Satellite Data for Use in the National Ambient Air Quality Standards Process

by Arlene Fiore, Jenny Bratburd, and Daegan Miller

To support state and local air quality agencies that want to bring the power of NASA's satellites to bear in the preparation of state implementation plans or exceptional event demonstrations, a collaborative team of NASA-funded scientists and public stakeholders recently developed a suite of easy-to-follow technical guidance documents to help illustrate common applications of satellite data. A primer introducing the documents follows.

The U.S. National Ambient Air Quality Standards (NAAQS) are set by the U.S. Environmental Protection Agency (EPA) for criteria pollutants such as ozone (O_3) and fine particulate matter ($PM_{2.5}$). States with areas that are in nonattainment of these standards must submit State Implementation Plans (SIPs) to EPA to demonstrate their approach to achieving compliance with NAAQS. Satellite data can inform and supplement SIPs to improve air quality. Although SIPs typically rely on observations from ground-level monitoring networks and regulatory modeling, relevant satellite data are increasingly available to state agencies. By providing information over a broader area that might otherwise be unmonitored, satellite data complement ground-based networks.

The National Aeronautics and Space Administration (NASA) Earth Science program maintains a large fleet of earth-observing satellites, all of which offer free data products that are useful in the NAAQS process. For areas designated as nonattainment, satellite data can play a role in the SIP attainment demonstration. Satellite data may be used to illustrate nitrogen oxides (NOx) emissions trends and their relevance to O_3 attainment. For example, satellite composition measurements may be included in SIPs as part of a weight-of-evidence to confirm or refute that a particular strategy is anticipated to succeed in attainment. At the model development stage, satellite data can also be used to evaluate air pollution models that are used to test control strategies. These different aspects of SIP attainment demonstrations all target improved air quality and public health.

Exceptional event demonstrations are another regulatory mechanism where satellite data have been used alongside ground monitoring data and model simulations in weight-of-evidence arguments. If an exceptional event demonstration to exclude data on a particular day is accepted by EPA, the day is excluded from regulatory actions and thus does not count toward a NAAQS nonattainment designation. For example, an exceptional event demonstration could lead to excluding a high pollution event caused by a non-controllable source, such as wildfire.

To support state and local air quality agencies that want to bring the power of NASA's satellites to bear in the preparation of SIPs or exceptional event demonstrations, a collaborative team of NASA-funded scientists and public stakeholders recently developed a suite of easy-to-follow technical guidance documents.[1] These documents aim to illustrate a few common applications of satellite data. A more comprehensive discussion of satellite data applications for air quality is provided by Duncan et al. (2014).[2]

Getting Started with Satellite Data for Nitrogen Dioxide

Trends in satellite measured pollutants are useful for SIPs during emission inventory development, model evaluation, and trend analyses. One of the most widely used satellite products is tropospheric column nitrogen dioxide (NO_2), a measure of the vertically integrated concentration from the surface to the tropopause. A criteria pollutant itself, NO_2 is also a precursor

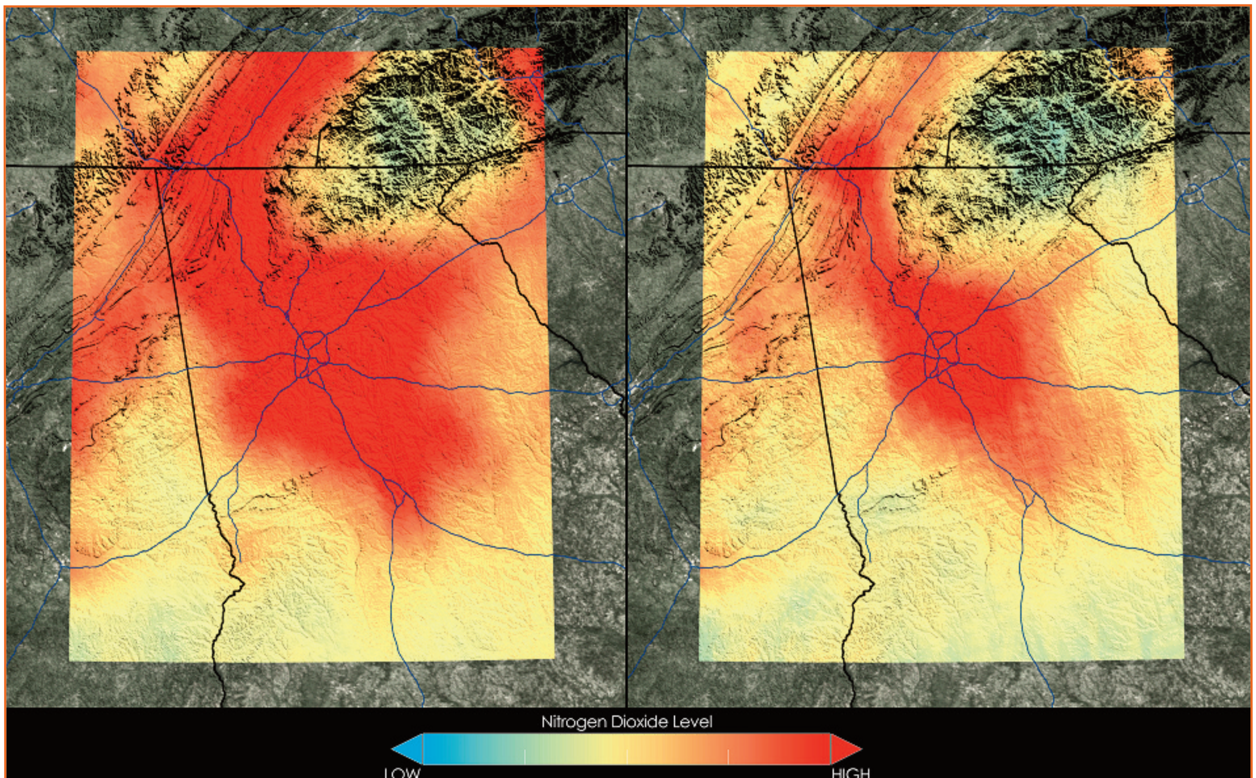

Figure 1. Satellite data show a 42% decrease in tropospheric column NO_2 over Atlanta, GA, between the 2005–2007 (left) and 2009–2011 (right) periods.
Image Credit: NASA Goddard's Scientific Visualization Studio/T. Schindler.

to ground-level O_3 and nitrate aerosol. For those looking to get started with satellite data and seeking a quick how-to, this step-by-step document (https://academiccommons.columbia.edu/doi/10.7916/d8-v9s1-a132) guides readers on using a NASA web tool, Giovanni, to create a regional-scale time series.[3] You can find more tutorials, including videos, among many of NASA's tools from the NASA Health and Air Quality Applied Sciences Team (HAQAST).[4]

To see how one state agency used satellite data to supplement a state implementation plan to improve air quality, check out this document (https://academiccommons.columbia.edu/catalog/ac:xksn02v715), "A Brief Tutorial on Using the Ozone Monitoring Instrument (OMI) Nitrogen Dioxide (NO_2) Data Product for SIP Preparation."[5] This report provides examples and guidance for using satellite products in SIPs, particularly for NO_2 and sulfur dioxide (SO_2), also a criteria pollutant and a precursor to sulfate aerosol. Figure 1 shows that OMI tropospheric NO_2 columns declined over Atlanta, GA, from 2005–2007 (left) to 2009–2011 (right), an example of the type of analysis that can be included in a SIP as weight-of-evidence for declining emissions or as background context for anticipated future changes. This document also includes background information on how satellites "see" pollution, and what types of satellite instruments are available to detect NO_2, differences between the instruments, and instructions on working with different data types.

Sensing Ground-Level Ozone Formation Chemistry

Satellite data analyses can be included in SIPs to examine the effectiveness of NOx or volatile organic compound (VOC) controls and to evaluate model sensitivity of O_3 formation to precursor emissions. Ground-level O_3 formation is driven by chemical reactions involving NOx and VOCs in the presence of sunlight (see Figure 2). Depending on the relative amounts of these precursors and the meteorological conditions, the most effective control strategy may vary from one urban area to another. Ground-level O_3 formation during the summer is most often limited by the availability of NOx. However, urban areas tend to have high levels of NOx emitted from smokestacks and tailpipes that is produced during combustion of fossil fuels. Where NOx is sufficiently high, O_3 formation can be limited by the availability of VOCs (see Figure 3).

Satellite instruments can detect chemical species that are related to VOCs and NOx: formaldehyde (HCHO, formed by the oxidation of various VOCs) and NO_2 (a component of NOx, together with nitric oxide [NO]). These space-based observations can offer insights into the sensitivity of O_3 production to these precursors at present, building on foundational work establishing chemical indicators of O_3 formation chemistry.[8] The ratio of HCHO to NO_2 indicates whether surface O_3 formation is NOx -limited (where reduction of NOx emissions decreases O_3) or VOC-limited (where reduction of VOC

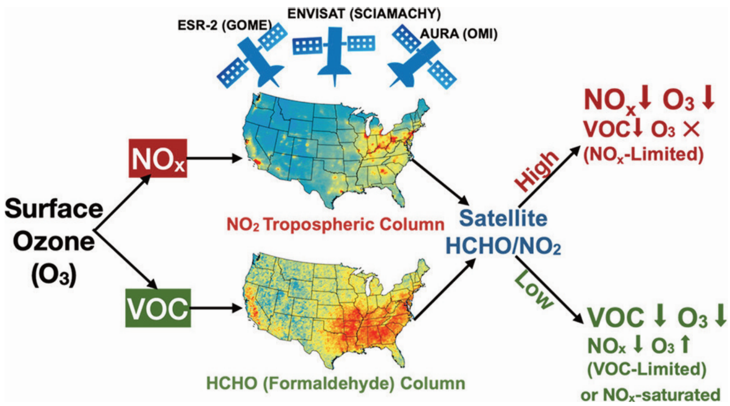

Figure 2. Diagram showing relationship between NOx and VOCs forming surface-level O_3. Satellite instruments (labeled above map) can detect NO_2 and HCHO (as displayed on the maps). The ratio of HCHO to NO_2 indicates whether surface O_3 formation is NOx-limited or VOC-limited. Arrows pointing upward or downward indicate increases or decreases, respectively, while an 'X' indicates little change in O_3.

Reproduced from Jin et al. (2020).[6]

emissions decrease O_3 while reduction of NOx may increase O_3). Over the length of the satellite record, these data products provide insight into how well past strategies worked, knowledge that can then be applied to steer future emissions control programs.[6] This document https://academic-commons.columbia.edu/catalog/ac:j9kd51c5dk, "Using satellite observed formaldehyde (HCHO) and nitrogen dioxide (NO_2) as an indicator of ozone sensitivity in a SIP," explains how these satellite products can be applied to interpret ground-level O_3 formation chemistry, and discusses caveats to the methods.[9]

Evaluating Models

Satellite data can also be applied to evaluate SIP model performance. When regional photochemical grid model simulations, such as with the Community Multiscale Air Quality (CMAQ) model or Comprehensive Air Quality Model with Extensions (CAMx)

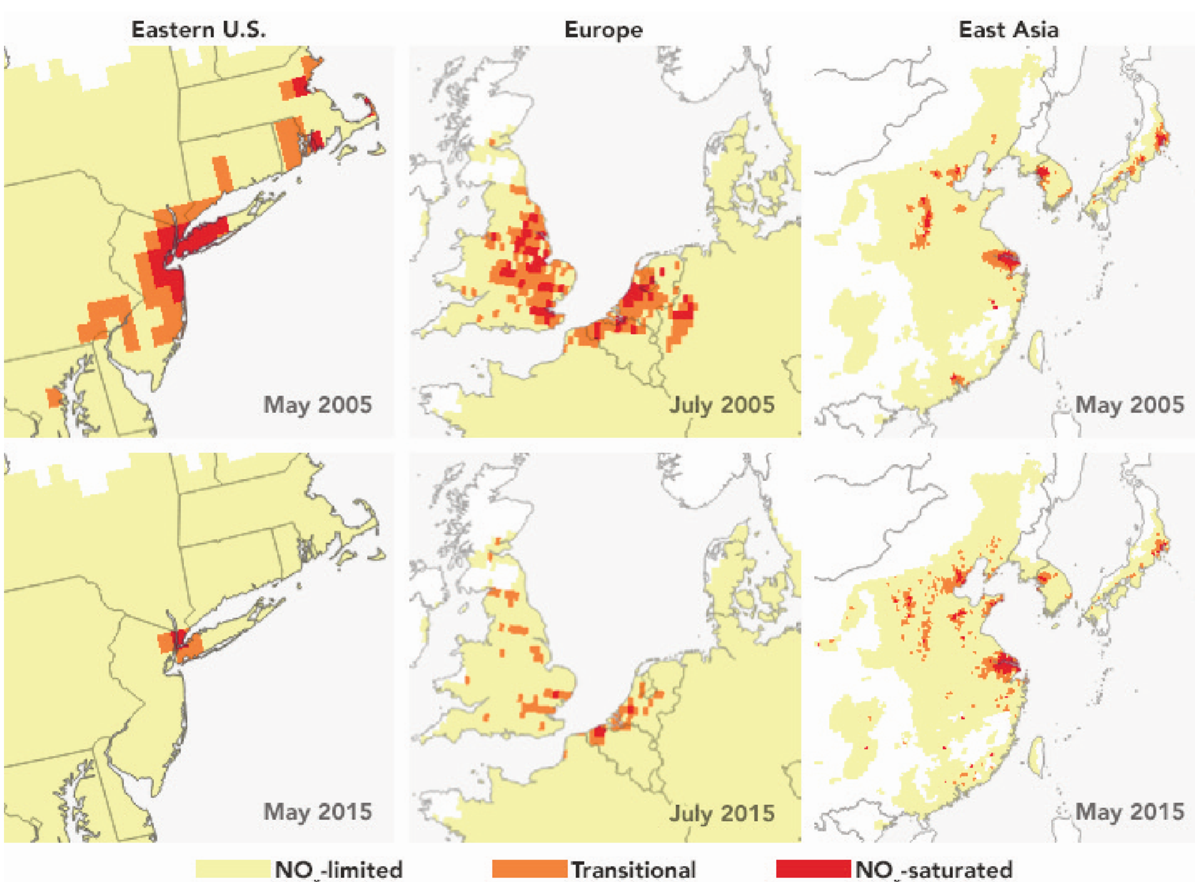

Figure 3. Maps show classifications for each region as NOx-limited, transitional, or NOx-saturated (VOC-limited) based on satellite column HCHO-to-NO_2 ratios, for Eastern United States, parts of Europe, and East Asia in 2005 and 2015.

Image Credit: NASA Earth Observatory image by Joshua Stevens, using data from Jin et al. (2017).[7]

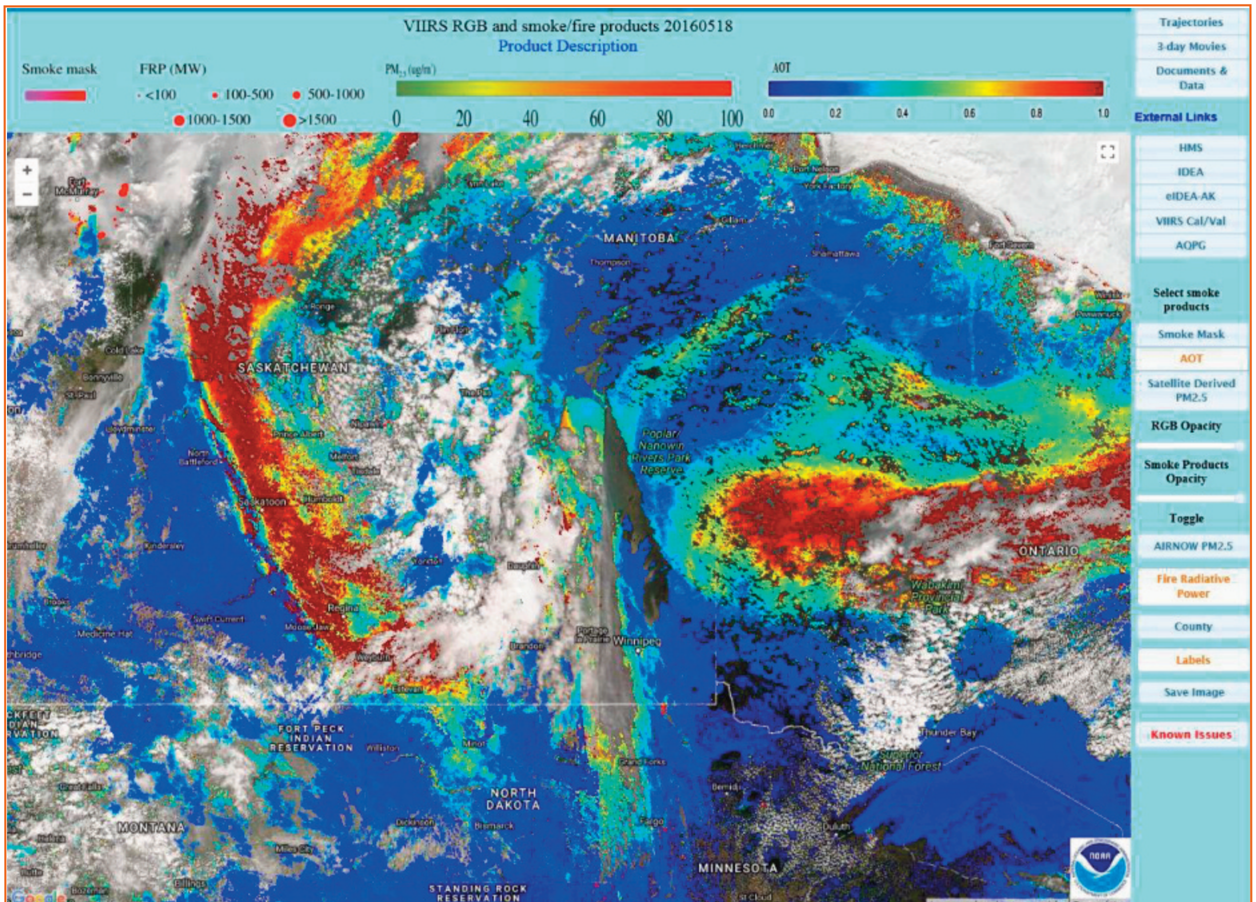

Figure 4. Screenshot of the interface for retrieving satellite data from **eIDEA**, a NASA–EPA–NOAA partnership. Satellite images of aerosol optical thickness (AOT, another term for AOD) of the wildfires at Fort McMurray, Alberta, Canada from May 25–26, 2016.
Reproduced from report: Geigert, M. (2018).[15]

model are evaluated, modeled NO_2 is typically compared with ground-based observations. Compared to sparse ground-based monitoring, satellite products are available in unmonitored areas, including over water and desert, although observations cannot be retrieved during cloudy conditions.

While satellite data can provide broad spatial distributions for evaluation of regional air quality models, several steps are needed to convert the quantities retrieved from spaceborne instruments and simulated by models for a quantitative comparison. This document (https://academiccommons.columbia.edu/doi/10.7916/d8-cfwm-5x30), "Comparison of CMAQ Simulation to Satellite Observations: NO_2 Column versus OMI NO_2," describes a procedure for comparing tropospheric NO_2 columns simulated by the CMAQ model to those retrieved from the OMI satellite, with an example application in the Great Lakes Region.[10] Specifically, the authors use the Wisconsin Horizontal Interpolation Program for Satellites (WHIPS), which is an open-source program that allows the user to map satellite data onto a more usable gridded format.[11]

Burning Questions on Exceptional Events

Satellite data have been used to support "exceptional events" demonstrations, which make the case for excluding non-c ontrollable high pollution events, such as those caused by wildfires, from counting toward nonattainment if the event strongly influences whether an area will be in violation of a NAAQS. Exceptional events refer to high-pollution events resulting from "unusual or naturally occurring events that are not reasonably controllable" that impact the air quality standard attainment status (designations or reclassification) of a region. This is further described in EPA's Exceptional Events Rule in Title 40 of the Code of Federal Regulations Part 50.[12] The EPA guidance on exceptional event demonstrations for wildfires, prescribed fires, and stratospheric intrusions specifically include analyses of satellite products.[12-14] Wildfires, for example, are the most common cause for pursuing an xceptional event demonstration for $PM_{2.5}$ and O_3.

Many elements go into technical support documents for an exceptional event demonstration. This technical guidance document (https://academiccommons.columbia.edu/catalog/ac:w0vt4b8gxt), "Guide to Using Satellite Images in Support of Exceptional Event Demonstrations," provides information regarding satellite images and data that can be used to support weight-of-evidence arguments, alongside analysis of ground-monitoring data and models.[15] Examples shown in this document played a role in the successful demonstration by the State of Connecticut to exclude O_3 data from May 25–26, 2016, at several of its monitors because of the transport of pollutants from wildfires at Fort McMurray, Alberta, Canada. A screenshot of the satellite data interface for obtaining this information is reproduced in Figure 4. This report[15] describes how satellite data can be used to track fires, smoke plumes, and aerosol optical depth (AOD). AOD is a measure of light attenuation in the atmospheric column due to the presence of aerosols and contains information relevant for mapping spatial and temporal variations in $PM_{2.5}$.

Have Air Quality Managers Successfully Used Satellite Data in Submitted SIPs and Exceptional Event Demonstrations?

Yes. The technical guidance documents highlighted above were developed in close concert with air quality experts at a number of state agencies, including the Texas Commission on Environmental Quality (TCEQ) and the Connecticut Department of Energy and Environmental Protection (DEEP), who used satellite data in SIPs as discussed in more detail in the above-mentioned reports,[5,9] which are all available on the NASA Air Quality from Space website.[1] Field-tested examples used by Connecticut DEEP in an exceptional event demonstration are also available.[15] Together, this collection of reports describes a few ways in which satellite data can be applied as one component of an overall weight-of-evidence approach, alongside measurements from ground monitors and data from other platforms and modelling products, as part of the NAAQS process.

If you are interested in using satellite data for state implementation plans, other topics, or have further questions, more information is available via NASA HAQAST at www.haqast.org. **em**

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