

Climate Change Policy Initiative

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Does global climate change affect air pollution in Illinois?

By Don Fullerton, Megan Konar, and Julian Reif

The clear scientific consensus is that the Earth's climate is changing. These changes include an increase in global average temperatures, a rise in the sea level, and an increase in weather extremes such as floods and droughts in the coming decades. Carbon dioxide is a major contributor to global climate change, but it does not directly impact air quality in the local area where it is emitted. Instead, a different set of pollutants impact local air quality, including sulfur dioxide, nitrous oxides, and particulate matter.

However, global climate change can interact with those local pollutants to have significant effects on local air pollution all around the world, including Illinois. For example, one of the most important local pollution problems is ground-level ozone, which contributes to respiratory disease, other health problems, and mortality. Ozone is created when nitrous oxides and other local emissions react to sunlight on hot summer days, and those hot summer days are expected to become more common because of climate change.

This policy brief provides an overview of research on climate change and air pollution, and it discusses the implications for Illinois. We first describe the effects of pollution and then look at trends in Illinois relative to the whole United States. We then describe estimates of the effects of climate change on local pollution, and the effects of pollution on health. Focusing on ground-level ozone—which is projected to rise in the future—we use those estimates to calculate the effects of climate change on the number of “life-years lost” for the

three million residents around Chicago. We calculate that the social costs of the mortality increase associated with increased ozone levels in the Chicago area could exceed \$250 million annually.

Air pollution and air quality standards

The amount of pollution in the air is measured in several different ways. The most common method measures the amount of particulate matter, typically in units of micrograms per cubic meter of air. Particulate matter consists of a mix of microscopic solids and liquid droplets. It has many components, including acids, dust, allergens, and metals. These are often byproducts of industrial processes and vehicular traffic.

Small particulate matter can find its way into a person's lungs and bloodstream, potentially causing severe health problems. Many studies have found an association between small particulate matter and adverse health outcomes such as respiratory disease, cardiovascular disease, and death.¹

Regulation of particulate matter began with The Clean Air Act of 1970, which authorizes the U.S. Environmental Protection Agency (EPA) to regulate air quality. The EPA initially regulated the level of total particulate matter in the air. The EPA later replaced this initial standard with a “PM 10” standard, which only measures particles with a diameter of 10 micrometers or less, because research

¹Examples of such studies are listed in the appendix. These include: Deryugina et al., 2016a; Deryugina et al., 2016b; and Dockery et al., 1993.

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Table 1: EPA’s current national ambient air quality standards

Pollutant	Primary/Secondary	Averaging Time	Maximum Level	Form
Carbon monoxide	Primary	8 hours	9,000 ppb	Not to be exceeded more than once per year
		1 hour	35,000 ppb	
Lead	Primary and secondary	Rolling 3 month period	0.15 µg/m ³	Not to be exceeded
Nitrogen Dioxide	Primary	1 hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Primary and secondary	1 year	53 ppb	Annual mean
Ozone	Primary and secondary	8 hours	70.0 ppb	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
PM 2.5	Primary	1 year	12.0 µg/m ³	Annual mean, averaged over 3 years
	Secondary	1 year	15.0 µg/m ³	Annual mean, averaged over 3 years
	Primary and secondary	24 hours	35 µg/m ³	98th percentile, averaged over 3 years
PM 10	Primary and secondary	24 hours	150 µg/m ³	Not to be exceeded more than once per year on average over 3 years
Sulfur dioxide	Primary	1 hour	75 ppb	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
	Secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

Note: Units of measure are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air (µg/m³).
Source: EPA, <https://www3.epa.gov/ttn/naaqs/criteria.html>

suggests that small particulates pose the greatest threat to health. Beginning in 1997, the EPA also implemented a “PM 2.5” standard, which regulates fine particulate matter with a diameter of 2.5 micrometers or less.

Besides particulate matter, the EPA also regulates five other air pollutants: sulfur dioxide, nitrogen dioxide, ground-level ozone, carbon monoxide, and lead. Sulfur dioxide is produced primarily by coal-fired power plants. Nitrogen dioxide comes mainly from motor vehicle exhaust, power plants, and industrial boilers. Both of these gases can react with other particles to form sulfates and nitrates, which are the two major constituents of PM 2.5.

Carbon monoxide and ozone are colorless, odorless gases. Carbon monoxide is emitted primarily by automobiles and fires. It has been linked to respiratory and cardiovascular disease, and exposure to high levels is lethal. Ground-level ozone, a key component of smog, is the end result of chemical reactions between sunlight and pollutants, including nitrates and volatile organic compounds that are emitted primarily by power plants and motor vehicles. Unlike sulfur dioxide and nitrogen dioxide, carbon monoxide and ozone are not precursors to fine particulate matter and thus do not affect measured levels of PM 2.5.

Lead is a toxic metal that can cause damage to the neurological, cardiovascular, and respiratory systems. Lead in the air comes primarily from ore and metals processing, as well as from leaded gasoline used by some small airplanes. Lead levels in the air decreased drastically following the phase-

out and subsequent ban on leaded automobile gasoline in the 1980’s and 1990’s.

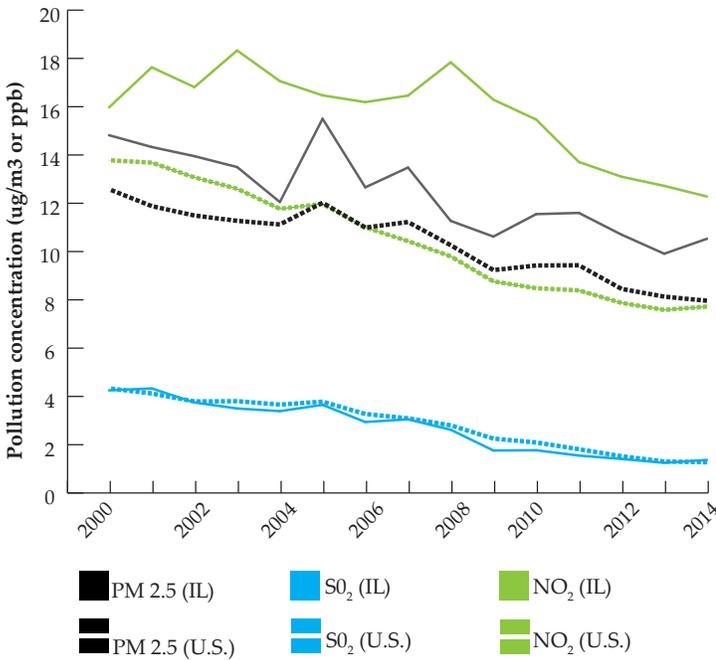
Table 1 lists the EPA’s current national ambient air quality standards. The “primary standard” is geared toward protecting public health, while the “secondary standard” is intended to protect non-human welfare such as animals, crops, and infrastructure. The number of standards and their forms vary by pollutant. For example, one of the primary standards for carbon monoxide, which can be highly toxic even with brief exposures, regulates the permissible amount of carbon monoxide in the air that is present over an 8-hour period. By contrast, the primary standards for PM 2.5 regulate the amount that is permissible over a three-year period.

The EPA works with state and local agencies to monitor and enforce these regulations. Pollution monitors are placed throughout the country to determine whether or not particular geographic areas are meeting the EPA’s air quality standards. Compliance with these standards is determined at the county or metropolitan area level. Areas found to be in violation of the EPA’s air quality standards are designated as “nonattainment.” Polluters in nonattainment areas will usually face substantially stricter regulations than polluters in attainment areas.

Air pollution in Illinois

Figure 1 displays trends in the annual levels of fine particulate matter (PM 2.5), sulfur dioxide (SO₂), and nitrogen dioxide

Figure 1: Trends in PM 2.5, sulfur dioxide, and nitrogen dioxide levels in Illinois and the U.S., 2000-2014



Notes: Graph plots annual averages. Fine particulate matter (PM 2.5) levels are measured in micrograms per cubic meter. Sulfur dioxide (SO₂) and Nitrogen Dioxide (NO₂) levels are measured in parts per billion.

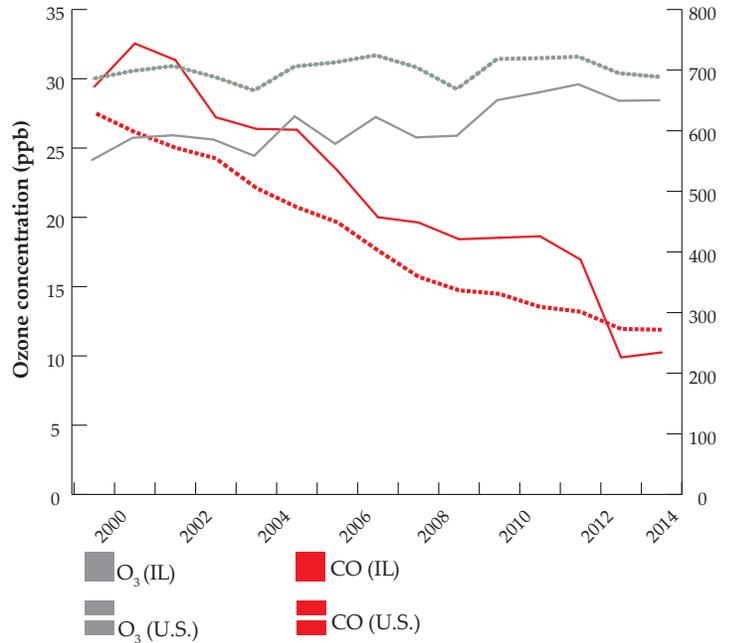
Source: Authors' calculations using data from the EPA's Air Quality System database. These data are publicly available from http://aqsdr1.epa.gov/aqsweb/aqstmp/airdata/download_files.html

(NO₂). The solid lines display trends for Illinois and the dashed lines display overall trends for the United States.

Largely due to the Clean Air Act of 1970 and subsequent amendments to make air regulations more stringent, the average level of PM 2.5 in Illinois decreased between 2000 and 2014, from 15 micrograms per cubic meter of air to 11. The average levels of sulfur dioxide and nitrogen dioxide, the two primary contributors to PM 2.5, also declined during this time period. The level of NO₂ in Illinois exceeds the U.S. average, while the level of SO₂ in Illinois does not exceed the U.S. average. Both of these pollutants contribute to PM 2.5, so the relatively high level of NO₂ in Illinois probably explains the high levels of fine particulate matter compared to the nation as a whole. For all three of these pollutants, however, the declining trends in Illinois line up with the declining trends observed nationwide.

Figure 2 displays corresponding trends for ozone (O₃) and carbon monoxide (CO), which do not contribute to levels of PM 2.5. CO levels decreased significantly between 2000 and 2014 both in Illinois (solid black line) and nationwide (dashed black line). In 2000, Illinois' annual average level of CO was 670 parts per billion, but in 2014 it was just 230. By contrast, O₃ levels in Illinois exhibited slow but positive growth during this time period, from 24 parts per billion in 2000 to 28 in 2014, although they remain below the average

Figure 2: Trends in ozone and carbon monoxide levels in Illinois and the U.S., 2000-2014



Notes: Graph plots annual averages. Units are measured in parts per billion.

Source: Authors' calculations using data from the EPA's Air Quality System database. These data are publicly available from http://aqsdr1.epa.gov/aqsweb/aqstmp/airdata/download_files.html

for the nation. As in Figure 1, Illinois' trends correlate strongly with nationwide trends.

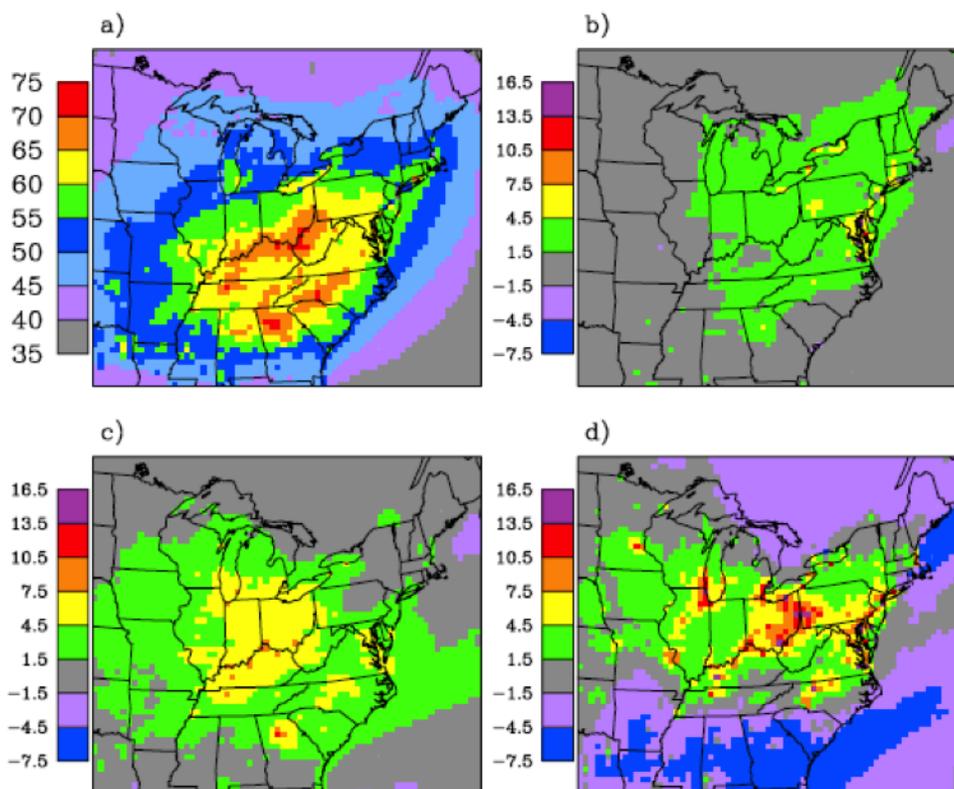
While statewide averages are informative, they can mask variation across different areas within the state. One reason the EPA enforces its standards at the level of the county or metropolitan area is that local air pollution levels may differ significantly between cities. As of October 1, 2015, 109 cities in the United States were out of compliance with the EPA's air quality standards and therefore designated as "nonattainment" areas. Two of these cities are in Illinois: Peoria was in violation of the EPA's sulfur dioxide standards, while the Chicago metropolitan area was in violation of the sulfur dioxide, lead, and ozone standards.²

How will climate change affect air pollution in Illinois?

The data displayed in Figures 1 and 2 show that—with the exception of ozone—air pollution levels in Illinois have declined over the past 15 years. What effect will climate change have on these trends? Scientists have begun paying more attention to the interaction between climate change

²See the EPA's Summary Nonattainment Area Population Exposure Report, available at <https://www3.epa.gov/airquality/greenbook/popexp.html>

Figure 3: Projected changes in ozone levels in the Midwest and the East, 2020s-2080's



Notes: Panel (a) reports summertime average daily maximum 8-hour ozone concentrations in the 1990's. Panels (b), (c), and (d) illustrate projected changes for the 2020's, 2050's, and 2080's, respectively, relative to the 1990's levels in panel (a). All units are in parts per billion. Source: Hogrefe et al. (2004), see Appendix for full citation.

and air pollution. Climate change is expected to affect temperatures, humidity, precipitation, and wind patterns around the world, each of which influences air pollution in different ways. For example, it is well known that hotter temperatures increase ozone levels.³ Scientists expect that climate change will increase ozone levels over large areas of the United States, but they have not reached consensus yet whether climate change will lead to an increase in the levels of other pollutants such as PM 2.5.⁴

We focus here on ozone levels, which—as was illustrated in Figure 2—have gradually increased recently in Illinois. A 2004 study published in the *Journal of Geophysical Research* used climate models to simulate ozone levels in future decades for the Midwestern and Eastern parts of the United States.⁵ Their results are displayed in Figure 3. Panel (a) serves as a baseline and displays average ozone levels during the 1990's.⁶ Illinois' levels are higher than its neighbors to the north and west (Wisconsin, Iowa, and Missouri) but lower than those to the east and south (Indiana and Kentucky).

³See the Appendix for resources, specifically Sillman and Samson, 1995.

⁴See the Appendix for resources, specifically U.S. Global Change Research Program, 2016.

⁵See the Appendix for resources, specifically Hogrefe et al., 2004.

⁶Figure 3 measures ozone levels as the average daily maximum 8-hour ozone concentration. Thus it is not directly comparable to Figure 2, which measures ozone as a simple yearly average.

Panels (b), (c), and (d) show predicted changes in ozone levels for the 2020s, 2050s, and 2080s, respectively, that are due to changes in climate and emissions. The ozone levels in Illinois in general, and Chicago in particular, are predicted to rise steadily throughout this century. The study predicted that levels in the Chicago area will rise more than 20 percent, from approximately 60 parts per billion in the 1990s to 73.5 in the 2080s. Not all parts of the country will experience increases in ozone levels. Panel (d) shows that ozone levels in the south are projected to decline in the 2080's. This underscores the importance of employing regional projections for understanding the effects of climate change.

Effects of increased pollution

The projected slow but continuing increase in ozone levels in Illinois is consistent with the historical trends presented in Figure 2. The projected increase is particularly concerning for a congested area like Chicago, which is already in violation of the EPA's current air quality standards for ozone. The precise consequences for health and mortality of a further rise in ozone levels are difficult to predict. Estimating even the effects of past changes in pollution levels is complicated, but existing research gives us some guidance.

Studies that evaluate the effects of air pollution must overcome two main challenges. First, experimental variation

in air pollution is rare, so researchers usually must employ observational data that suffers from various imperfections. For example, consider using data on health and pollution that is collected before and after the end of a major road construction job. The reduction in traffic congestion following the end of construction may reduce both ozone levels and stress levels simultaneously. Attributing any subsequent improvements in health solely to the reduction in ozone levels may overestimate the magnitude of the effect because some of the health improvement may come from the reduction in stress. A second challenge is that ozone levels are correlated with the levels of other air pollutants, such as fine particulate matter. Researchers must disentangle these effects from each other to be certain that observed changes are due to ozone and not to changes in other pollutants.

A 2016 working paper addresses these challenges in several ways.⁷ First, the research team employs variation in air pollution due to changes in local wind patterns, which are unlikely to be related to other confounding variables such as traffic patterns. Second, different air pollutants are transported by wind patterns in different ways, which allows their effects to be identified separately. Third, although the researchers focus on PM 2.5, their estimates potentially provide an instructive upper bound on the mortality costs of increased ozone levels, because most studies estimate that the health effects of ozone are smaller than those of other pollutants.⁸

A simple calculation here can be instructive. We combine estimates of the causal effect of air pollution on mortality from the working paper with the Illinois ozone projections for Chicago from the 2004 study summarized above. The result implies that the rise in ozone levels may reduce life expectancy in the Chicago area by up to 2,500 life-years annually by the 2080s.⁹ For example, this result could mean that 250 individuals per year will die 10 years earlier than otherwise. By comparison, the annual number of fatal car crashes in Cook County—which encompasses Chicago—is less than 250, according to the Illinois Department of Transportation. If we multiply the number of life-years lost due to increased ozone levels by \$100,000, a common estimate of the value of a life-year, then this calculation implies a total social cost equal to \$250 million per year just for Chicago. Although a simple hypothetical exercise, these results suggest that mitigating the effects of increases in air pollution due to climate change may be quite valuable for Illinois, especially in dense urban areas.

⁷See Appendix for resources, specifically Deryugina et al., 2016a.

⁸See Appendix for resources, specifically Currie and Neidell, 2005 and Dockery, 1993.

⁹Hogrefe et al. (2004) predict an increase in ozone levels of about 20 percent. An analogous increase in PM 2.5 levels corresponds to an increase of 2 micrograms per cubic meter of air. For the Chicago area with a population of 3 million people, the estimates from Deryugina et al. (2016a) then imply reduced life expectancy on an annual basis of $1.13 \times 2 \times 365 \times 3 = 2,480$ life-years. Specifically, this number is calculated as 1.13 life-years lost per million residents (Deryugina et al. 2016a, Table 9) times 2 micrograms per cubic meter, times 365 days per year, times 3 million residents.

Policy Implications

Air pollution is believed to have large negative effects on human health. Fortunately, with the exception of ozone, air pollution levels have been declining in Illinois over the past 15 years. However, climate change and atmospheric pollution models predict that ozone levels will increase over the next several decades, especially in densely populated areas like Chicago. It therefore may be beneficial to take steps now to discourage activities that contribute to ground-level ozone, such as the operation of chemical plants, power plants, and cars.

For example, increasing the gasoline tax would discourage driving and encourage purchase of more fuel-efficient cars, which may be an efficient way to reduce ozone levels in the future (while at the same time raising needed funds for road maintenance). Another option is to enact policies that reduce the demand for electricity, particularly on days forecast to have high ozone levels. Of course, local authorities can undertake a number of options to reduce the number of “ozone action days,” such as prohibiting the use of lawnmowers on those days, or giving out free rides on the bus system so that people can avoid driving. Doing nothing, by contrast, risks incurring significant costs in the future.

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IGPA’s Climate Change Policy Initiative is led by University of Illinois at Urbana Champaign finance scholars Don Fullerton and Julian Reif. The initiative seeks to understand how public policy can protect people from the effects of climate change in Illinois. Hotter temperatures will require more power for air conditioning, and greater weather volatility will mean increased numbers of droughts, floods, and storm damage. Beyond these consequences, Illinois will also be greatly affected by the interactions between uncertain water supplies and energy needs. The Climate Change Policy Initiative evaluates forward-thinking public policies that can help protect Illinois’s productivity, health, and future economic welfare.

Contact Don Fullerton, dfullert@uillinois.edu or Julian Reif, jreif@uillinois.edu, to learn more about the initiative.

Appendix: Resources

- Balbus, J., A. Crimmins, J.L. Gamble, D.R. Easterling, K.E. Kunkel, S. Saha, and M.C. Sarofim, 2016: Ch. 1: Introduction: Climate Change and Human Health. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. U.S. Global Change Research Program, Washington, DC, 25–42. <http://dx.doi.org/10.7930/J0VX0DFW>
- Currie, Janet, and Matthew Neidell. "Air Pollution and Infant Health: What Can We Learn from California's Recent Experience?" *The Quarterly Journal of Economics* 120, no. 3 (2005): 1003-1030.
- Cutler, D. M. (2004). *Your money or your life: Strong medicine for America's health care system*. Oxford University Press.
- Deryugina, T., Heutel, G., Miller, N., Molitor, D. and J. Reif. *The Effect of Pollution on Health and Health Care Utilization: Evidence from Changes in Wind Patterns* (2016 working paper).
- Deryugina, T., Reif, J., Reimer, N., and M. West. *The Wind's Fatal Blow: The Effect of Transported Air Pollution on Infant and Adult Mortality* (2016 working paper).
- Dockery, D., C. Pope, X. Xu, J. Spengler, J. Ware, M. Fay, B. Ferris Jr., and F. Speizer (1993). An association between air pollution and mortality in six us cities. *New England Journal of Medicine* 329(24), 1753-1759.
- Environmental Protection Agency (2004). "The particle pollution report: Current understanding of air quality and emissions through 2003". Available from <https://www3.epa.gov/airtrends/aqtrnd04/pm.html>
- Environmental Protection Agency. Particulate Matter, Basic Information. Available from <http://www3.epa.gov/airquality/particlepollution/basic.html>.
- Hogrefe, C., B. Lynn, K. Civerolo, J-Y. Ku, J. Rosenthal, C. Rosenzweig, R. Goldberg, S. Gaffin, K. Knowlton, and P. L. Kinney. "Simulating changes in regional air pollution over the eastern United States due to changes in global and regional climate and emissions." *Journal of Geophysical Research* 109, no. D22 (2004).
- IL Department of Transportation. 2013 Illinois Crash Facts and Statistics. Available from <http://www.idot.illinois.gov/Assets/uploads/files/Transportation-System/Resources/Safety/Crash-Reports/crash-facts/2013%20CF.pdf>.
- Mickley, Loretta J., Daniel James Jacob, B. D. Field, and D. Rind. "Effects of future climate change on regional air pollution episodes in the United States." *Geophysical Research Letters* 31, no. 24 (2004).
- Patz, Jonathan A., Diarmid Campbell-Lendrum, Tracey Holloway, and Jonathan A. Foley. "Impact of regional climate change on human health." *Nature* 438, no. 7066 (2005): 310-317.
- Sillman, Sanford, and Perry J. Samson. "Impact of temperature on oxidant photochemistry in urban, polluted rural and remote environments." *Journal of Geophysical Research: Atmospheres* 100, no. D6 (1995): 11497-11508.
- U.S. Global Change Research Program, 2016: "The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment". Crimmins, A., J. Balbus, J.L. Gamble, C.B. Beard, J.E. Bell, D. Dodgen, R.J. Eisen, N. Fann, M.D. Hawkins, S.C. Herring, L. Jantarasami, D.M. Mills, S. Saha, M.C. Sarofim, J. Trtanj, and L. Ziska, Eds., Washington, DC, 312 pp. <http://dx.doi.org/10.7930/J0R49NQX>