutory and regulatory options to address natural and non-U.S. sources often require technical data, modeling, and analyses that may be cost prohibitive.
3. Modeling results that attempt to quantify levels of contribution from sources are uncertain, and they represent historical, or average, impacts.
4. In most locations, especially urban locations, many studies (including the whitepaper published by EPA[45]) have shown that local sources contribute a large part to total local ozone.

Most recently, the U.S. Court of Appeals for the D.C. Circuit considered whether EPA should take background ozone into account when setting NAAQS. The case has not been decided at the time this report was published.

A potential avenue for Congress to address gaps in the scientific understanding of background ozone is through research and development. Therefore, Congress may consider funding implications of the following recommendations, made by stakeholders in the scientific and regulatory communities, that are intended to improve the understanding of contributions from background ozone:[46]

- International engagement and/or cooperation at the federal level and through research collaborations that may improve understanding of non-U.S. contributions to U.S. air quality and may increase cooperation for pollution reduction goals.
- Increased monitoring at ground level and at higher levels in the atmosphere, through state or federal regulatory air quality monitoring projects or research campaigns, to aid in analysis of background ozone trends and improve confidence in the performance of the models used to estimate background contributions.
- Additional research and development into model estimates of background ozone, representing additional weather patterns (i.e., El Nino/La Nina patterns can influence background ozone), and model simplification schemes to provide more information about the variability associated with background ozone contributions.

[44] Many state and regional level air quality policy leaders and interested parties provided feedback to the white paper, and those comments were summarized by EPA and are available at https://www.epa.gov/sites/production/files/2016-03/documents/bgo3-high-level-summary.pdf. Additional written comments from stakeholders can be found in a separate EPA docket available at http://www.regulations.gov (Docket ID No. EPA-HQ-OAR-2016-0097).

[45] EPA, "Implementation of the 2015 Primary Ozone NAAQS."

[46] Many state and regional level air quality policy leaders and interested parties provided feedback to the white paper, and those comments were summarized by EPA and are available at https://www.epa.gov/sites/production/files/2016-03/documents/bgo3-high-level-summary.pdf. Additional written comments from stakeholders can be found in a separate EPA docket available at http://www.regulations.gov (Docket ID No. EPA-HQ-OAR-2016-0097).

Finally, Congress may consider the role that methane plays in air quality. Methane is a precursor to ozone, and so methane emission reductions have been suggested as one option to reduce global background concentrations of ozone.[47] Additionally, ozone itself is a strong greenhouse gas.

EPA's review of the ozone NAAQS is underway and set to be completed in 2020, with background ozone contributions suggested as a topic to be addressed. Congress may conduct oversight as EPA carries out this effort.

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[47] A. M. Fiore et al., "Characterizing the Tropospheric Ozone Response to Methane Emission Controls and the Benefits to Climate and Air Quality," *Journal of Geophysical Research: Atmospheres*, vol. 113, no. D8 (2008).