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Review

Satellite data of atmospheric pollution for U.S. air quality applications: Examples of applications, summary of data end-user resources, answers to FAQs, and common mistakes to avoid

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HIGHLIGHTS

- Review of the primary uses of satellite data for air quality applications.
- Background information on satellite capabilities for measuring pollutants.
- Summary of the resources available to data end-users.
- Answers provided to common questions in plain language.

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ABSTRACT

Satellite data of atmospheric pollutants are becoming more widely used in the decision-making and environmental management activities of public, private sector and non-profit organizations. They are employed for estimating emissions, tracking pollutant plumes, supporting air quality forecasting activities, providing evidence for "exceptional event" declarations, monitoring regional long-term trends, and evaluating air quality model output. However, many air quality managers are not taking full advantage of the data for these applications nor has the full potential of satellite data for air quality applications been realized. A key barrier is the inherent difficulties associated with accessing, processing, and properly interpreting observational data. A degree of technical skill is required on the part of the data end-user, which is often problematic for air quality agencies with limited resources. Therefore, we 1) review the primary uses of satellite data for air quality applications, 2) provide some background information on

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End-user resources
Remote sensing

satellite capabilities for measuring pollutants, 3) discuss the many resources available to the end-user for accessing, processing, and visualizing the data, and 4) provide answers to common questions in plain language.

1. Introduction

There is now a wealth of atmospheric composition satellite data for air quality (AQ) applications that has proven valuable to environmental professionals: nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ammonia (NH_3), carbon monoxide (CO), some volatile organic compounds (VOCs), and aerosol optical depth (AOD), from which surface particulate matter ($PM_{2.5}$) may be inferred. The data are primarily collected by instruments on satellites operated by the National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA). A barrier to using these data is the inherent difficulties associated with accessing, processing, and properly interpreting them. A degree of technical skill is required on the part of the data end-user, which is often problematic for organizations with limited resources. Therefore, the purpose of this review article is to inform data end-users of 1) how data are being used by the environmental community for U.S. AQ applications (Sections 2 and 3), 2) what free resources are available for accessing and processing the data (Section 4), and 3) straight answers in plain language to frequently-asked questions, including common mistakes to avoid when working with data (Section 5). Our intended audience is AQ managers and other environmental professionals, particularly those who do not currently use satellite data for their AQ applications, but wish to, or do so sparingly.

There are other informative review articles on various aspects of the use of satellite data for AQ applications that will provide additional information to the uninitiated end-user. Examples are Fishman et al. (2008) on the current capabilities of satellite instruments to measure pollutants and Streets et al. (2013) on the use of satellite data for estimating surface emissions of pollutants. The National Science and Technology Council (NSTC) provides an overview of satellite observations relevant to AQ applications (NSTC, 2013). The instructive review articles of Martin (2008) and Hoff and Christopher (2009) are more technical in their discussions and, therefore, more appropriate for the intermediate and advanced satellite data end-user. Ichoku et al. (2012) provide a comprehensive, but technical, overview of using satellite data to characterize various properties of wildfires, such as emission strength and plume rise.

In this review, we focus on satellite data that provide information on the distributions of pollutants and pollutant emissions. We do not discuss the many ways that meteorological satellite data are used in AQ applications. We refer the reader to Table 1 of Streets et al. (2013) and Table 1 of Kahn (2012) for lists of the main satellite gas and aerosol products relevant for AQ applications. The reader should refer to Table 1 for a list of acronyms that are frequently used in this article.

2. Current satellite data applications in the U.S.

The U.S. Environmental Protection Agency (EPA) and many state AQ agencies recognize the utility of satellite data and some of them are actively considering how they can be further used for monitoring and regulatory purposes. We identified four main categories of current applications (i.e., tracking pollutant plumes, support for AQ forecasting, evidence in exceptional event demonstrations, and input to AQ models and data for model evaluation) and two main categories of potential applications (i.e., estimating ozone precursor and aerosols emissions, and monitoring regional long-term trends in ozone precursors and aerosols), all of which take advantage of the primary strength that satellite data have over the conventional ground-based monitoring networks – spatial coverage (e.g., Fig. 1). The four main categories of current applications are discussed in this section and the two main categories of potential applications are discussed in Section 3.

2.1. Tracking pollutant plumes

Over the last decade, satellite data have been used widely to track pollution from agricultural and wild fires. For example, Fig. 2 shows AOD data from the Visible Infrared Imager Radiometer Suite (VIIRS) instrument on the Suomi National Polar-orbiting Partnership (NPP) satellite and illustrates the long-range transport of

Table 1
Frequently used acronyms and terms.

Acronym/name	Phrase/description
AQAST	NASA *Air Quality Applied Sciences Team*; http://acmg.seas.harvard.edu/aqast/
ARSET	NASA *Applied Remote SEnsing Training*; http://arset.gsfc.nasa.gov/
Chemical species	
AOD	*Aerosol Optical Depth*, also referred to as Aerosol Optical Thickness (AOT) – the degree to which aerosols prevent the transmission of light by absorption or scattering of light through the entire vertical column of the atmosphere from the ground to the satellite's sensor
NO_x	*Nitrogen Oxides*, the sum of NO and NO_2
PM, $PM_{2.5}$	*Particulate Matter*, <2.5 μm in aerodynamic diameter
SO_2	*Sulfur Dioxide*
VOCs	*Volatile Organic Compounds*
Agencies	
EPA	*Environmental Protection Agency*
ESA	*European Space Agency*
EUMETSAT	*European Organisation for the Exploitation of Meteorological Satellites*
NASA	*National Aeronautics and Space Administration*
NOAA	*National Oceanic and Atmospheric Administration*
Instruments	
AIRS	NASA Aqua *Atmospheric Infrared Sounder*
GASP	*GOES East Aerosol/Smoke Product* on the NOAA GOES East satellite
GOES	NOAA *Geostationary Operational Environmental Satellite*
GOME-2	*Global Ozone Monitoring Experiment-2* on the EUMETSAT Metop-A satellite
MISR	NASA Terra *Multi-angle Imaging SpectroRadiometer*
MOPITT	NASA Terra *Measurements of Pollution in the Troposphere*
MODIS	*Moderate Resolution Imaging Spectroradiometer* on the NASA Terra and Aqua satellites
OMI	NASA Aura *Ozone Monitoring Instrument*
TEMPO	*Nasa Tropospheric Emissions: Monitoring of Pollution*
VIIRS	*Visible Infrared Imager Radiometer Suite* instrument on the Suomi National Polar-orbiting Partnership (NPP) satellite
Other	
AQ	*Air Quality*
AQS	EPA *Air Quality System* of monitoring stations
NAAQS	EPA *National Ambient Air Quality Standards*
VCD	*Vertical Column Density* – the number of molecules of an atmospheric gas between the satellite instrument and the Earth's surface per area of the Earth's surface