Food Security from Space

Monitoring Indicators of Air Quality on Crop Yields

National Aeronautics and Space Administration

While its effects are often overlooked, air pollution negatively impacts crops around the world, resulting in significant economic losses, with the greatest economic loss occurring in the United States. Satellites can give farmers, scientists and policy makers important knowledge of how air quality affects food security, enabling more informed decision-making to ensure access to food resources.

Effects of Air Pollution on Plants

Ozone (O_3) is the most destructive pollutant to crops. While scientists have been working with farmers for decades to identify and breed ozone-tolerant varieties to maintain high crop productivity, the issue continues to persist, and resulting crop losses are projected to increase in many regions of the world over the next decade.

PHOTO: DR. JOHN SKELLY

Characteristic ozone–induced injury on the topside of green bean plant leaves. The stippling, which does not occur on veins, is associated with dark pigments accumulating within injured cells. Ozone injury symptoms often vary with different crops.

When elevated concentrations of surface-level ozone are taken up through a plant's stomata (the tiny pores on the lower surfaces of leaves), it results in a chemical reaction that hurts the plant, resulting in reduced crop yields. Ozone injury to plants is often visible as a fine tan- to dark-colored stippling pattern on the upper surface of leaves that accumulates throughout the growing season. Therefore, the lowest, oldest leaves on ozone-sensitive plants typically show the greatest amount of damage by the end of the growing season. However, the impact of ozone on plants isn't always obvious to the naked eye. Periods of stagnant air can cause ozone levels to exceed crop injury thresholds and seriously affect the overall health of plants, ultimately reducing their growth and yields. This effect is referred to as "hidden" ozone injury.

PHOTO: DR. JOHN SKELLY

As shown in an early field study in the 1970s, ozone-sensitive varieties of potatoes (left rows) show reduced growth and lower yields than ozone-tolerant varieties (right rows).

While ozone pollution has been shown to have a clear, negative impact on plant health, the impact of pollution from particulate matter (PM), such as dust and smoke, is more complicated. Depending on its concentration, particulate matter in the atmosphere can either reduce or enhance crop yields. For example, particulate matter can diffuse sunlight, creating a more even and efficient distribution of photons that can actually offset a reduction in total sunlight reaching a plant as a result of haze.

Air pollution can also negatively impact the pollinators of crops. About 40 percent of crops rely on insect pollination to some extent. By pollinating many species of crops and flowers, honey bees and other pollinators are integral to the health of ecosystems and the security of food resources. Overall, air pollution has likely contributed to a decline in honey bees, though many other factors may have contributed.

The economic impact of crop yield loss due to air pollution is significant in many world regions

$11-18 Billion

in global annual crop losses for wheat, corn, and soybeans[1]

$3.1 Billion

in crop losses for the United States, the country with the greatest economic loss[2]

8.6 Billion

estimated global population by 2030, increasing demand for food resources (UN)[3]

Satellite Observations Track Air Pollution

Ozone is not directly emitted to the atmosphere from human activities. Instead, it is formed within the atmosphere through a series of complex chemical reactions involving volatile organic compounds (VOCs) and nitrogen oxides (NO_x), which include nitric oxide (NO) and nitrogen dioxide (NO_2). Both of these compounds occur naturally in the atmosphere, but human activities, such as the burning of fossil fuels, elevate their concentrations, allowing unhealthy levels of surface ozone to form. While it is not currently feasible to infer surface ozone from satellite data, satellite observations of these ingredients provide valuable information on ozone levels.

Since nitrogen dioxide serves as a proxy for nitrogen oxides and can be measured from space, it can be used as input to computer simulations of atmospheric chemistry and transport to estimate surface ozone pollution. These simulations provide valuable information on ozone levels in agricultural areas and how these levels are evolving over time. Nitrogen dioxide data from the Dutch-Finnish Ozone Monitoring Instrument (OMI) on NASA's Aura satellite have given us an unprecedented look at how this pollutant has varied around the world, including agricultural regions, since 2005.

Given its relatively long lifetime in the atmosphere, ozone may be transported by winds far from the original sources of nitrogen oxides to agricultural regions, exposing crops to elevated ozone levels. While thermal power plants and automobiles are the dominant nitrogen oxide sources in most areas, in agricultural regions, the use of nitrogen-based fertilizers may also serve as an important source of nitrogen oxides to the atmosphere. If atmospheric conditions are conducive, high levels of surface ozone may form, exposing crops and potentially reducing the overall yields of ozone-sensitive species.

Formaldehyde (HCHO), a VOC, is also observable from space. It is an effective proxy for many VOCs, as it is produced when they are oxidized (i.e., broken down) in the atmosphere through chemical reactions. However, the presence of abundant natural sources of VOCs (e.g., plants), typically make controlling human-generated emissions of nitrogen oxides the only viable way, especially in agricultural areas, to reduce the formation of high levels of surface ozone. Therefore, observations of nitrogen dioxide are typically more important than formaldehyde observations for estimating ozone using computer simulations.

Observations of atmospheric ammonia (NH_3) from satellite instruments provide complementary information to nitrogen dioxide data by indicating when and where fertilizer is applied. However, satellite datasets of ammonia are still in development and are considered research products at this time.

Several new satellite instruments promise to provide even better nitrogen dioxide data. For instance, the European Space Agency's TROPOspheric Monitoring Instrument (TROPOMI; launched in 2017) collects data on nitrogen dioxide at sub-urban spatial resolutions (e.g., a few kilometers), a much finer resolution than OMI. Additionally, a planned fleet of satellites, called the Air Quality Constellation, is expected to launch in the early 2020s. The fleet will be located in geosynchronous orbit over East Asia, North America and Europe. That is, the satellites will remain in fixed locations in the sky relative to observers on the ground, providing much needed information on how air pollutant concentrations and emissions vary throughout the day. In contrast, OMI and TROPOMI are on polar-orbiting satellites that provide only one overpass over a given location on Earth's surface around 2 p.m. local time each day.

Global Nitrogen Dioxide

Data from NASA's Aura satellite show that nitrogen dioxide levels decreased by 40 to 60 percent over U.S. cities between 2005 and 2014 because of emission controls on cars and power plants. (Compare this image to the image on p. 3) Ozone (not shown) decreased by about 14 percent as a consequence.

Geophysical Variables Monitored

Product	Satellite Sensors*	Spatial Resolution	Period	Frequency
NO_2 /HCHO	GOME ERS-1	320x40 km^2	1995–2003	3 days
NO_2 /HCHO	SCIAMACHY ENVISAT	60x30 km^2	2002–2012	6 days
NH_3	AIRS Aqua	13.5x13.5 km^2	2002–present	2 days
NH_3	TES Aura	5.3x8.5 km^2	2004–2011	N/A
NO_2 /HCHO	OMI Aura	24x13 km^2	2004–present	2 days
NO_2 /HCHO	GOME-2 MetOp	80x40 km^2	2006–present	1 day
NH_3	IASI MetOp-A	12x12 km^2	2007–present	1 day
NH_3	IASI MetOp-B	12x12 km^2	2013–present	1 day
NH_3	CrIS Suomi NPP	14x14 km^2	2014–present	1 day
NO_2 /HCHO	TROPOMI Sentinel-5 Precursor	7x7 km^2	2017–present	1 day
NO_2 /HCHO	TEMPO**	2.1x4.7 km^2	launch early 2020s	1 day (N. America)

** Satellites operated by NASA and other U.S. and international agencies* *** Geostationary orbit*

Data Sources and Training

The information presented here focuses on NASA resources and datasets distributed through the Goddard Earth Science Data and Information Services Center. See airquality.gsfc.nasa.gov for further reading.

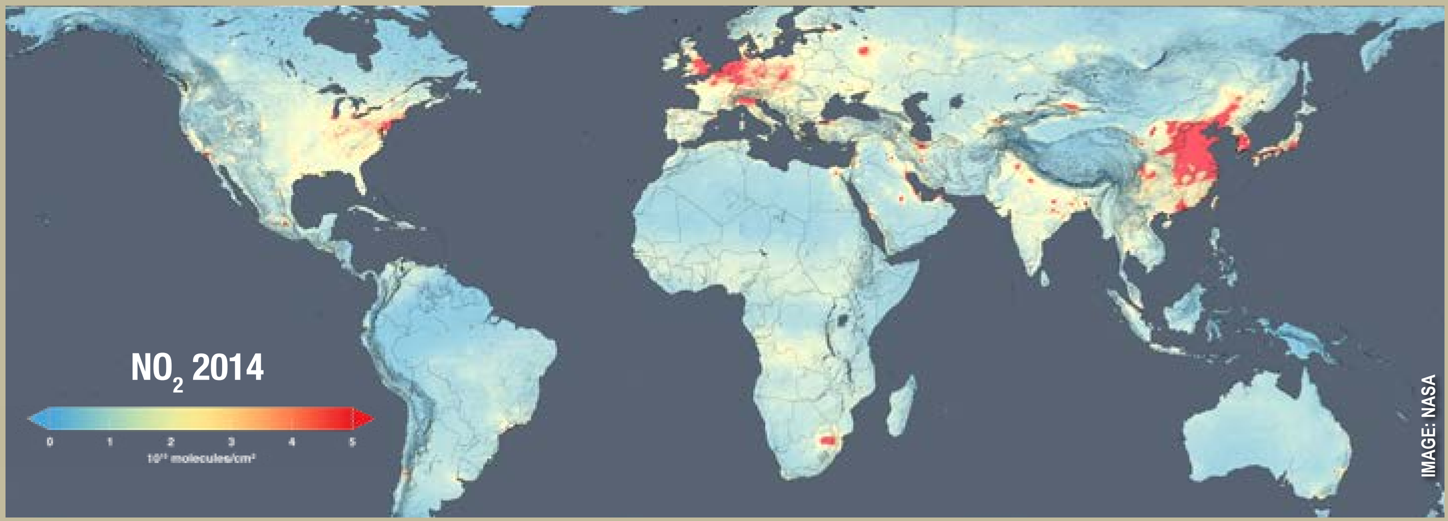
Webinar: arset.gsfc.nasa.gov/airquality/webinars/introduction-satellite-remote-sensing-air-quality-applications

References

[1] Avnery, S., et al. (2011). Global crop yield reductions due to surface ozone exposure: 1. Year 2000 crop production losses and economic damage. Atmospheric Environment, 45(13), 2284-2296

[2] Ainsworth, E.A. (2017). Understanding and Improving Global Crop Response to Ozone Pollution. The Plant Journal, 90(5): 886-97. https://doi.org/10.1111/tpj.13298

[3] Avnery, S., et al., (2011). Global crop yield reductions due to surface ozone exposure: 2. Year 2030 potential crop production losses and economic damage under two scenarios of O3 pollution. Atmospheric Environment, 45(13), 2297-2309



Aura data show that nitrogen dioxide levels decreased from 2005 to 2014 in much of Europe and Japan, but increased in South Asia with increased energy usage as these country economies have grown.

NASA Food Security Program

We live in a hungry world. A rapidly growing world population, its socioeconomic development, and finite natural resources in the midst of more frequent extreme weather and a changing climate, all increase our vulnerability to any disruption in the food system. Maintaining situational awareness about food production requires the global view of Earth as a system that only a fleet of satellites can provide.

IMAGE: NASA EARTH OBSERVATORY

Agribusiness in the Colorado River floodplain where the Mohave nation meets Arizona, Nevada, and California: commodity crops alfalfa, corn, and soybeans are grown in rectangular and round fields.

To help address these urgent challenges, NASA sponsors Harvest, a Food Security and Agriculture Consortium led by the University of Maryland. NASA partners with operational agencies such as the U.S. Department of Agriculture (USDA), the U.S. Agency for International Development (USAID) and the National Oceanic and Atmospheric Administration (NOAA), along with international organizations and private industry, to advance the use of remotely-sensed data for more informed decision-making.

We also have a team of NASA scientists with expertise in food and water systems, working with universities, governmental and non-governmental organizations to support the food security and agriculture communities in a more agile and futuristic way.

These researchers draw on the ingenuity of NASA with its unique technological and scientific capabilities in synergy with the NASA Harvest Consortium.

The Harvest Consortium is a NASA-funded collection of partners with domestic and international activities that are enhancing the use of satellite data in agricultural decision-making. Harvest places a strong emphasis on transitioning research to operations.

The NASA Food Security Program also:

- Fosters the assimilation of satellite and airborne remote sensing data into Earth systems models and other tools designed to address global food security challenges.
- Explores the research needs, sources of uncertainty and technical barriers that limit the operational use of Earth observations in decisions.
- Works with NASA's Earth Science Technology Office to advance state-of-the-art technology to public and private agencies focused on global food security challenges.
- Works with current and future NASA missions before and during their formulation to ensure that food security science and applications are incorporated into new satellite missions.
- Represents NASA on government initiatives, assisting interagency programs in the use of NASA resources.

PHOTO: SIMONSKAFAR/ISTOCK

A new generation of farmers uses aerial and satellite remote sensing imagery to help efficiently manage croplands. Farmers monitor a range of variables that affect their crops—such as soil moisture, surface temperature, photosynthetic activity, and more.

Further Reading

NASA Food Security Program: science.gsfc.nasa.gov/610/applied-sciences/food.html

NASA Harvest: nasaharvest.org

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