Using Satellite Data for Air Quality and Health Applications

Vital Strategies

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Key Characteristics of Satellite Data

- Critical source of spatially resolved publicly available data since the 1990s
- Routinely used to characterize exposures for estimates of global burden of disease from air pollution
- Provide estimates of regional and local air quality estimates in the absence of data from ground monitoring

Innovations in monitoring technology, remote sensing and modelling can provide actionable air pollution data more rapidly and at lower cost than solely relying on conventional monitoring approaches. Satellites orbiting around Earth have been capturing global air quality data for more than two decades and have become critical source of global air quality trends. Satellites "see" the atmospheric column that is converted to surface estimates using mathematical models. **These satellite-derived estimates can fill data gaps for regions with little or no ground monitoring.**

Integrated Air Quality Monitoring System

For low- and middle-income countries with limited monitoring capacity, there is no one solution for air quality management. Instead, a hybrid approach that combines conventional solutions with innovative approaches at different scales is more cost effective (Figure 1). Depending on the existing monitoring capacity, satellite data can be used to inform different air quality questions. For regions with no ground monitoring, satellite data can help identify areas that likely have pollutant concentrations well above health action levels[1]. In countries with sufficient ground monitoring capacity, satellite data can be part of an integrated air quality management framework to inform long-term spatiotemporal trends. This brief lays out the basics of satellite data along with some use cases for air quality and health applications.

1 Vital Strategies 2020, Accelerating City Progress on Clean Air, Technical Guide.

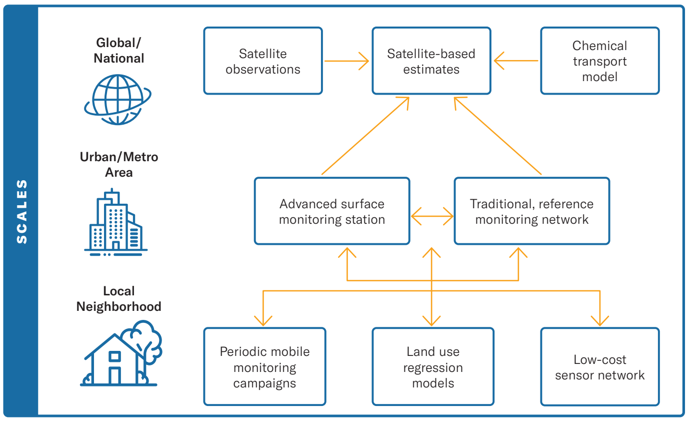

Figure 1 Integrated air quality monitoring system

Air Pollution Related Disease in Cities

Many cities lack ground monitoring data needed to track air pollutants that impact public health. Burden of disease calculations use satellite-derived estimates to fill the critical gaps in exposure data over space and time. Annual averages concentrations are calculated across the entire globe at 1x1 km grid resolution and linked to population size to estimate how many people are exposed. The population level exposures are then linked to underlying disease rates in cities and countries to estimate the disease burden of air pollution. Most recent estimates include global burden of disease from $PM_{2.5}$ and NO_2[2]

Satellites and Sensors

Satellites are platforms on which instruments or sensors are placed. One satellite may have multiple sensors on board, and the same sensor can be on board multiple satellites. Each sensor can capture information on multiple parameters. For example, the MODIS[3] sensor is on board both Aqua and Terra satellites and is a critical source of global $PM_{2.5}$ estimates. TROPOMI, short for Tropospheric Monitoring Instrument, is on board Sentinel 5 - Precursor satellite and measures gases like Ozone, NO_2, SO_2, CO, and aerosols like dust, smoke and black carbon. $PM_{2.5}$ and NO_2 are the most widely

2 Health Effects Institute 2022. Air Quality and Health In Cities: A State of Global Air Report.
3 MODerate resolution Imaging Spectro-radiometer

used satellite data products for air quality and health applications.

How do satellites measure pollutants?
Each constituent of earth's atmosphere - particles, aerosols, gases have their own spectral signature i.e., the amount of electromagnetic radiation they can absorb, scatter and reflect. Sensors like MODIS and TROPOMI are designed to capture this information which is then converted to geophysical characteristics using mathematical models and computer algorithms.

Satellites vs Ground Monitors
An important distinction between data from satellites and ground monitors is the quantity they measure. While ground monitors measure surface concentrations, satellites capture information in a vertical atmospheric column (Figure 2). These column measurements are then converted to surface estimates using statistical models or full meteorology-chemical transport models to provide spatially resolved estimates of air quality. The raw satellite data undergoes several processing and validation steps before it is publicly released for practical applications. Ground measurements are used to improve satellite-based estimates where feasible. Gridded data sometimes known as Level 3 data[4] in the form of daily estimates and monthly averages are most commonly used for large studies. Non-gridded native or level 2 data are more suitable for advanced users and is available within a day or two of measurements.

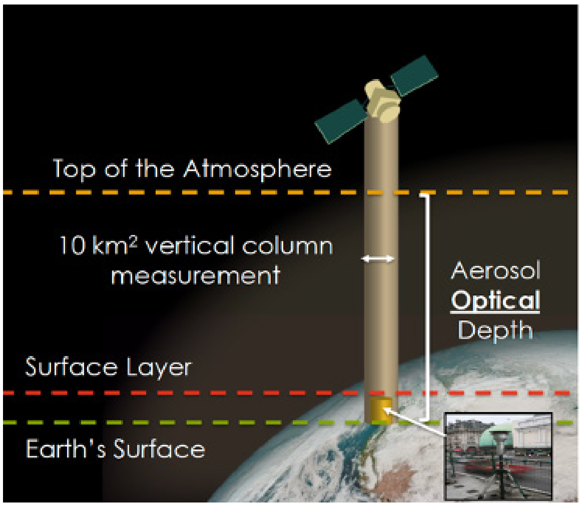

Figure 2 Satellite vs ground-based measurements [5]

$PM_{2.5}$ Measurements
Satellites do not measure $PM_{2.5}$ directly. Rather, they measure Aerosol Optical Depth or AOD, which can be considered a proxy for $PM_{2.5}$. AOD is a unitless quantity that represents the amount of aerosols in a column of the atmosphere. Satellite AOD data is extensively used to determine $PM_{2.5}$ concentrations (Figure 3).

NO_2 Measurements
Satellites are now able to also capture spatial patterns in NO_2 at high resolution, at fine enough resolution to estimate concentrations in major cities and from individual sources like power plants and industries. Long term trends are available from OMI[6] and TROPOMI measurements of columnar NO_2.

Spatial and Temporal Resolution
Depending on the satellite technology and retrieval algorithm, spatial resolution can vary from anywhere between 1km to ~100 km grids. For example, level 2 MODIS AOD data are available at 1km, 3 km and 10 km-grid resolutions while the gridded level 3 data is available at a coarser resolution of ~110 km-grid. The 1 km product has relatively high spatial resolution but more instrument "noise", while the 10 km product has less instrument "noise", but is at coarser spatial resolution.

Temporal resolution largely depends on the orbit that satellites follow. There are two broad types - one that have sun-synchronous polar orbits - so they "see" the same place on earth once or twice a day at the same time which translates to one or two measurements per day. For example - MODIS sensors aboard the Aqua and Terra satellites make daily morning and afternoon measurements respectively. The second type of satellite stays stationary relative to the earth and can observe data with higher temporal coverage of a selected region - also called geostationary satellites.

Other Measurements
Beyond aerosols and gases, true color images and temperature measurements from satellites can help identify extreme pollution episodes like crop burning and wildfires by detecting smoke and temperature anomalies. (Table 1).

4 NASA nomenclature

5 NASA's Applied Remote Sensing Training Program
6 Ozone Monitoring Instrument

Satellite Data for Air Quality and Health

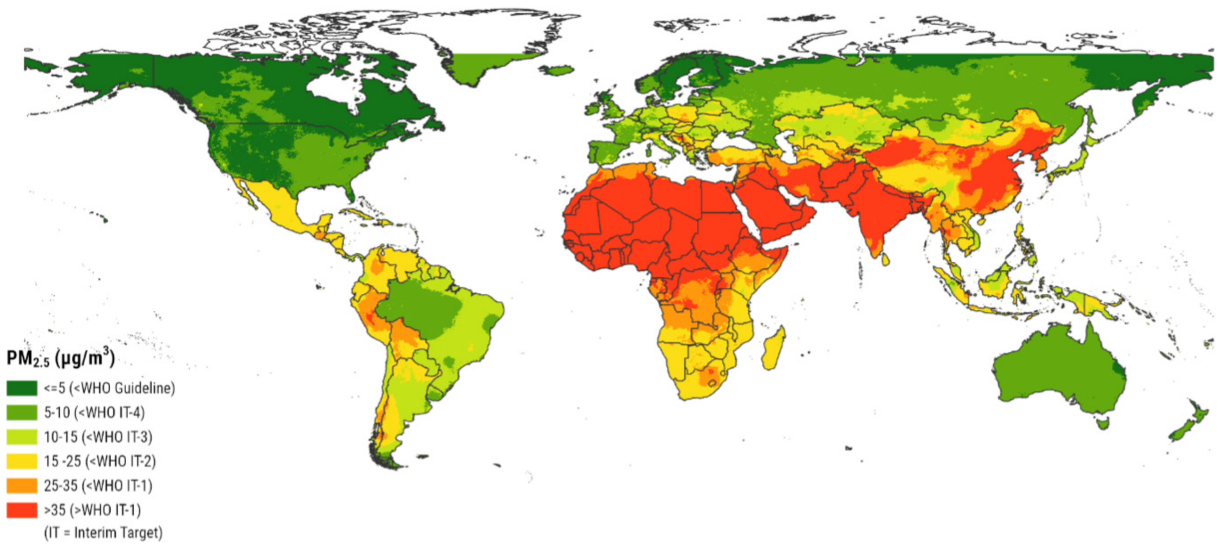

Figure 3 Annual average ambient $PM_{2.5}$ concentrations in 2019 relative to WHO Air Quality Guideline. The $PM_{2.5}$ estimates are generated by combining, satellite data, mathematical models and ground-based measurements. Source: Health Effects Institute 2022.

Satellite Data for Health Studies

The upcoming MAIA[7] mission is the first NASA mission designed specifically for public health analysis. The MAIA sensors are designed to distinguish between different types of particles and will collect daily data over a set of primary target areas including the world's major cities. These data will be used to support future health studies on relative toxicity of different particulate matter components.

Getting Started

As the technology evolves, the inventory of instruments and hence the data available is continuously growing. While the datasets are publicly available, analyzing and interpreting this data requires specialized technical skills. Cities wanting to integrate satellite data in their air quality management plan may consider investing in training and capacity building or work with technical partners with this capability. Below are some links to publicly available training resources and datasets.

Training Resources

NASA ARSET Training The Applied Remote SEnsing Training (ARSET) program offers free webinars and in-person training on the use of NASA satellite data for various applications. Information on future training as well as recordings and materials from past webinars can be found on their website.

NASA HAQAST NASA Health and Air Quality Applied Science (HAQAST) is working towards practical applications of remote sensing data by air quality and health professionals. They have documented various resources for accessing and analyzing satellite data along with helpful tutorials and use cases.

Data Sources

NASA Giovanni Allows users to interactively analyze satellite data online - users can select geography, satellites and parameters of interest, create maps and plots in different formats.

NASA Data pathfinder Designed to help guide users through the process of selecting and using datasets applicable to health and air quality, with guidance on resolutions and direct links to the data sources.

Google Earth Engine is freely available for research and academic use and has data from Sentinel, Landsat satellites and MODIS sensor. Using available APIs data can be analyzed on cloud without the need to download data to a local computer.

Urban AQ This website combines satellite data with surface estimates and mathematical models to provide estimates of $PM_{2.5}$, NO_2 and ozone concentrations for >13,000 urban areas globally. Users can visualize and download data by pollutant, year, country and city.

National/Regional data sources

The resources listed here are not meant to be exhaustive. Check with local agencies for regional or national datasets that may be available upon request.

7 Multi-Angle Imager for Aerosols

Satellite Data for Air Quality and Health

Application	Question To Be Asked	Example	Region	Source
Air Quality Trends	Are some place becoming more or less polluted?	Analysis of AOD data over 18 years revealed that frequency of extreme pollution days in the Indo-gangetic basin increased from 5-15% to 20-30% between 2001 to 2018.	India	Dey et al. 2022
Air Quality Regulation	Where is most pollution coming from?	Isolated NO_2 emission from a cluster of three closely spaced regulated sites in urban area using TROPOMI data.	UK	Potts et al. 2021
	Where to place new regulatory monitors?	Satellite data is informing placement of new NH_3 monitors, an important precursor of $PM_{2.5}$.	US	Puchalski et al. 2019
Policy Evaluation	How effective is a pollution mitigation policy?	Data from OMI and TROPOMI were used to compare NO_2 concentrations over Madrid, from before and after implementation of a transportation emission reduction policy.	Spain	Anenberg et al. 2020
Extreme Pollution Events	How is air pollution moving spatially?	Seasonal haze from land/forest fires for the purpose of clearing vegetation is a recurring problem in the south-east Asian region. Satellite data is used to issue warnings for transboundary haze movements.	SE Asia	ASMC
	How is the air quality changing due to wildfires?	Data from multiple satellites are used to estimate location of wildfires, movement of smoke plumes and changes in particle concentrations.	US	Holloway et al. 2021
Exposure Assessment	Which parts of the world are exposed to hazardous levels of $PM_{2.5}$?	AOD data from VIIRS and MODIS were combined with aerosol vertical profiles from the GEOS-Chem global chemical transport model to estimate long term global $PM_{2.5}$ concentrations.	Global	Van Donkelaar et al. 2010
Health Impact Assessments	What is the projected health impact of an emission reduction policy?	<10 km resolution satellite data were combined with mathematical models to estimate how many global deaths would be avoided by removal of national emissions from use of cookstove fuel.	Global	Lacey et al. 2017
Epidemiological Studies	What is the burden of disease in a given population due to air pollution?	Exposure estimates derived by van Donkelaar et al. were used to estimate global pre-mature deaths associated with long term exposure to $PM_{2.5}$.	Global	Evans et al. 2012
		Combined satellite and ground-level NO_2 data to determine proportion of pediatric asthma cases attributable to NO_2. While this proportion declined in high-income countries between 2000 and 2019, it increased in the rest of the world.	Global	Anenberg et al. 2022

Table 1 Applications of satellite data for Air Quality Management and Health

1. Anenberg, Susan C., et al. "Long-term trends in urban NO2 concentrations and associated paediatric asthma incidence: estimates from global datasets." The Lancet Planetary Health 6.1 (2022): e49-e58.3.
2. Anenberg, Susan C., et al. "Using satellites to track indicators of global air pollution and climate change impacts: Lessons learned from a NASA-supported science-stakeholder collaborative." GeoHealth 4.7 (2020): e2020GH000270.
3. ASEAN Specialized Meterological Center. Available from: http://asmc.asean.org/asmc-about/
4. Dey, Sagnik, and Sourangsu Chowdhury. "Air quality management in India using satellite data." Asian Atmospheric Pollution. Elsevier, 2022. 239-254.
5. Evans, Jessica, et al. "Estimates of global mortality attributable to particulate air pollution using satellite imagery." Environmental research 120 (2013): 33-42.
6. Health Effects Institute. 2022. How Does Your Air Measure Up Against the WHO Air Quality Guidelines? A State of Global Air Special Analysis. Boston, MA: Health Effects Institute.
7. Holloway, Tracey, et al. "Satellite monitoring for air quality and health." Annual Review of Biomedical Data Science 4 (2021): 417-447.
8. Lacey, Forrest G., et al. "Transient climate and ambient health impacts due to national solid fuel cookstove emissions." Proceedings of the National Academy of Sciences 114.6 (2017): 1269-1274.
9. Potts, Daniel A., et al. "Satellite data applications for site-specific air quality regulation in the UK: Pilot study and prospects." Atmosphere 12.12 (2021): 1659.
10. Puchalski, M. A., et al. "Need for improved monitoring of spatial and temporal trends of reduced nitrogen." EM, July (2019).
11. Van Donkelaar, Aaron, et al. "Global estimates of ambient fine particulate matter concentrations from satellite-based aerosol optical depth: development and application." Environmental health perspectives 118.6 (2010): 847-855.