Virtual Workshop Summary

Health Applications for Satellite-Derived Air Quality: Opportunities and Potential Pitfalls

April and May 2022

Co-chairs: Jeff Brook and Heather Holmes, HEI Research Committee

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Background

As satellite remote sensing products for air quality become more widespread, with increased spatial and temporal coverage, the range of their applications in public health — including epidemiological studies and burden assessment — has grown. For example, satellite-based long-term average $PM_{2.5}$ estimates are used by the Institute for Health Metrics and Evaluation's (IHME's) Global Burden of Disease program, helping to inform the need for air quality policy worldwide. Additionally, new satellite instruments are being launched to monitor air quality at higher spatial and temporal resolution and for a wider array of pollutants than have previously been available. Given the emerging satellite technologies and maturing satellite remote sensing products for assessing air quality around the world, HEI held a workshop to consider greater focus on this research area. The goals of the workshop were to identify opportunities for health application research using new and expected satellite remote sensing-based products and to identify potential pitfalls to avoid. The focus was on research questions related to the use of satellites for assessing air quality generally without emphasis on any specific technology and to identify gaps where research is needed to improve quality and credibility of the underlying data in the United States and globally. The workshop was held over four webinar sessions in April and May 2022 and was free and open to the general public.

Why Satellite Data?

- Data products are increasingly accessible and used in air quality and health applications
- Data providers are enthusiastic about developing data and tools with end users in mind
- Work can build on HEI's experience with large-scale epidemiological studies (e.g., health effects of low levels of air pollution) and burden assessment (e.g., Global Burden of Disease)

Workshop Agenda

Setting the stage for trusted, high-quality satellite remote sensing data of air quality in health applications

Wednesday April 20, 2022, 10:00 AM to 12:00 PM EDT

Global applications of satellite-derived air quality data

Friday April 29, 2022, 9:00 AM to 11:00 AM EDT

Pushing the methodological limits on satellite use in health applications

Thursday May 5, 2022, 1:00 PM to 3:00 PM EDT

Roundtable discussion on the future of satellite remote sensing of air quality in health applications

Wednesday May 18, 2022, 10:00 AM to 11:30 AM EDT

For the full program, speaker bios, slides, recordings, and additional resources please visit: https://tinyurl.com/HEISatelliteWorkshop.

Setting the Stage

Presenters in Session 1 introduced satellite remote sensing (see **Figure 1**), gave a detailed description of how satellite data have been used for exposure assessment, broadly and in a recent epidemiological study in the United States, and described how capacity is being built for applications of satellite data in many fields. The speakers shared resources for accessing data products from space agencies around the world and user-friendly data visualization tools (see additional resources on the workshop webpage). They also directed workshop attendees to guides and trainings for new users that are hosted by the United States National Aeronautics and Space Administration (NASA) Applied Remote Sensing Training (ARSET) and NASA Health and Air Quality Applied Sciences Team (HAQAST). The presenters explained how the diverse needs of the audience inform how satellite products are combined with multiple complementary datasets in the development of exposure estimates and what spatial and temporal resolutions are needed. Hotpot and baking metaphors were used to highlight the need for thoughtful consideration of inputs from many disciplines to prepare recipes that are appropriate for a specific exposure assessment or epidemiological application. They concluded that satellite-derived air quality and health is a growing field where flexible toolboxes, creative users, and relevant science questions will be needed to move the field forward. The connection between satellite data products and health applications will continue to grow with the NASA Multi-Angle Imager for Aerosols (MAIA) mission — the first satellite mission designed with health applications in mind — and in other ongoing and future missions by NASA and other space agencies.

Workshop Guiding Questions

- What opportunities do satellite-based products bring for advancing knowledge on air quality and health, and what are the challenges?
- What is coming in the future from satellite observations, and how can they help address these challenges?
- How well do we appreciate the limitations of the satellite products, and how do we interpret those in the context of health impacts and burden estimates?
- How far can we take satellite products?

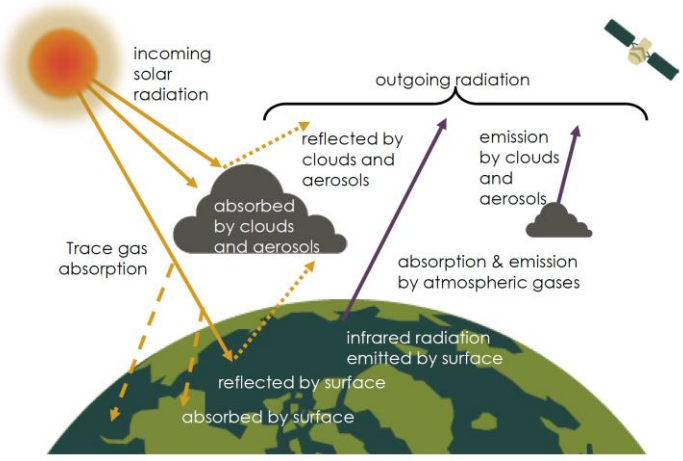

Figure 1. *Overview of how satellites measure levels of pollutants in the air between Earth's surface and the radiation detectors. Satellites detect the outgoing radiation across a wide range of wavelengths. Through the application of multiple physics-based models, users infer trace gas and aerosol concentrations in a vertical column. Additional models help to estimate surface concentrations. Most satellites produce several readings per day that can offer regional to global snapshots, particularly as multiple days are averaged together. Source: NASA ARSET Training Program.*

Global applications

Session 2 explored ways in which the potential of satellite-derived remote sensing of air quality is beginning to be realized around the world. The first presentation provided an overview of how satellite, ground, and model-based data are combined to enhance the value of information on air pollution from specific industry sectors and sources. The next presentation explored exposure assessment and health burden assessment, with a specific example of wildfire smoke. Examples of how satellite-derived air quality products are being used in three countries for air quality management, health impact studies, and constraining emissions were then provided.

- In India, satellite-derived $PM_{2.5}$ products are being used for air quality management and health impact studies.
- In Colombia, biomass burning contributes substantially to ambient particulate matter, but mainly in locations far from monitoring stations. Satellite-derived air quality data are being used to explore the health burden from $PM_{2.5}$.
- In South Africa, data on emissions and on pollutants other than $PM_{2.5}$ are scarce; satellite data help to constrain emissions and measure trace gases, particularly NO_2.

Presenters discussed the value of open and consistent data in informing the siting of ground-based monitors, tracking air quality trends, and contributing to better exposure estimates. They noted that the best information available should be used to inform good policy and that some of their analyses were possible only because satellite data were available. Developing research questions and tools that center local priorities, strengthening local technical expertise, and collaborating and engaging with scientists in different regions were highlighted as important aspects of using satellite remote sensing data in global health studies.

Pushing the methodological limits

Session 3 delved into methodological issues related to the use of satellite data in health applications. The session started by noting that air pollution observed from space reflects real-time changes in emissions and has high correlations with measurements made by ground monitors. Complementary information is provided by different sources of air pollution data, with satellites adding to but not replacing the information that can be obtained from models, high-quality ground-based monitors, and low-cost sensors. Advances in geostationary instruments were demonstrated with the presentation of data from the Geostationary Environment Monitoring Spectrometer (GEMS, from the Korean National Institute of Environmental Research [NIER]), the first geostationary satellite in a constellation that will cover the northern hemisphere. The constellation will eventually be completed with the launches of SENTINEL-4 (from the European Space Agency as part of the European Earth Observation Programme, which is known as Copernicus) and the Tropospheric Emissions: Monitoring Pollution instrument (TEMPO, from NASA) (**Figure 2**). After having focused mostly on large-scale applications (e.g., using data from the TROPOspheric Monitoring Instrument [TROPOMI]), the presentations concluded with a look at the ability to apply satellite-derived air quality data to questions related to exposure and health inequities within a city and to inform decision-making related to air pollution health disparities.

Presenters discussed challenges associated with using satellite data in new applications for which they were not designed. They discussed how the most-used satellite air pollution products are those where column measurements best represent surface concentrations (e.g., NO_2). Products where column measurements are less correlated with surface concentrations (e.g., O_3) or there is less ground monitoring for validation

(e.g., volatile organic compounds in many locations) are more difficult to retrieve and apply with confidence. Uncertainty in the measurements varies, with lower uncertainty in locations where the satellite observations are supported by detailed field studies and the averaging time of observations increases. Potential barriers to new users were related to the logistics of computational power and storage space for the vast amount of data being generated, disciplinary differences in standard file formats and units, and selection of the appropriate product (among several) from the most-relevant source for the question(s) in mind.

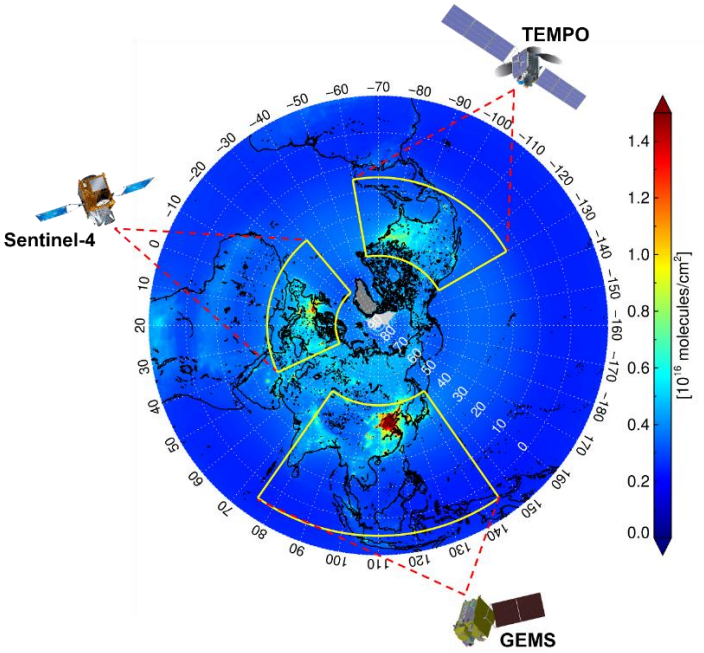

Figure 2. *Diagram of spatial coverage of GEMS and the upcoming SENTINEL-4 and TEMPO instruments. Source: Kim J et al, Bulletin of the American Meteorological Society, 2020. © American Meteorological Society. Used with permission.*[1]

Even with those challenges, the presenters emphasized that much work can be done now and discussed the following ideas:

- Questions about where air pollution is highest and which populations the hot spots affect, which locations or sources can be targeted for emissions controls, and where ground monitors should be sited can all be addressed using current satellite products and tools.
- Satellite products provide information where other sources are missing, for example, in the many cities and rural areas with no ground monitors.
- More complete understanding of known biases in satellite-derived air quality products and their effects on the results of health studies would be valuable. For example, ground monitors measure some of the highest emissions and concentrations of air pollutants for pixels covered by clouds, but those observations are typically removed by quality assurance filters and filled with spatially and temporally interpolated values. Another example of bias is that TROPOMI air quality products have

[1] Kim J, Jeong U, Ahn M-H, Kim JH, Park RJ, Lee H, et al. 2020. New Era of Air Quality Monitoring from Space: Geostationary Environment Monitoring Spectrometer (GEMS). Bulletin of the American Meteorological Society 101:E1–E22; doi:10.1175/BAMS-D-18-0013.1.

been reported to underestimate ground and aircraft measurements in urban areas. However, retrieval algorithms and interpolation methods are continually being improved, and the existing algorithms might underestimate rather than overestimate many of the spatial differences in air quality.
- The presenters recommended a continued interdisciplinary approach to progress, supported by resources being built out by NASA and other organizations.

Future of satellite remote sensing of air quality in health applications

In Session 4, panelists in a roundtable discussion summarized and synthesized the main research needs identified in the earlier sessions to make the best possible use of opportunities to apply air quality information from satellites in trusted, high-quality health research. The panelists identified several key strengths of satellite-derived air quality products, including large spatial coverage over long periods, which can be especially important where ground monitors are scarce. They also noted several limitations, including challenges with data assimilation (e.g., interpreting surface concentrations obtained from column measurements and accounting for missing data) and the need for more easily accessible data repositories and file formats for intended end users. Overall, they discussed that there are huge opportunities for new and creative uses for satellite-derived air quality and gave several specific recommendations:

- Data users should read the peer-reviewed publications and documentation to be informed, then discuss their needs with data providers.
- Potential users should communicate with data providers to help motivate and shape the direction of product development in this growing field.
- Caveats are normal in any new and growing field, and limitations need to be carefully characterized, but that does not negate the value and quality of the satellite products; much can be done with the data we have now.

Workshop outcomes and next steps

The workshop provided an interdisciplinary exchange of ideas on the current and future capabilities of satellite remote sensing for air quality, exposure assessment, and health applications. The full program, speaker bios, slides, recordings, and additional resources are all available on the workshop webpage at https://tinyurl.com/HEISatelliteWorkshop.

HEI's next step will be to work with its Research Committee to decide how the institute can best contribute to work in this area. We are continuing our internal discussion on how best to disseminate the information shared during the workshop, engage with the satellite air quality community, and possibly fund research on health applications of satellite-derived air quality data.

Questions or suggestions? Email Dr. Allison Patton at appatton@healtheffects.org or contact us at info@healtheffects.org.

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