Features

New generation of satellites will shed light on respiratory disease

From industrial and urban air pollution and wildfire smoke to volcanic eruptions, dust storms, and even pollen, data from Earth-observing satellites are helping environmental epidemiologists to study respiratory disease and other public health problems worldwide. A new generation of satellites specifically designed for public health research will be operational by the early 2020s, bolstering and accelerating such research, according to officials from the US National Aeronautics and Space Administration (NASA), and researchers contacted by *The Lancet Respiratory Medicine*.

Globally, ground-level air quality monitoring is patchy and especially sparse in lower-income countries. Africa and the Middle East are nearly devoid of air-monitoring stations.

Satellites provide an "unprecedented ability to assess health impacts from air pollution throughout the world and to assess trends over time", said Michael Brauer (University of British Columbia, Vancouver, BC, Canada). "From the use of satellite data in health-effects research; globally, they have been essential for the Global Burden of Disease [Programme] and also in North America, as it allows us to expand our studies to include rural populations."

Satellites have been "extremely important" in tracking dust storms and forest fire smoke as it moves over large areas, he explained. They also offer standardised measurements across jurisdictions where ground-based air measurement techniques can vary. However, unlike ground monitors, which directly measure pollutants, satellite instruments infer pollutants using optical reflectance data from the visible-light, ultraviolet, and infrared spectra.

Remote sensing has been "key" in providing insight into volcanic and dust storm events, said Dale W Griffin (US Geological Survey, St Petersburg, FL, USA), who has helped study the long-distance transportation and public health implications of dust from the Sahara Desert. "It allows us to see the formation of these events and track these clouds of dust as they are dispersed around the world."

Environmental epidemiologist Leslie McClure (Drexel University, Philadelphia, PA, USA) sees opportunities to use satellite data to inform public health decision-making, "especially for infectious diseases." McClure has used satellite data to augment ground-station air pollution measurements in studies of stroke risk. "The reality is, we can say we're going to use data from the closest ground-level monitor, but that might be [...] a 10-mile or 30-mile radius or more in rural areas", she said. "So we can better characterise areas on a finer scale. But keep in mind that we can only do so based on our modelled data and not directly-measured data."

Richard Kiang, a NASA scientist emeritus now consulting with the Naval Medical Research Unit 6 in Lima, Peru, and his NASA colleagues, are developing models that use satellite and other data to predict the transmission dynamics of influenza and other respiratory viruses. Using rainfall and ground temperature data from NASA's Tropical Rainfall Measuring Mission (TRMM) and successor Global Precipitation Measurement instruments, and Moderate Resolution Imaging Spectroradiometer (MODIS) orbiting instruments, as well as output from NASA climate models, Kiang and colleagues seek to improve short-term transmission activity projections available to public health officials in Latin America and elsewhere.

Vaccines and antivirals must be delivered quickly to epicentres of infection. Timely detection of the regions where influenza transmission will be most intense in the coming one or two weeks can help public health authorities quickly reallocate scarce vaccines and antivirals to those regions, Kiang said.

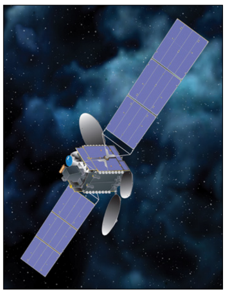
Infectious disease models also depend on accurate epidemiological information from health clinics and surveillance data of disease-carrying vectors in affected areas, Kiang noted—and collecting that information is sometimes a challenge. His team has developed similar models for malaria transmission but found that such details were frequently unavailable in places like Afghanistan, where limited resources and security concerns have hampered collection efforts, he said.

Satellite data can offer insights into air quality and habitat for the mosquito vectors of diseases like dengue, yellow fever, chikungunya and Zika virus, Kiang noted: "The propagation of these mosquito species, and hence the transmission of these diseases, have been associated with air temperature, humidity, precipitation, and water bodies." Using satellite measurements of such variables, transmission intensities for these viruses can be predicted.

Satellite data for precipitation, soil temperature, airborne aerosols, and other variables are packaged into so-called products—statistical models—by NASA scientists for research partners, explained NASA's John Haynes (Health and Air Quality Applications Program Manager, NASA Applied Sciences Program, Washington, DC, USA).

NASA is also modelling how air pollutant distributions will be affected by climate change. Urban levels of lung-damaging ozone are likely to get worse with global warming.

Satellite data can also be used to model and analyse airborne levels of the US Environmental Protection Agency (EPA)'s so-called criteria pollutants, which are tracked to enforce national air quality standards. Among these pollutants are fine particulate matter (PM 2·5), ozone, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and formaldehyde. NASA has helped the US EPA to improve its tracking of PM 2·5 aerosols, for example, augmenting a nationwide network of ground monitoring stations with satellite data.



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For more on **differentials in global air-quality monitoring on the ground** see Comment *Lancet Respir Med* 2016; **4:** 603–05

To read **McClure and colleagues' paper on satellites' environmental public health applications** see *Geocarto Int* 2014; **29:** 85–98

For more on **NASA's Applied Sciences Program on Health & Air Quality** see http://appliedsciences.nasa.gov/programs/health-air-quality-program

NASA data has similarly informed studies of air quality in India and China, where large expanses of territory lack ground-based air monitoring stations.

After smog emergencies, China established a national urban air PM 2·5 ground-based monitoring network in late 2012. "The network was unable to fully capture remote power plant emissions, dust storms, and rural biomass burnings, which contribute substantially to the bad air quality in cities", Liu said. "Satellite remote sensing is a great tool—I would argue, the only tool—to fill these observation gaps and provide the much-needed big picture."

Liu's team is collaborating with epidemiologists in China to estimate PM 2·5 concentrations using satellite data, for studies of influenza-like illnesses, type 2 diabetes, birth outcomes, and premature deaths—a list that will "certainly grow" as modelling techniques mature, Liu said.

NASA's existing, ageing fleet of orbiting satellite sensors were not specifically designed for public health research, Liu noted. But NASA has sought input from epidemiologists and air quality researchers to design a new generation of public health-oriented satellite missions, like the Multi-Angle Imager for Aerosols (MAIA) and Tropospheric Emissions: Monitoring Pollution (TEMPO) spectrometer satellite instruments, which should be operational by 2022.

For more on **the July 12–13, 2016 TEMPO research meeting held in Huntsville, AL, USA, including research presentations** see http://nsstc.uah.edu/tempo/agenda.html

"MAIA is specifically designed to provide high-resolution particulate matter speciation information at selected regions around the world to support respiratory, cardiovascular, and birth outcome research", Liu noted. Launch dates have not yet been identified.

TEMPO will be a "game-changer" in the field of air quality tracking by satellite, according to Haynes. TEMPO will be built by 2017, and should be in orbit by 2021, attached to a commercial satellite.

TEMPO will be unique in the US fleet of Earth-observing satellite instruments because it will remain in geostationary orbit over North America, whereas the existing constellation of Earth-observing satellites are in polar orbit, circling the planet (MAIA will also be in low-earth orbit.)

While low-earth polar-orbiting satellites can gather data around the globe, in a fashion Haynes likens to peeling an apple, their orbit creates a time-lag in coverage of any given region. A satellite might not revisit an area of interest for several hours or even days, Haynes explained.

TEMPO, in contrast, will allow hourly, high-spatial-resolution daytime monitoring of air pollutants—allowing more timely responses to disasters and emergencies, or the study of air pollution pulses associated with morning and evening traffic commutes. TEMPO also captures data from the Earth's surface, so its data can be more closely correlated with public health outcomes like acute cardiovascular or pulmonary-related admissions to hospital.

Kelly Chance, at the Smithsonian Astrophysical Observatory (Cambridge, MA, USA), who is TEMPO's principle investigator, has been studying satellite data approaches to measuring lower-troposphere ozone levels since 1985. TEMPO will be, in part, a culmination of that work.

"We've never had an instrument specifically designed to address the ozone problem correctly", Chance told *The Lancet Respiratory Medicine.* "Not doing it correctly means we've had limited data on ozone at the surface. Getting it directly [via ground-based monitors] has been problematic. That's one of the major things that TEMPO is aimed at doing; it is specifically designed to measure lower-troposphere ozone with sensitivity [down] to the Earth's surface." (Ozone gas absorbs light in ultraviolet and infrared wavelengths that are invisible to the human eye but readily detected with satellite instruments.)

TEMPO's hourly data streams will "tremendously enhance" understanding of ground-monitoring data, and the behaviours and transportation of specific pollutants, said Kathy Jones, Air Monitoring Manager for the Chattanooga Hamilton County Air Pollution Control Bureau (Chattanooga, TN, USA).

"When the air monitoring community discovered satellite pictures in the late 1990s, we began to pay attention to large wildfire events, prescribed burning, agricultural burning, African and Asian sands transport, all of which were revealed to us on the pictures and all of which can affect significant portions of the US", Jones said. "We will be eagerly anticipating the opportunity to view the hourly information that TEMPO will provide."

TEMPO, and satellites generally, are "only a piece of the puzzle, not a panacea", Haynes was quick to note. They will not replace ground sensors, he and others told *The Lancet Respiratory Medicine*. Reflectance-based aerosol optical depth (AOD) measurement of air pollutants works during the day, not at night—and daytime cloud cover can be a big challenge, Chance and Haynes both acknowledged. Bright surfaces like snowpack or desert sands can also overwhelm satellite sensors, he said.

Because TEMPO is expected to have a planned operational lifetime of 2 years, and an anticipated operations window of 2–5 years, it is unlikely to prove suitable for long-term studies of chronic air pollution exposure and health, noted Liu.

In reality, TEMPO might well survive longer. "Many of our 17 currently orbiting satellites are in extended operations, and they're still going strong", Haynes noted.

TEMPO will be the first satellite dedicated to monitoring air pollution over North America. Two other, similar geostationary instruments will cover Europe, the UK, and Russia (the European Space Agency's Sentinel-4), and much of Asia (the Korea Aerospace Research Institute's Geostationary Environment Monitoring Spectrometer [GEMS]).

"When all three are in orbit, we'll have a near-continuous look at the northern hemisphere's air quality", Haynes said. "It will be quite revolutionary."

Bryant Furlow