New Developments and Opportunities in Global Satellite Technology for Air Pollution and Health Studies

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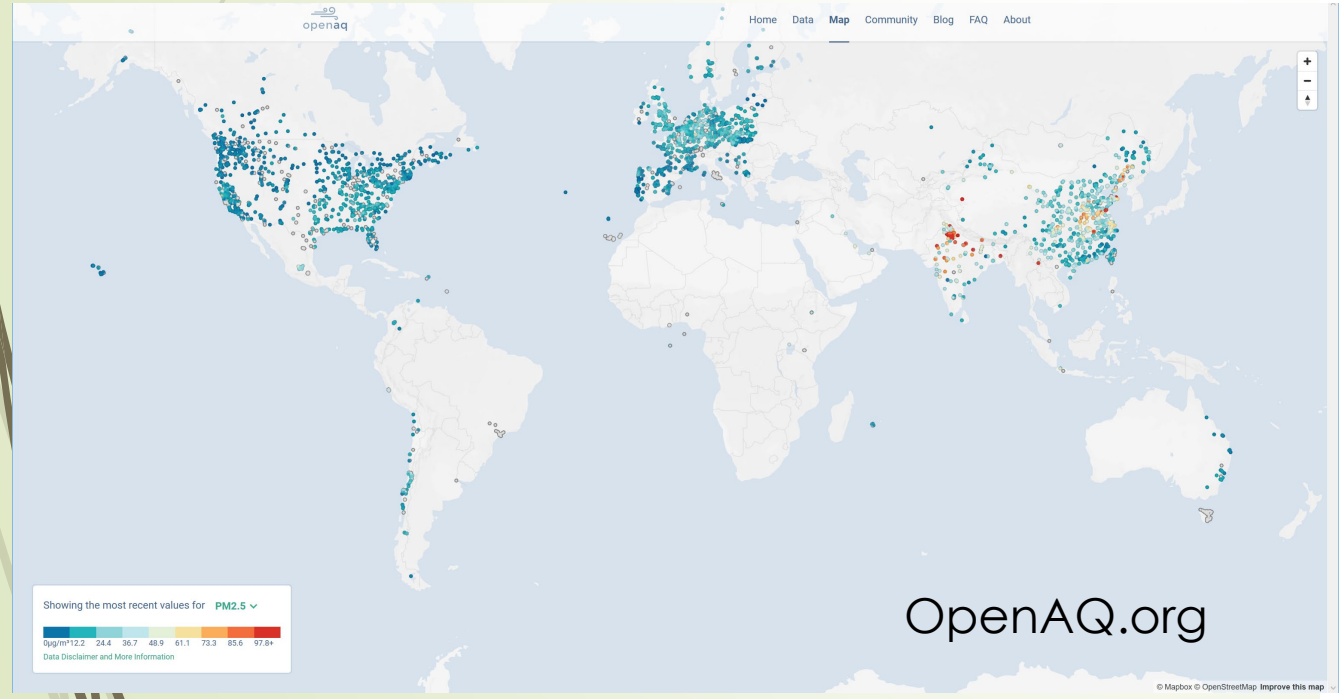
NASA Goddard Space Flight Center

Health Effects Institute Annual Meeting, Seattle, May 2019

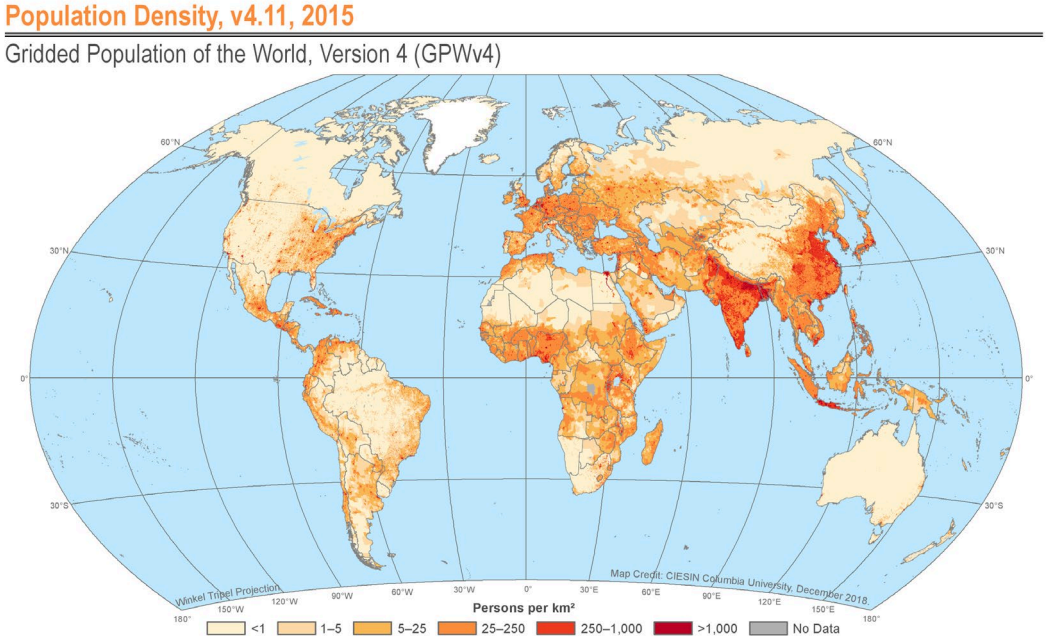
Poor Spatial Coverage of Surface Monitor Network

OpenAQ Surface Monitor Locations



OpenAQ.org

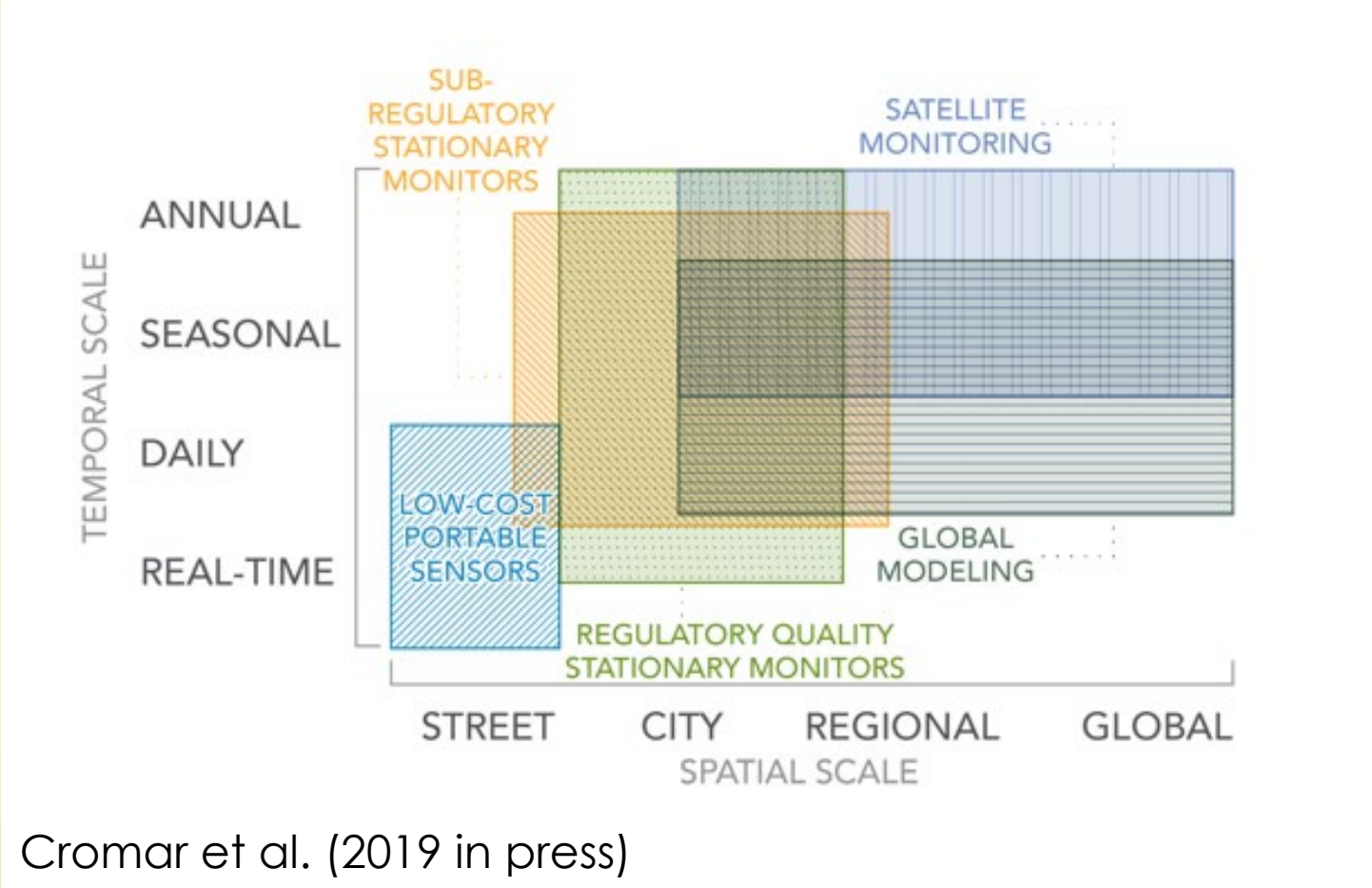
Population Density



NASA SEDAC

SEDEC = Socioeconomic Data and Applications Center

"Air Pollution Monitoring for Health Research and Patient Care": ATS Workshop Report



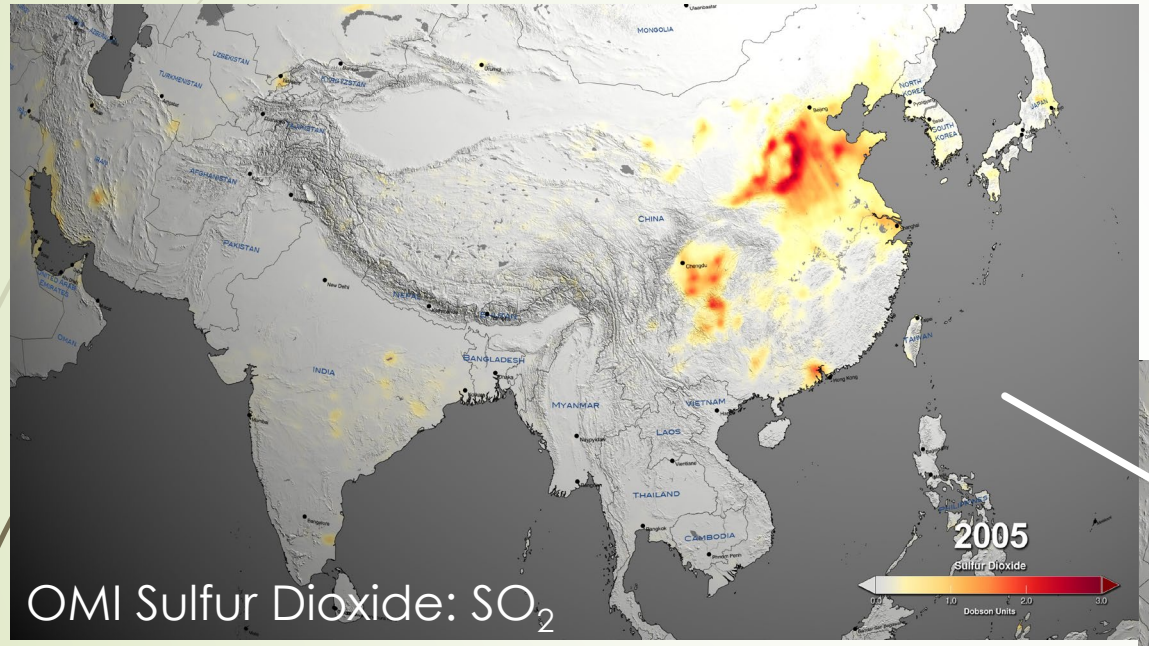
Cromar et al. (2019 in press)

Integrated Approach to Air Pollution Monitoring

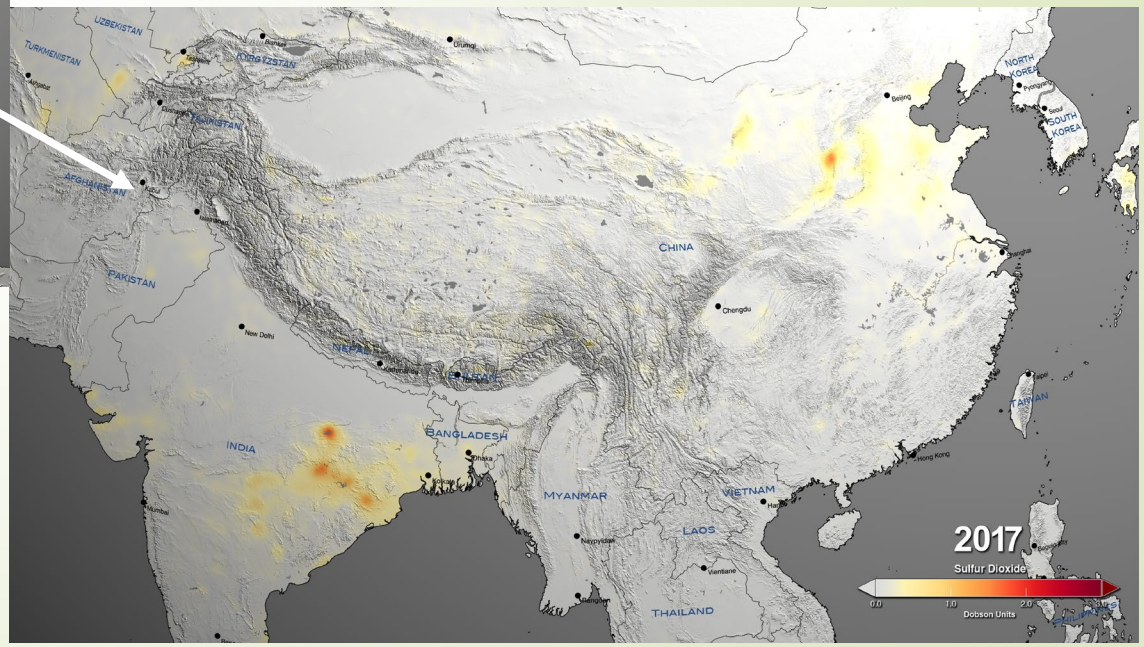
"Each of these technologies has strengths and limitations that need to be considered when integrating them to develop a robust and diverse global air quality monitoring network."

ATS = American Thoracic Society

Unique Advantages of Satellite Data: Spatial Coverage & Changes over Time



OMI = Ozone Monitoring Instrument



Units = x 2.687×10^{16} molec/cm^2

Potentially useful space-based observations for the health community

- Aerosols (aerosol optical depth [AOD], fire detection) → can be used to infer "nose-level" $PM_{2.5}$ with atmospheric models

- Ozone (O_3) → no information on "nose-level" concentrations
- Nitrogen dioxide (NO_2) → most straightforward to observe & excellent tracer of combustion
- Carbon monoxide (CO) → another tracer of combustion

- Sulfur dioxide (SO_2)
- Ammonia (NH_3)
- Formaldehyde (HCHO)

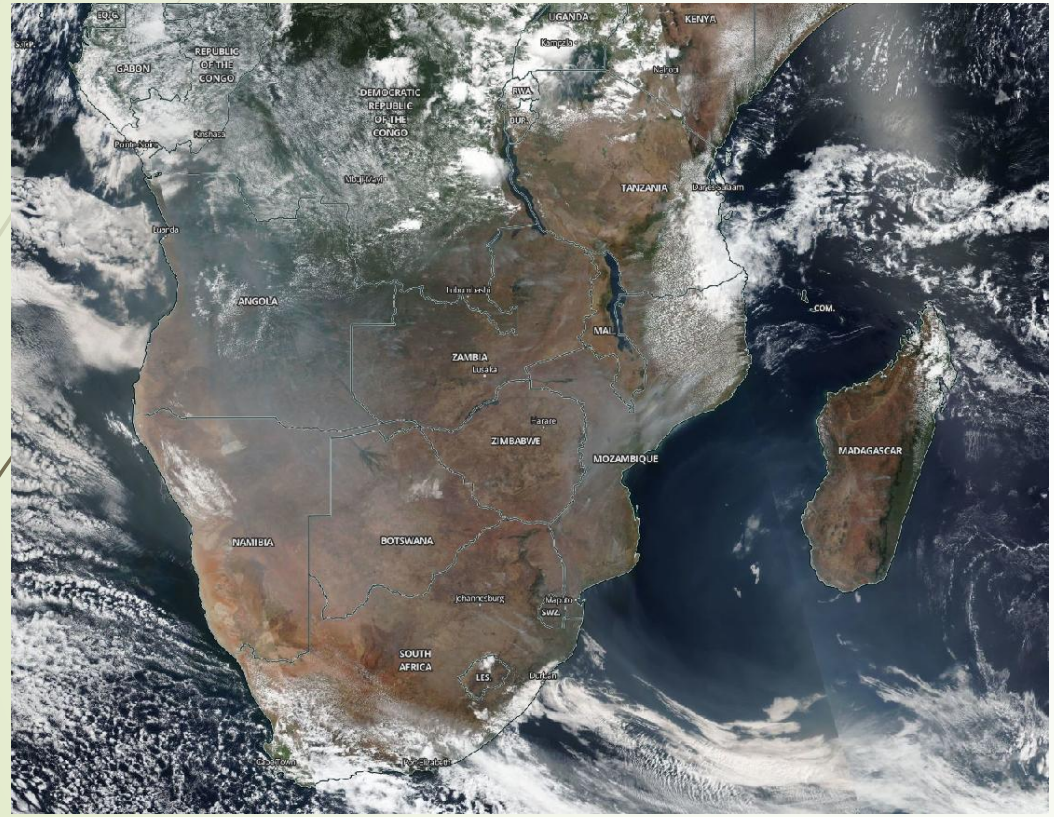
} precision and accuracy not suitable for most health studies

- Surface ultraviolet (UV) → not a pollutant, but …

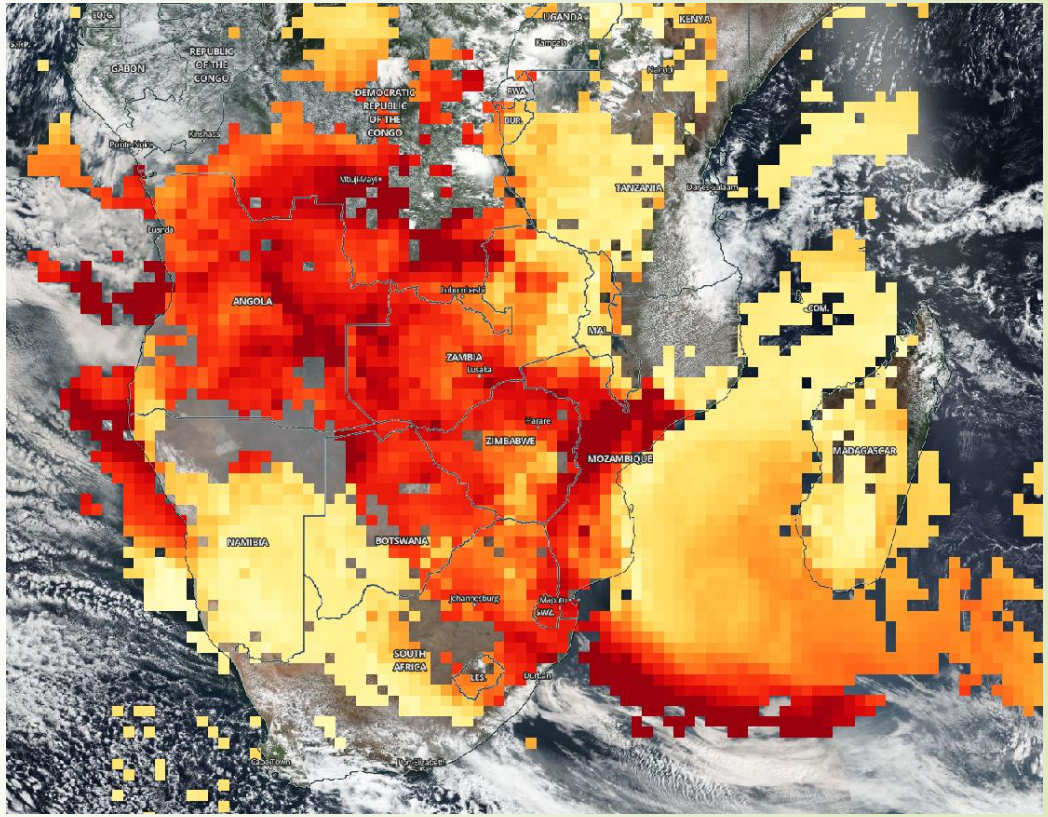
Synergy of Satellite Data Products

~Two decade data record

True Color Image (VIIRS)



MODIS AOD (10x10 km^2)



VIIRS = Visible Infrared Imaging Radiometer Suite
MODIS = Moderate Resolution Imaging Spectroradiometer
AOD = Aerosol Optical Depth

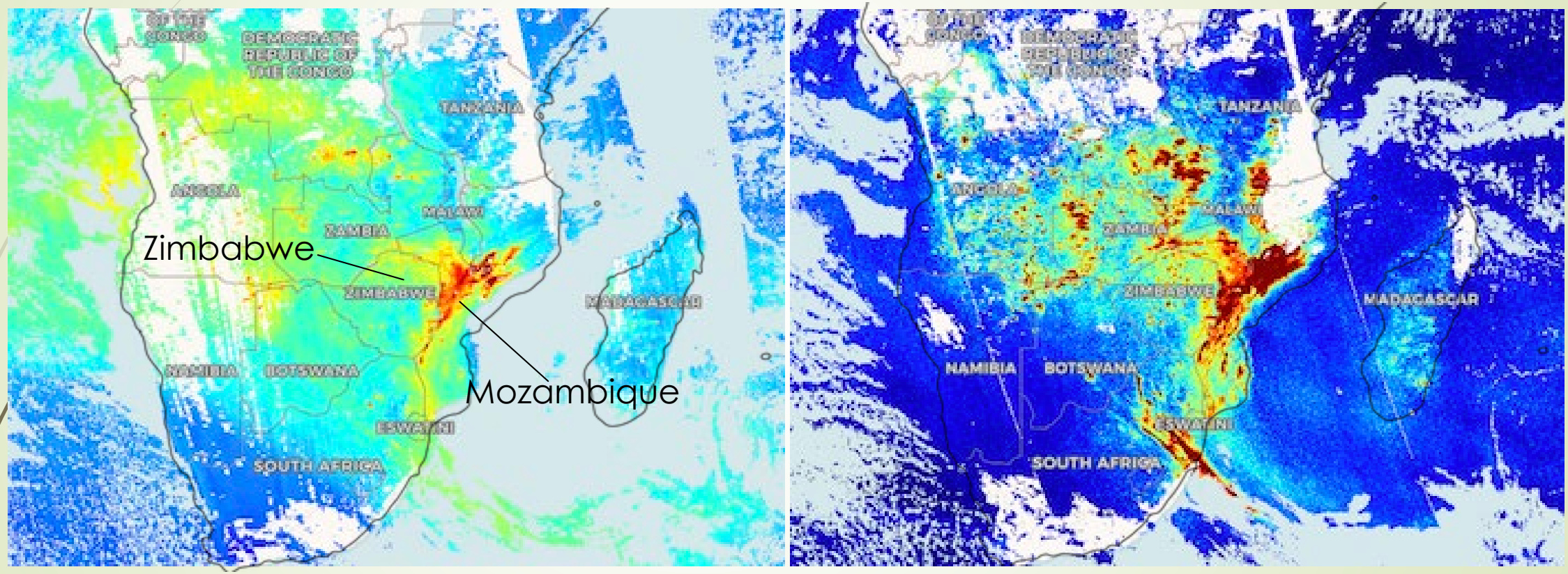
September 19, 2018

Seasonal agricultural burning is an important source of pollution over much of the tropics and sub-tropics, including in areas without any air pollution monitors.

Synergy of Satellite Data Products

Carbon Monoxide (TROPOMI)

Nitrogen Dioxide (TROPOMI)



Species Range from Low to High Values

September 19, 2018

TROPOMI = TROPOspheric Monitoring Instrument, the satellite instrument on board of the Copernicus Sentinel-5 Precursor satellite

Evolving Technology

GOME = Global Ozone Monitoring Experiment instrument; OMI = Ozone Monitoring Instrument; TROPOMI = TROPOspheric Monitoring Instrument; TEMPO = Tropospheric Emissions: Monitoring Pollution mission

GOME (1996)
40 x 40 km^2 & greater

↓

OMI (2004)
13 x 24 km^2 & greater

↓

TROPOMI (2017)
~3.5 x 7 km^2

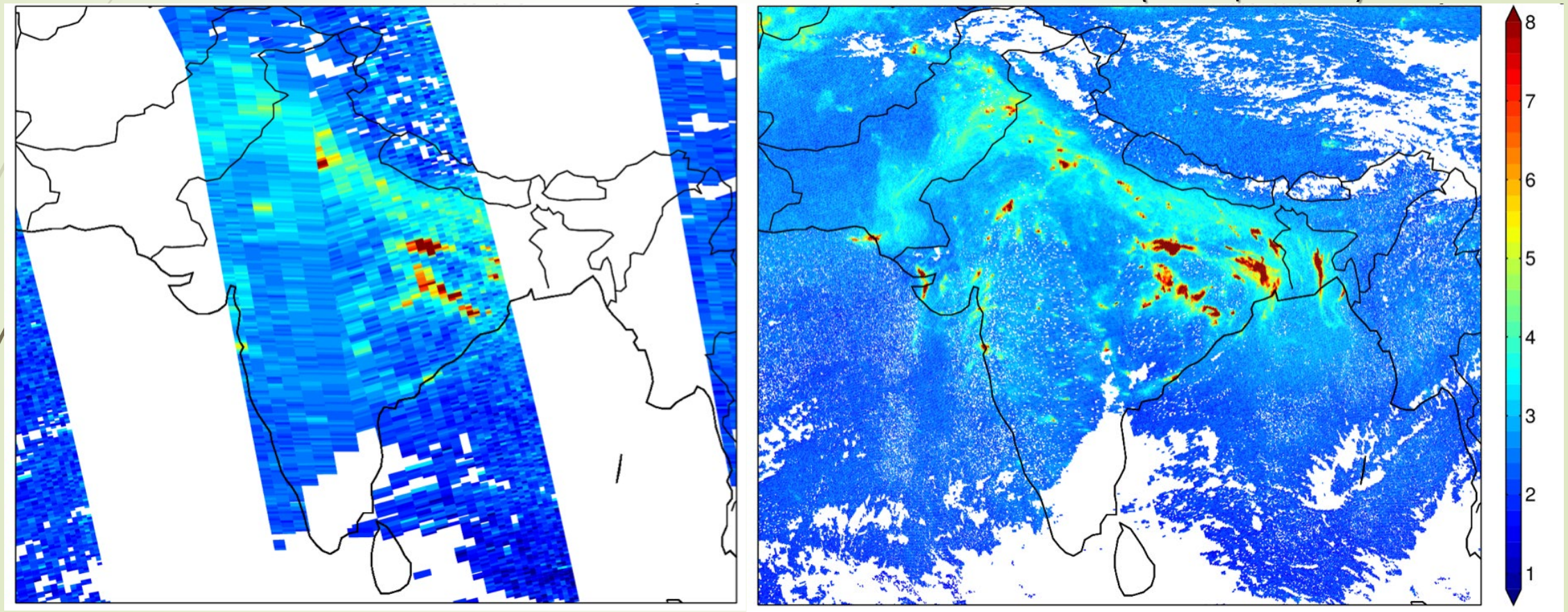
↓

TEMPO (202x)
2 x 5 km^2

TROPOMI: Evolving Technology
Nitrogen Dioxide (NO_2)

OMI (2005-present)

TROPOMI (2017-present)

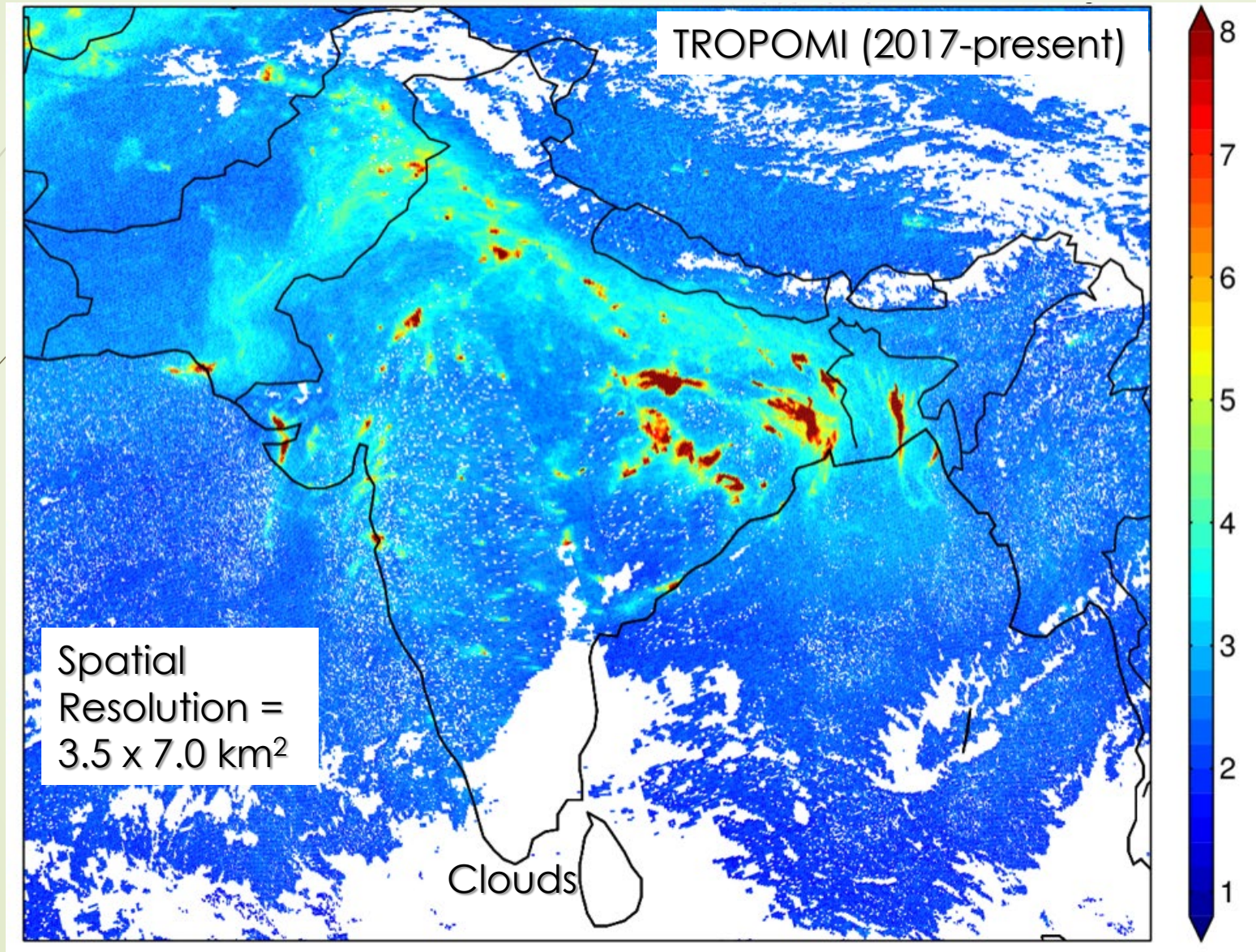


November 28, 2017

Courtesy Lok Lamsal (NASA)

Units = $x10^{15}$ molecules/cm^2

TROPOMI: Evolving Technology

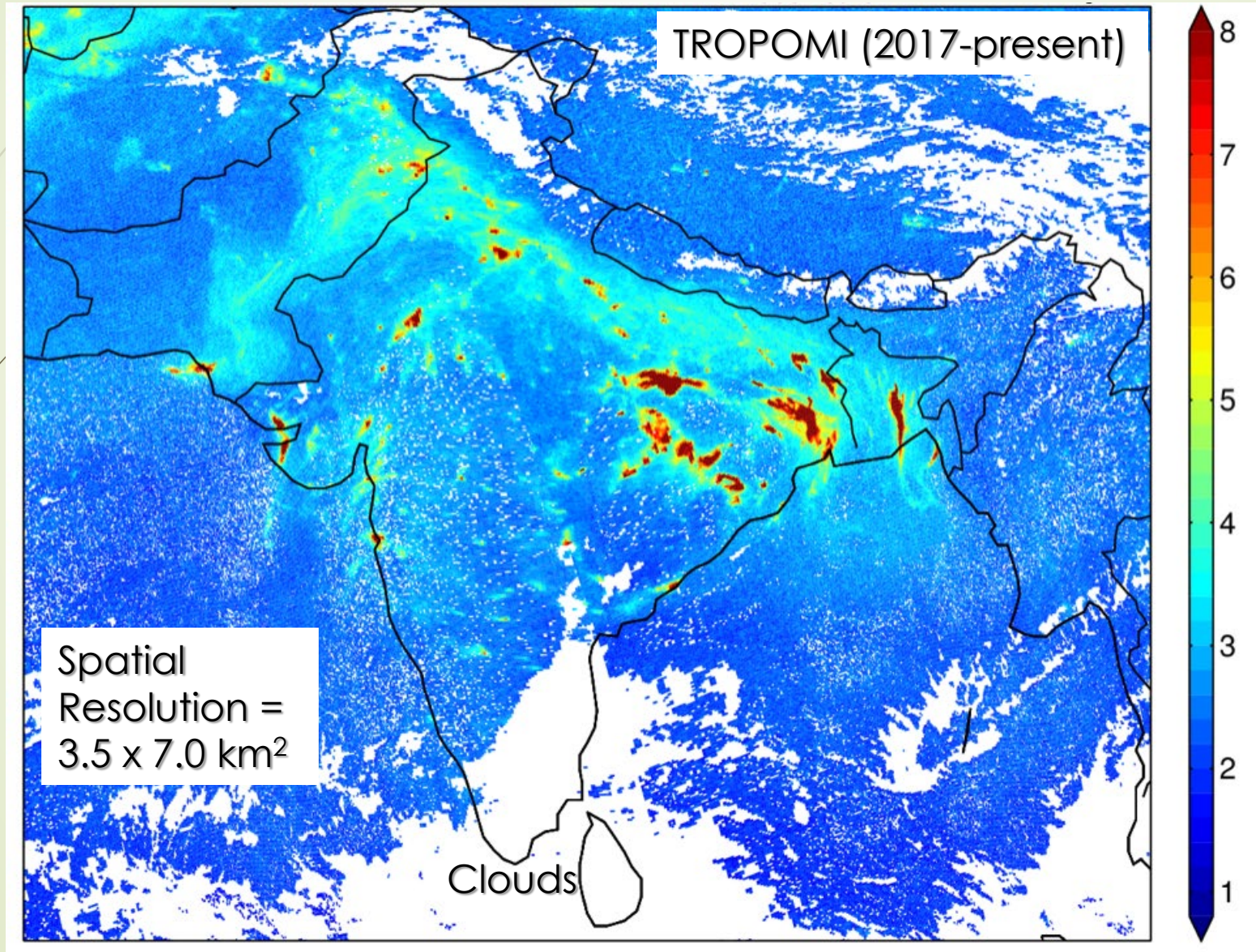


Units = $x10^{15}$ molecules/cm^2

Atmospheric Model

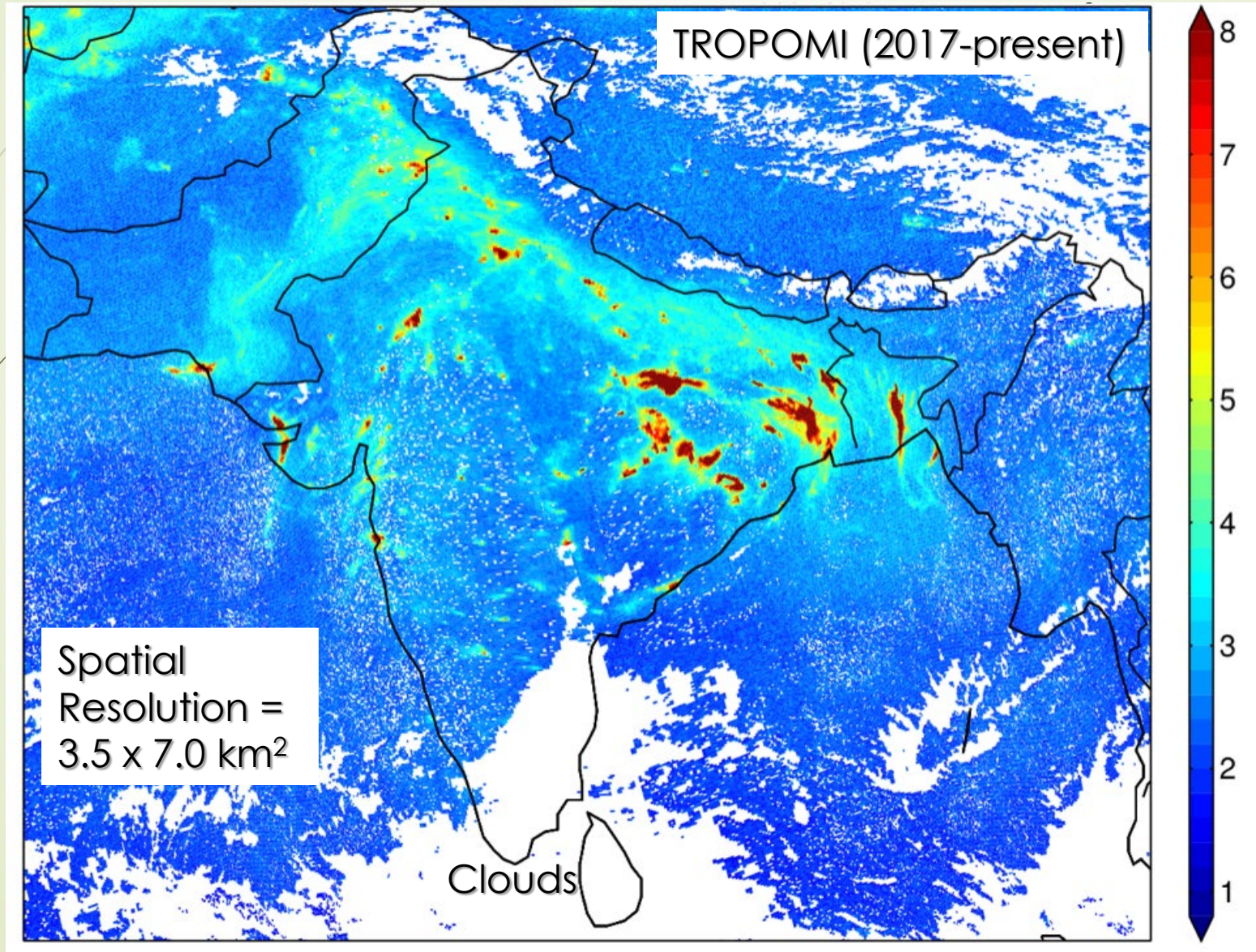
"Nose-level" concentrations

TROPOMI: Evolving Technology



Validation of all surface pollutants inferred from satellite data is key, but independent surface observations are sparse.

TROPOMI: Evolving Technology



NO_2 has strong spatial gradients that can't (yet) be resolved from space

Land Use Regression Model

"Nose-level" concentrations on finer spatial scales

Research

A Section 508–conformant HTML version of this article is available at https://doi.org/10.1289/EHP3766.

Estimates of the Global Burden of Ambient $PM_{2.5}$, Ozone, and NO_2 on Asthma Incidence and Emergency Room Visits

Susan C. Anenberg,[1] Daven K. Henze,[2] Veronica Tinney,[1] Patrick L. Kinney,[3] William Raich,[4] Neal Fann,[5] Chris S. Malley,[6] Henry Roman,[4] Lok Lamsal,[7] Bryan Duncan,[7] Randall V. Martin,[8,9] Aaron van Donkelaar,[8] Michael Brauer,[10,11] Ruth Doherty,[12] Jan Eiof Jonson,[13] Yanko Davila,[2] Kengo Sudo,[14,15] and Johan C.I. Kuylenstierna[6]

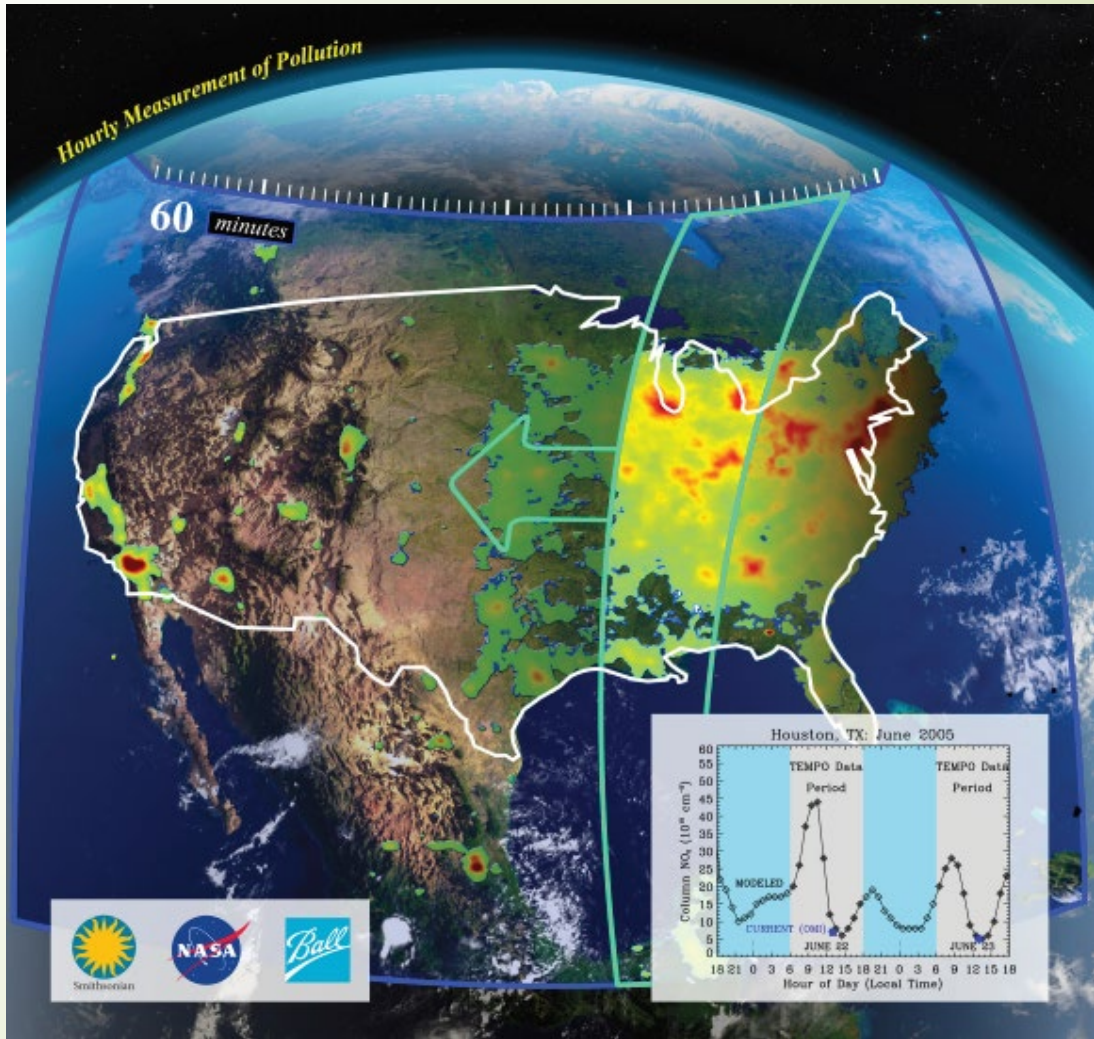
- Current Global Burden of Disease (GBD) studies include only $PM_{2.5}$ and ozone, but Anenberg et al. (2018) added NO_2.
  - Particulate matter < 2.5 μm ($PM_{2.5}$): inferred using satellite data of aerosol optical depth (AOD) and a model of atmospheric chemistry and transport [van Donkelaar et al., 2016] at 0.1°x0.1°
  - Ozone (O_3): multi-model mean of models of atmospheric chemistry and transport at 0.1°x0.1°
  - Nitrogen dioxide (NO_2): Ozone Monitoring Instrument (OMI) NO_2 at 0.1°x0.1°
- For asthma incidence, the study found the strongest evidence for associations with traffic-related NO_2 and for children, but the methods were unable to capture realistic near-roadway exposures.
- Next Step: Apply NO_2 estimates from Land Use Regression Model using satellite-derived NO_2 data as input.
  - They used Land-Use Regression data from Larkin et al. (2017): Concentrations ranged 0-72 ppb, compared with 0-17.5 ppb from Anenberg et al. 2018. See Achakulwisut et al. (2019).

A New Era for Health Research: Upcoming & Recent Satellite Missions

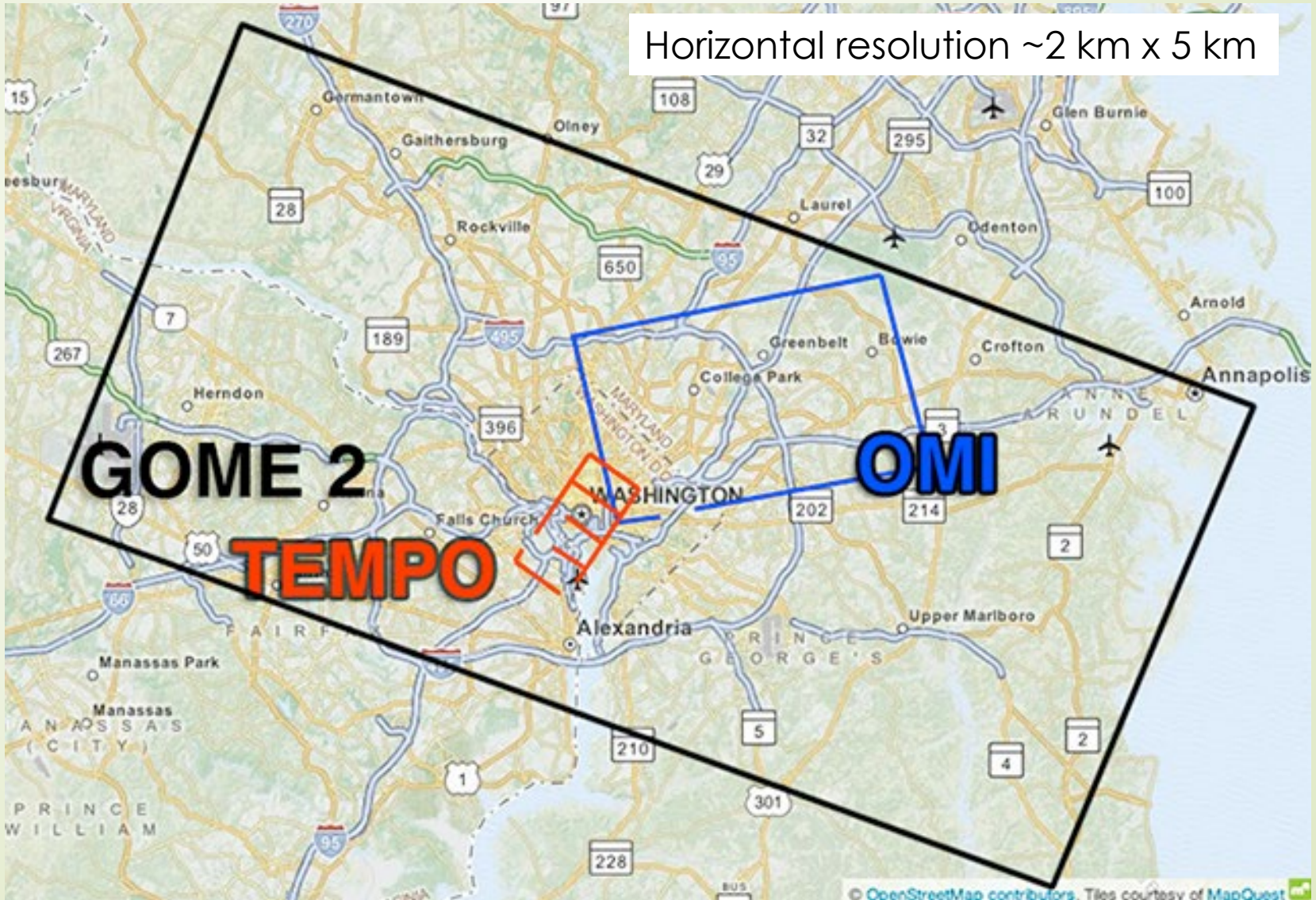
- The number of health-related publications using satellite data has been increasing over the last 5-10 years.
- However, the use of satellite data in health research is still a bit of a novelty.
- Two upcoming missions and several new missions will likely be game-changers for health researchers:
  - 3 Geosynchronous Satellites: Hourly data (during daylight) of NO_2, SO_2, CO, etc. over N. America, E. Asia, Europe, N. Africa, & parts of the Middle East
  - 4 Geosynchronous Satellites: Hourly data of AOD over N. & S. America and E. Asia & Australia
  - First health-based mission for particulate matter for 10+ world cities

Upcoming: TEMPO

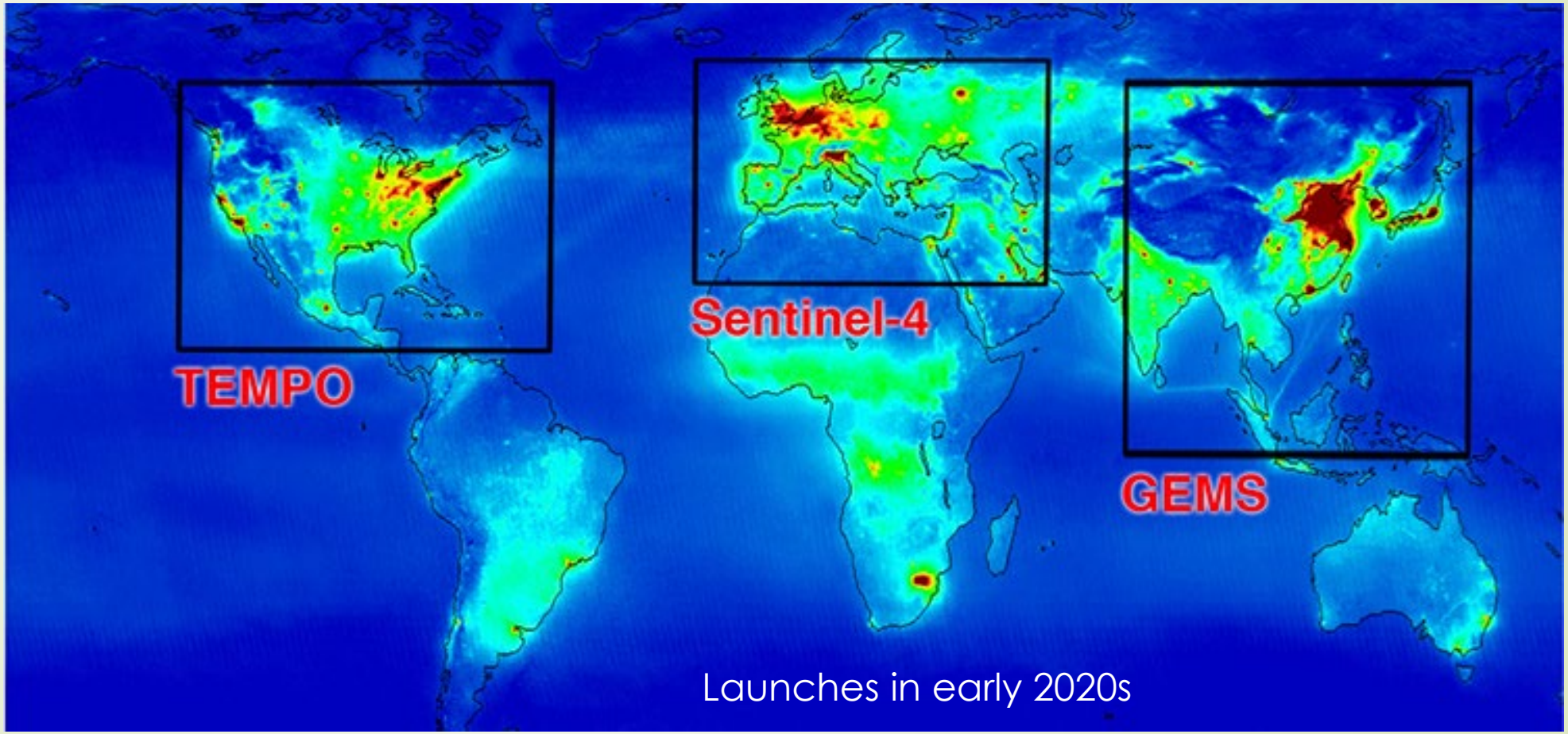
- Tropospheric Emissions: Monitoring Pollution (TEMPO) has similar heritage as TROPOMI & OMI
- Atmospheric Trace Pollutants (NO_2, SO_2, formaldehyde [HCHO])
- Unprecedented spatio-temporal resolution
  - Hourly data over N. America (geosynchronous orbit vs polar orbit)
- For more about TEMPO:
  - https://tempo.si.edu/



Upcoming: TEMPO

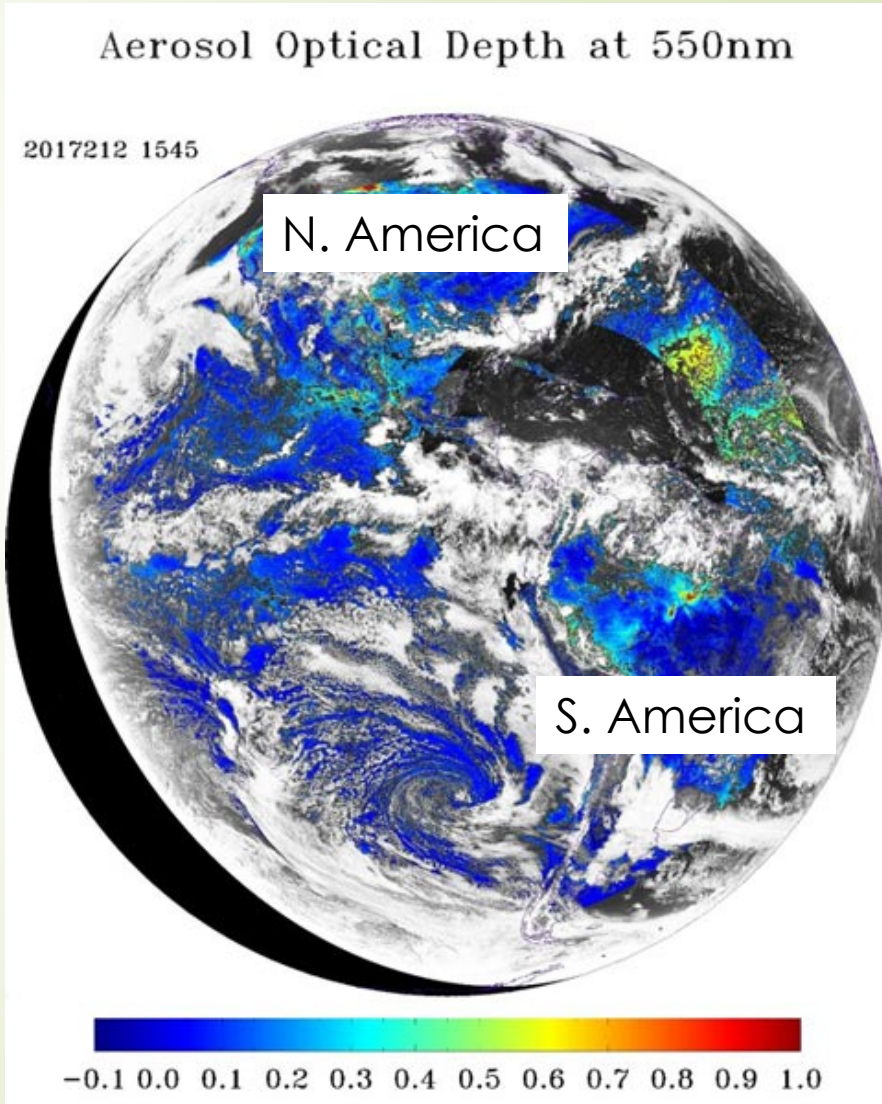


Upcoming Suite:
TEMPO + Sentinel-4 + GEMS



Existing GOES-16/17 (N. & S. America) & Himawari-8/9 (E. Asia)

- There are efforts to enable the development of 30-min/hourly surface $PM_{2.5}$ products.
- GOES-16/17 Advanced Baseline Imager (ABI)
- Himawari-8/9 Advanced Himawari Imager (AHI)



GOES = NOAA Geostationary Satellite Server

Upcoming: MAIA
NASA's First Health-Based Mission

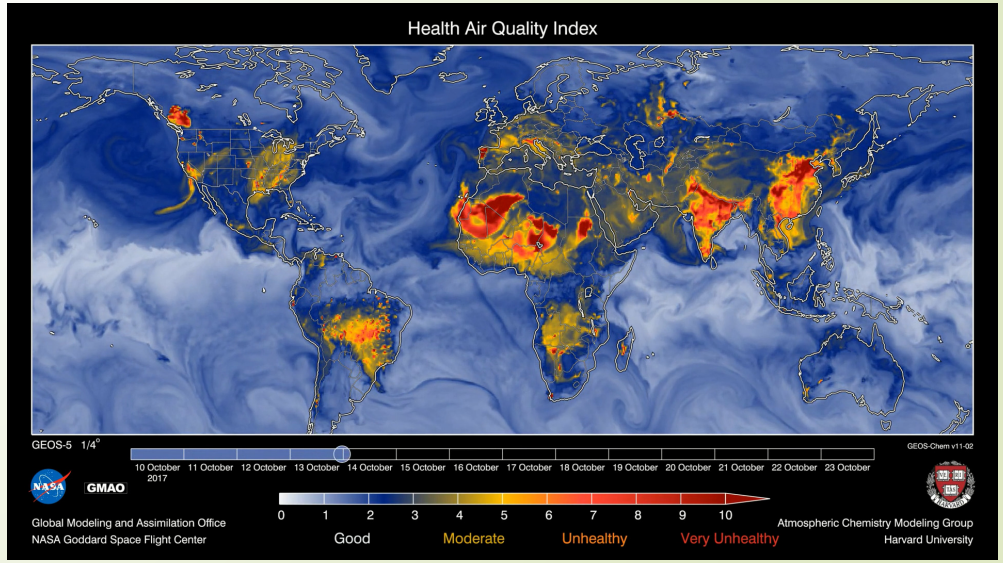
- Multi-Angle Imager for Aerosols (MAIA)
- Atmospheric Pollutant: PM
- Unprecedented characterization of PM on urban scale
- **Targeted Data Users:** Epidemiologists for health studies
- Expected Launch: 2022
- For more about MAIA:
  - https://maia.jpl.nasa.gov/
  - Liu, Y., and D.J. Diner (2017). "Multi-angle Imager for Aerosols: A satellite investigation to benefit public health." Public Health Reports 132 (1): 14-17.

MAIA will characterize the sizes, compositions and quantities of particulate matter in air pollution.

PM = particulate matter

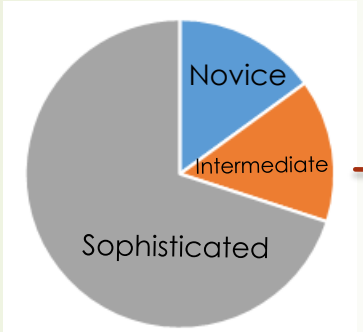
A New Era for Health Research: Global Air Pollution Models on the Horizon

- Ongoing improvements in global air pollution models, including with satellite data assimilation techniques, will enable high spatio-temporal representation of pollutants for health research.
- Model output fills the gaps left by surface monitors and satellite data (e.g., clouds).
- NASA's air quality forecast system
  - https://airquality.gsfc.nasa.gov/forecast
  - 25x25 km^2 now, but looking to 12x12 km^2 to …
- https://airquality.gsfc.nasa.gov/forecast



Enabling New Stakeholders: New Satellites, Gridded Products, Capacity Building

Current Pool of Data Users

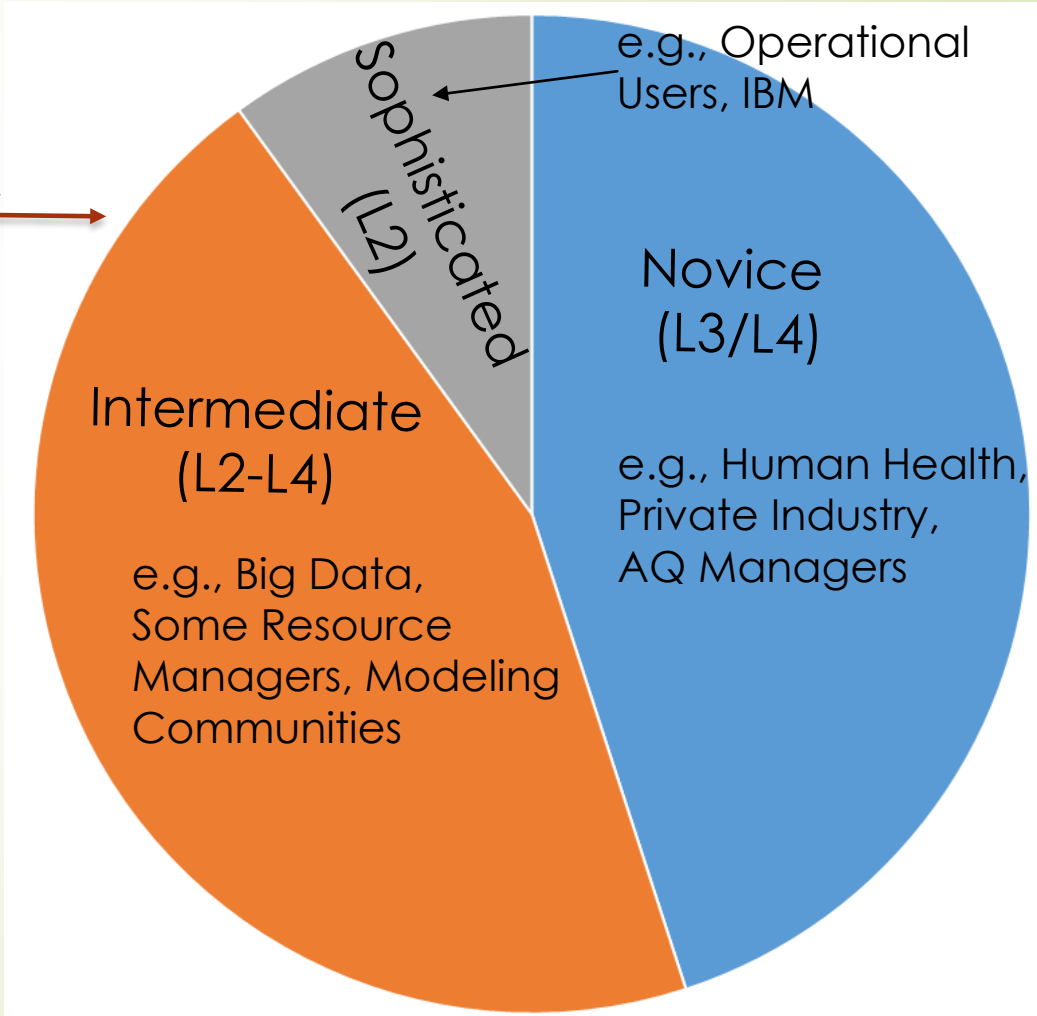


NASA HAQAST, ARSET, Applied Sciences

Level of Data Processing	Example
L0-1: unprocessed or limited processing	Radiances
L2: geophysical variable	AOD from an individual overpass
L3: variable mapped to uniform space-time grid	AOD on latitude-longitude grid, time averaging, quality controlled
L4: derived non-observed quantity	Gridded surface $PM_{2.5}$

HAQAST = Health and Air Quality Applied Sciences Team
ARSET = Applied Remote Sensing Training

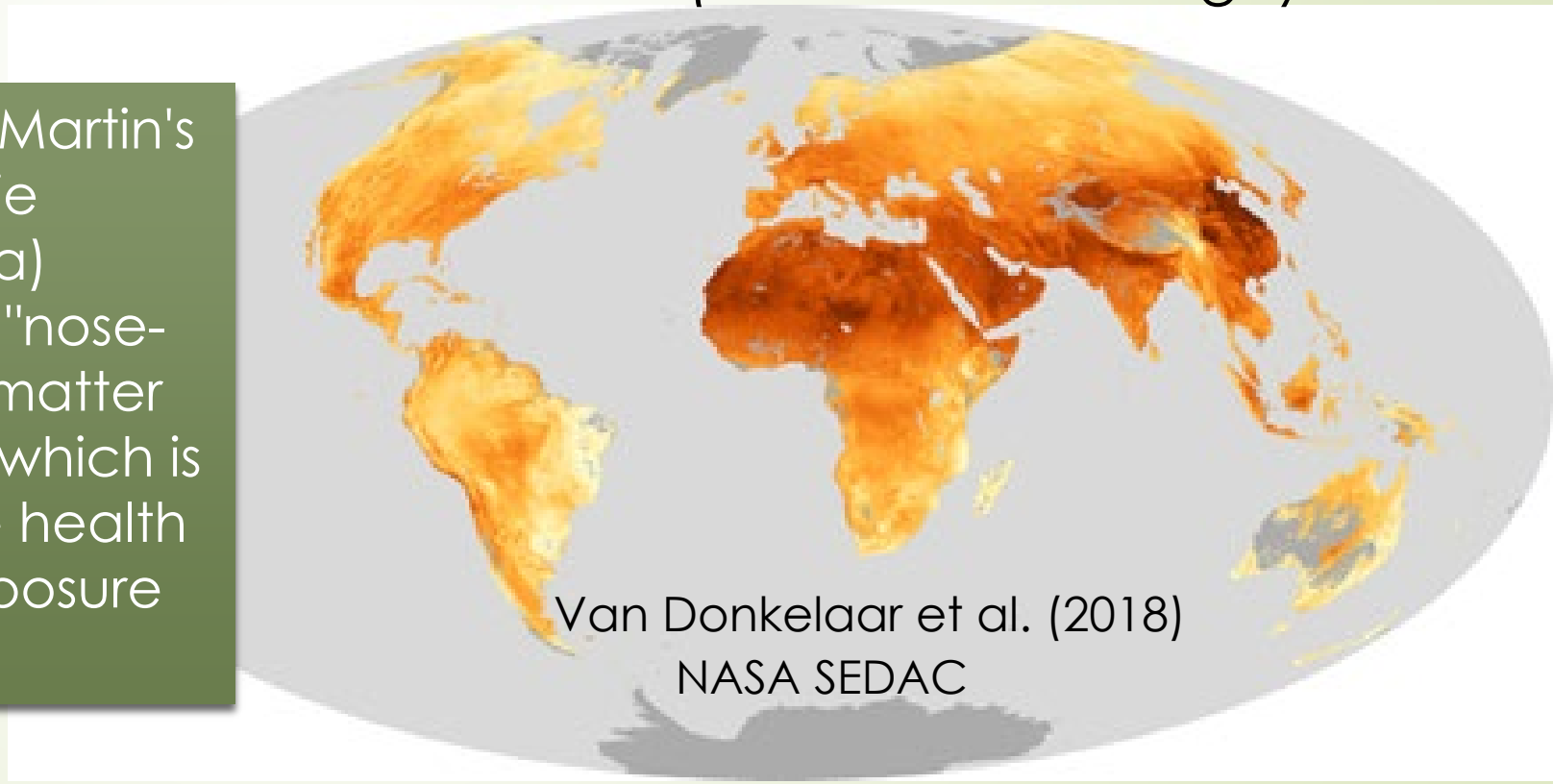
Potential Pool of Data Users



Aerosol Optical Depth → "Nose-Level" Surface $PM_{2.5}$

Surface PM (1998-2016 Average)

Example: Randall Martin's Group at Dalhousie University (Canada) created a Level 4 "nose-level" particulate matter (2.5 µm) product, which is being used by the health community for exposure assessments, etc.



Satellite Data (MODIS, MISR, SeaWiFS) + Atmospheric Model

Free & Publicly-Available Resources

- NASA's Air Quality Website
  - https://airquality.gsfc.nasa.gov/
- NASA's Health & Air Quality Applied Sciences Team (HAQAST)
  - https://haqast.org/
  - Next meeting: July 10-12, 2019 in Pasadena, CA (travel funds available)
- NASA's Applied Remote Sensing Training (ARSET)
  - https://arset.gsfc.nasa.gov/
- NASA's Applied Sciences Program
  - https://appliedsciences.nasa.gov/programs/health-air-quality-program

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