National Aeronautics and Space Administration

Clean Air Act from Space

Environmental Regulations in the U.S. are Working

NASA satellites, with their "god's eye" view, confirm that air quality in the U.S. is improving for a number of air pollutants, including nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and fine particulate matter ($PM_{2.5}$), such as smoke and dust. That is, the Clean Air Act is working. While it is estimated that the health benefits of these pollutant reductions are substantial, levels of pollutants in the U.S. are still an environmental health risk today.

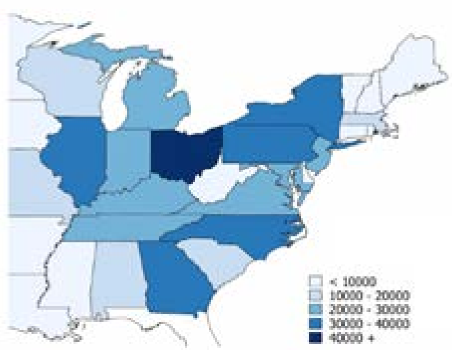
Impacts of Air Pollution on Health

The pollutants that cause the majority of negative health effects associated with U.S. air pollution are fine particulate matter (PM) and ozone (O_3). Exposure to PM causes and/or exacerbates a number of health issues, such as respiratory disease, ischemic heart disease, chronic obstructive pulmonary disease, lung cancer and stroke. When breathed in, O_3 chemically reacts with lung tissue, causing respiratory issues (e.g., shortness of breath, coughing, and aggravation of asthma) and injury to lung tissue that accumulates over time with continued exposure. Nitrogen dioxide (NO_2) also causes respiratory issues and is associated with, for instance, new cases of asthma among children (Anenberg et al., 2018).

Improved AQ = Improved Health

Between 2002 and 2011, new emissions controls reduced emissions of nitrogen oxides (NO_X) in the eastern US. NO_X is a necessary ingredient for the formation of high ozone levels. In 2011 the number of days with unhealthful ozone levels was about 9-13 less than in 2002 in much of the Ohio River Valley, and the Washington, D.C.-Baltimore area had 3-9 fewer days with unhealthy ozone levels (Loughner et al., 2014). In unpublished work, scientists estimate that in the eastern US this improvement in air quality prevented about 570-800 deaths, about 950 hospital admissions due to respiratory symptoms, and about 570 emergency room visits for asthma. More than 430,000 people avoided asthma exacerbation symptoms.

Avoided Asthma Exacerbations in July 2011 from Air Pollution Decreases since 2002



Estimated Benefits of Improving U.S. Air Quality

Health Benefits: The average U.S. concentration of $PM_{2.5}$ decreased by 37% and average O_3 decreased by 22% between 1990 and 2015 as estimated from surface air quality instrument data (US EPA, 2018). These substantial improvements are estimated to have had concomitant health benefits (i.e., avoided deaths and improvements in health). For instance, it is estimated that deaths related to air pollution exposure in the U.S. decreased by about 47 percent, dropping from about 135,000 deaths in 1990 to 71,000 in 2010 (Zhang et al., 2018). Despite these improvements, about 1 in 35 U.S. deaths today is associated with air pollution, which is as many deaths from all traffic accidents and all gun shootings combined.

Economic Benefits: The benefits of air pollution mitigation more than 30 times exceed the associated costs; although the U.S. dedicates roughly $65 billion annually to improve air quality, there is a resulting $2 trillion in benefits from economic production due to reduced premature mortality (US EPA, 2011). For example, O_3 is harmful to vegetation and reduces yields for some crops (e.g., soybeans), costing an estimated $3.1 billion annually in the U.S. (Averny et al., 2011).

NASA satellite data show that:

$PM_{2.5}$ decreased 30% over Eastern U.S. from **1998** to **2012**

Boys et al. (2014)

SO_2 decreased 50% or more over most power plants in eastern U.S. **from 2005 to 2018**

Fioletov et al. (2011; 2016)

NO_2 decreased 40-60% over most U.S. cities from **2005** to **2018**

Duncan et al. (2016)

While: **47% decrease** in U.S. deaths related to airpollution

1990: 135,000

2010: 71,000

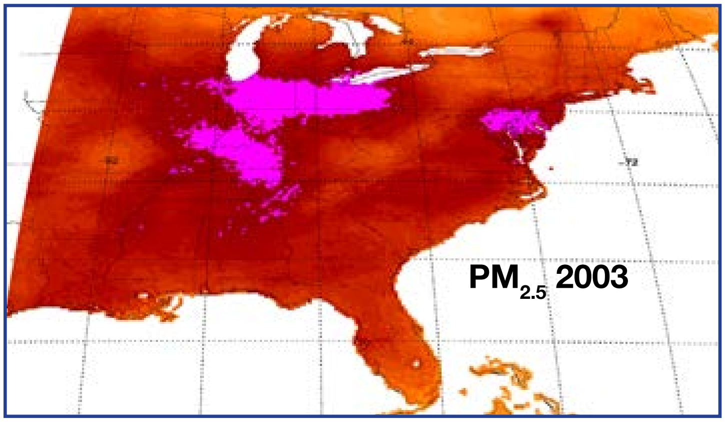
Still: **1 in 35 U.S. Deaths from air pollution,** as many as from traffic accidents and gun shootings combined

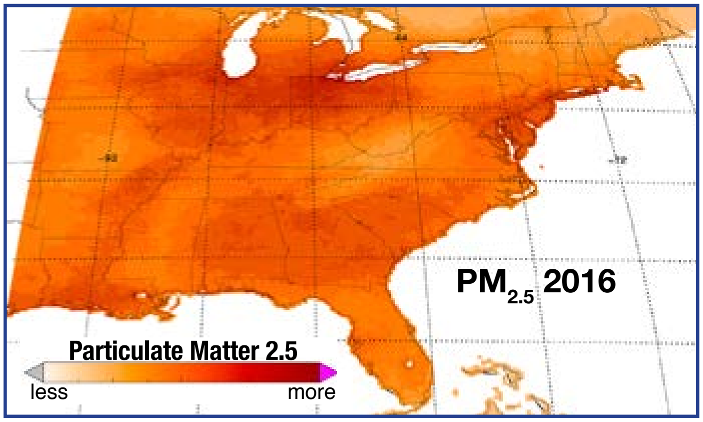
Zhang et al. (2018)

Satellite Data Demonstrate that US Air Quality is Improving

Fine Particulate Matter and Sulfur Dioxide

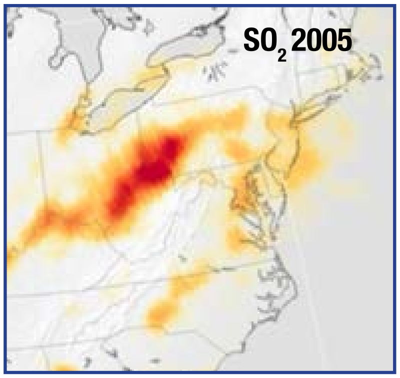
Fine particulate matter <2.5 μm in width ($PM_{2.5}$) is directly emitted to the atmosphere, such as in the form of smoke and dust. $PM_{2.5}$ can also form in the atmosphere through chemical reactions that transform gaseous precursor pollutants, such as sulfur dioxide (SO_2), ammonia (NH_3), or nitrogen dioxide (NO_2) to particles (i.e., gas to particle conversion). Satellite data indicate that $PM_{2.5}$ levels have decreased by about 30% or more over the Eastern U.S. from 1998 to 2012 because of emission control measures (Boys et al., 2014). Satellite data confirm that the concentrations of several $PM_{2.5}$ precursors are going down over time over the U.S. NO_2 levels decreased by about 40-60% over most major U.S. cities from 2005 to 2017 (Duncan et al., 2016) and SO_2 levels also decreased dramatically near coal-burning power plants (Fioletov et al., 2011, 2016).

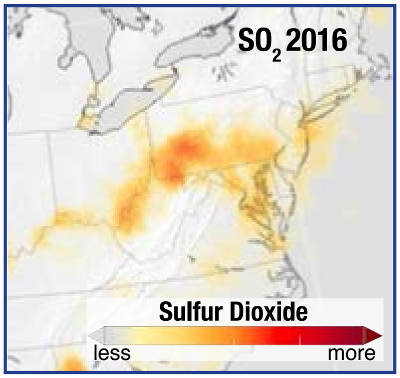




Surface $PM_{2.5}$ levels, as inferred form NASA satellite data, have decreased about 30% from 1998 to 2012 (Boys et al., 2014). The spatial distributions of annual pollutants are shown for 2003 and 2016.

SO_2 concentrations decreased over most U.S. power plants in the Eastern U.S. by 50% or higher (Fioletov et al., 2011, 2016). These decreases have contributed to the overall decline of $PM_{2.5}$ in the Eastern U.S. from 2005-2016.





MILESTONES

1990 — 1995 — 2000 — 2005

1990
CAA amendments. included mandates for SO_2 and NO_X reductions to control acid rain

1994
CAA amendments of 1990 Tier 1 standards were in force between 1994 and 1997 to reduce mobile NO_X emissions

1995
ESA GOME instrument first observes NO_2, SO_2, and CH_2O

1998
NO_X SIP Call required NO_X emission reductions between 2003 and 2008 from power plants in the Eastern US to reduce the regional transport of pollution

1999
NASA Terra MODIS and MISR instruments provide first state-of-art global maps of aerosol distribution, an important step in monitoring surface $PM_{2.5}$

2004
NASA Aura OMI instrument first measures trace gas air pollutants at sub-urban levels.

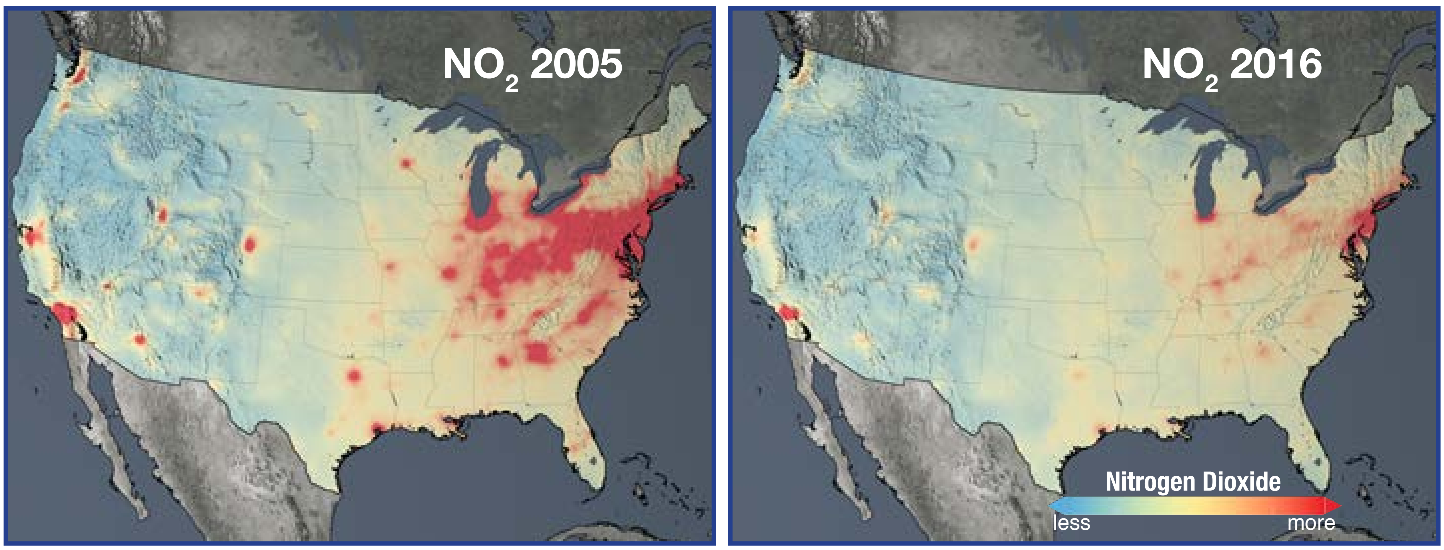
2004
CAA amendments of 1990 Tier 2 standards were in force between 2004 and 2009 to reduce mobile NO_X emissions

2005
CAIR (Clean Air Interstate Rule) required reductions in SO_2 and NO_2 emissions from 2009 to 2014 in Eastern states to address the interstate transport of O_3 and $PM_{2.5}$ pollution

Ozone and Nitrogen Dioxide

At Earth's surface, ozone (O_3) is an air pollutant that is not directly emitted into the air, but instead is formed through chemical reactions in the atmosphere when ultraviolet (UV) radiation from the sun interacts with nitrogen oxides ($NO_x = NO_2 + NO$) and volatile organic compounds (VOCs). Both compounds are released to the atmosphere through human actions, such as the burning of fossil fuels. (Surface O_3 pollution is not to be confused with the stratospheric "ozone layer," which filters out most harmful UV rays from the sun.)

With today's technology, it is not currently feasible to monitor surface levels of O_3 from space. However, it is possible to observe NO_2 levels from space and NO_2 serves as an effective proxy for NO_x. While NO_2 is unhealthy to breathe, NO_x is primarily regulated to improve air quality as it is a necessary ingredient of the formation of unhealthy levels of O_3. Satellite data indicate that there have been substantial decreases (40-60%) in NO_2 levels over most major U.S. cities between 2005 and 2017. Surface air quality monitors in the U.S. indicate that there has been about a 15% decrease in surface O_3 from 2005 to 2016 (US EPA, 2018). However, satellite data and surface monitors both indicate that the downward trend in NO_2 has stalled since about 2011 (Jiang et al., 2018).



NASA satellite data show that NO_2 has decreased by 40-60% over U.S. cities from 2005-2016 (Duncan et al., 2016).

2010 — 2015 — 2020

2006
NASA CALIPSO instrument measures vertical distribution of aerosols, an important parameter in estimation of surface $PM_{2.5}$

2008
OMI confirms large reductions in NO_2 and SO_2 levels over thermal power plants due to emission controls

2000-2009
American Cancer Society Study is reanalyzed, updated, and extended in several studies, consistently reporting associations between particulate pollution and mortality

2011
CSAPR (Cross-State Air Pollution Rule) replaced CAIR beginning in 2015

1997-2012
Harvard Six Cities Study connected air pollution to mortality and showed that mortality went down when air quality improved.

2015
OMI data reveal a 40-60% reduction in NO_2 levels over major U.S. cities between 2005-2015

2016
NOAA/NASA ABI instrument provides very high frequency aerosol measurements for tracking fire smoke, volcanic plumes and dust storms

2017
ESA TROPOMI instrument observes NO_2, SO_2, CH_2O, and CO at unprecedented sub-urban spatial resolutions and on daily time-scales

2019+
Upcoming Launches: NASA MAIA, the first satellite mission dedicated to human health, and NASA TEMPO, the first geosynchronous satellite to observe many pollutants hourly

Satellite Data Help Assess Impacts of Wildfire Pollution

Numerous satellite datasets are used to identify wildfire locations, assess burned area, track smoke transport, issue air quality alerts, and estimate health effects. Despite significant progress on reducing anthropogenic $PM_{2.5}$, wildfires are an infrequent, but significant source of $PM_{2.5}$ that can expose large populations to unhealthy levels of pollution. For instance, smoke from persistent wildfires in the Western U.S. during 2017 and 2018 degraded air quality in a number of large cities, such as San Francisco, Portland, and Seattle. While less frequent in the Eastern U.S., fire smoke is a significant health risk. For instance, wildfires in the Southeast U.S. impacted large regions, including heavily populated cities like Atlanta, in the fall of 2016.

Satellite image of California wildfires October 11, 2017
Blazes that started on a few hundred acres around Napa Valley were fanned by strong northeasterly winds into more than 100,000 acres of burned land in just two days impacting the air quality for entire counties in California.

For More About Air Quality Data

Images, animations, and other information related to this factsheet may be found at airquality.gsfc.nasa.gov/us-air-quality-trends

Visit arset.gsfc.nasa.gov for information on accessing and visualizing NASA satellite data. Health and Air Quality Applied Sciences Team website haqast.org.

NASA Health and Air Quality Applied Sciences Team (HAQAST)

NASA's Applied Science Program launched the three-year Health and Air Quality Applied Sciences Team (HAQAST) in the fall of 2016. The team includes thirteen air quality and public health scientists spread across the U.S., in government offices and public and private universities. HAQAST uses NASA satellite data to help solve real-world public health and air quality problems, working with stakeholders all around the world on issues from wildfire smoke to diesel emissions. HAQAST also pursues short-term, high-impact projects in small groups called Tiger Teams. This factsheet is the result of a Tiger Team, entitled "Efficacy of Environmental Regulations to Improve Air Quality in the Eastern U.S.", which is led by Dr. Bryan Duncan (NASA) and Dr. Jason West (UNC). More results of this Tiger Team can be found on the NASA Air Quality web site: https://airquality.gsfc.nasa.gov/

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