Satellite Data for Air Quality Environmental Justice and Equity Applications
Part 2: Satellite Remote Sensing of Air Quality for Environmental Justice

Carl Malings (NASA & Morgan State University)
August 30, 2023
Part 2 – Trainer

Carl Malings
Assistant Research Scientist
NASA, Morgan State U.
Part 2 Objectives

By the end of Part 2, participants will be able to:

• Identify remote sensing data products which are most relevant to assessing EJ related to air quality and pollutant exposure

• Articulate the benefits and limitations of using remote sensing data to assess EJ concerns related to air quality
Based on the review of environmental justice applications for remote sensing data presented in Part 1, what was the most common category for the studies discussed?

A: Light Pollution  
B: Temperature and Urban Heat  
C: Access to Green Space  
D: Air Pollution  
E: Flooding or Drought
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A: Light Pollution
B: Temperature and Urban Heat
C: Access to Green Space
D: Air Pollution
E: Flooding or Drought

✓ D: Air Pollution
Review of Prior Knowledge

• Past applications of satellite data to investigate environmental justice issues:
  – air pollution (focus of today’s training)
  – green space
  – extreme temperatures (heat & cold)
  – drought, flooding, and water access
  – light at night

• Satellite remote sensing data can be combined with socio-economic information to provide evidence of disparities, inequality, and environmental injustice.

• Advantages of using satellite data to investigate environmental justice include their wide spatial coverage and long data records.

• Limitations of using satellite data to investigate environmental justice include spatial resolution, temporal frequency, and validation against ground data.
How to Ask Questions

• Please put your questions in the Questions box and we will address them at the end of the webinar.

• Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.

• The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.
Background on Air Quality and its Health Impacts
The Scale of the Global Air Quality Problem

- Poor air quality is the **number one environmental and occupational risk factor** for premature death globally.
- Air pollution is estimated to be responsible for about **7 million premature deaths** each year.
- Air pollution also has many negative **economic impacts** as well, for example, crop damage due to near-surface Ozone.
- Air pollution improvements can have **numerous co-benefits**, especially in greenhouse gas emission reductions.

## Air Quality Standards

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Time Basis</th>
<th>Standard</th>
<th>Time Basis</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PM$_{2.5}$</strong></td>
<td>annual</td>
<td>12 µg/m$^3$</td>
<td>annual</td>
<td>5 µg/m$^3$</td>
</tr>
<tr>
<td>(fine particulates)</td>
<td>daily</td>
<td>35 µg/m$^3$</td>
<td>daily</td>
<td>15 µg/m$^3$</td>
</tr>
<tr>
<td><strong>PM$_{10}$</strong></td>
<td>daily</td>
<td>150 µg/m$^3$</td>
<td>daily</td>
<td>45 µg/m$^3$</td>
</tr>
<tr>
<td>(coarse particulates)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pb</strong></td>
<td>3-month</td>
<td>0.15 µg/m$^3$</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>NO$_2$</strong></td>
<td>annual</td>
<td>53 ppb</td>
<td>annual</td>
<td>10 µg/m$^3$</td>
</tr>
<tr>
<td></td>
<td>hourly</td>
<td>100 ppb</td>
<td>daily</td>
<td>25 µg/m$^3$</td>
</tr>
<tr>
<td><strong>SO$_2$</strong></td>
<td>3-hour</td>
<td>500 ppb</td>
<td>daily</td>
<td>40 µg/m$^3$</td>
</tr>
<tr>
<td></td>
<td>hourly</td>
<td>75 ppb</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>O$_3$</strong></td>
<td>8-hour</td>
<td>70 ppb</td>
<td>8-hour</td>
<td>100 µg/m$^3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>peak season</td>
<td>60 µg/m$^3$</td>
</tr>
<tr>
<td><strong>CO</strong></td>
<td>8-hour</td>
<td>9 ppm</td>
<td>daily</td>
<td>4 mg/m$^3$</td>
</tr>
<tr>
<td></td>
<td>hourly</td>
<td>35 ppm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Aerosols**

**Trace Gases**


NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
The Air Quality Index and Pollutant Concentrations

- An Air Quality Index is used to convey air quality information to the public.
- Different countries use different indices.
- US EPA AQI is calculated separately for each criteria pollutant.
- The highest AQI across all criteria pollutants is the reported AQI.
- Measured AQI are based on the previous day’s measurements, and only for the pollutants measured by each station.
- Nowcast AQI covers Ozone and PM$_{2.5}$, using the most recent hourly data.
- Forecast AQI usually also covers Ozone and PM$_{2.5}$, based on multiple data sources and forecaster judgement.
- AQI is informational but not regulatory.

<table>
<thead>
<tr>
<th>AQI</th>
<th>Description</th>
<th>Range PM$_{2.5}$, daily [µg/m$^3$]</th>
<th>Range O$_3$, 8-hour [ppb]</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 -  50</td>
<td>Good</td>
<td>0 - 12</td>
<td>0 - 54</td>
<td>...</td>
</tr>
<tr>
<td>51 - 100</td>
<td>Moderate</td>
<td>12.1 - 35.4</td>
<td>55 - 70</td>
<td>...</td>
</tr>
<tr>
<td>101 - 150</td>
<td>Unhealthy for Sensitive Groups</td>
<td>35.5 - 55.4</td>
<td>71 - 85</td>
<td>...</td>
</tr>
<tr>
<td>151 - 200</td>
<td>Unhealthy</td>
<td>55.5 - 150.4</td>
<td>86 - 105</td>
<td>...</td>
</tr>
<tr>
<td>201 - 300</td>
<td>Very Unhealthy</td>
<td>150.5 - 250.4</td>
<td>106 - 200</td>
<td>...</td>
</tr>
<tr>
<td>301 +</td>
<td>Hazardous</td>
<td>250.5 +</td>
<td>201 +</td>
<td>...</td>
</tr>
</tbody>
</table>

Characterizing Air Pollution Exposure

Ground-based monitors

Sensor networks

Models – statistical and physical

Satellite remote sensing
The Global Air Quality Data Gap

• Most regions have fewer than 10 regulatory air quality monitors per million people for PM$_{2.5}$ (and generally fewer for other pollutants).

• Densities vary greatly regionally; regions with higher concentrations tend to be less well monitored.

• Low-cost sensors increase monitor density by up to ten times in some regions.

• This may still be insufficient in areas with highly variable pollution.


NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
Local Data Gaps and Spatial Variability

- Only about a third of US counties have regulatory air quality monitors.
- Only 60% of census urban areas have regulatory air quality monitors.
- Pollutants may vary on small spatial scales due to their sources and atmospheric lifetimes.
- Pollutants with longer lifetimes will be more spatially uniform and temporally consistent.

Sources:
- Do you have outdoor air monitoring data for all counties in the U.S.? US Environmental Protection Agency.
Characterizing Air Pollution Exposure

Ground-based monitors

Sensor networks

Models – statistical and physical

Satellite remote sensing
Basics of Air Quality Remote Sensing
Relevant Prior ARSET Introductory Training

- ARSET - An Inside Look at How NASA Measures Air Pollution
- ARSET - Un Vistazo a Cómo la NASA Mide la Contaminación del Aire
The NASA Earth Observing Fleet

- NASA (and other space agencies) operate Earth observation satellites.
- These satellites provide remotely sensed retrievals of geophysical quantities.
- These can be interpreted, with the aid of physical and atmospheric chemistry models, to inform us about surface air quality.

Source: NASA Earth Science

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
Principles of Remote Sensing for Air Quality

- Satellites measure backscattered **UV**, **visible**, and **IR** radiation from the Earth’s surface and atmosphere.

- **Retrieval algorithms** use radiation measurements and physics-informed models to infer **geophysical quantities** such as optical depth, particle number density, or partial pressure.

- **Aerosol Optical Depth** for all aerosols in the atmosphere is calculated using the measured scattering and absorption of visible light at certain wavelengths.

- Unique “spectral fingerprints” for the radiation absorption of certain trace gases are used to retrieve the **trace gas total column density**.


NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
Typical Satellite Orbits

**Polar Orbit (LEO)**
- Sun synchronous orbit ~600-1,000 km above Earth passing close to the North and South poles with passes at similar local solar time each day
- Most instruments achieve full global coverage every 1-2 days.

**Geostationary Orbit (GEO)**
- Orbit ~36,000 km above the Equator with the same rotational period as Earth
- Appears ‘fixed’ above Earth, offering a continuous daytime view of its hemisphere or field of regard
- Always observes in the same hemisphere

Multispectral and Hyperspectral Instruments

- **Multispectral instruments** have larger spectral band widths.
- Coarser spectral resolution is suitable for detecting certain prominent atmospheric features.
- **Aerosol optical depth** at ~550nm wavelength is generally well suited for measuring ambient particulate matter.
- **Hyperspectral instruments** have smaller spectral band widths.
- This higher spectral resolution is necessary for distinguishing the absorption spectra of different trace gases.

Spatial Resolution: Improvements Over Time


NASA ARSET - Satellite Data for Air Quality Environmental Justice and Equity Applications
Spatial Resolution: Improvements Over Time

TROPOMI Tropospheric NO₂

OMI Tropospheric NO₂

Spatial Resolution: Room for Improvement Remains

Spatial Resolution: Room for Improvement Remains

Spatial Resolution: Room for Improvement Remains

Advantages of Satellites for Air Quality Applications

- Examine a large area with one instrument: spatial variability, hotspots, transport
- Track changes over time: instruments with longer data records can quantify trends, including changes due to policy interventions.
- Improving spatial resolution: modern instruments can distinguish intra-urban variations & major point sources, but not yet “block-scale” variability.

Sources: tropomino2.us, The George Washington University Milken Institute School of Public Health. (left) NASA GSFC Nitrogen Dioxide Trends for World Cities. (right)
Limitations of Satellites for Air Quality Applications

- **Night**: most satellite instruments require sunlight to make their retrievals.
- **Clouds & Smoke**: most instruments are blocked by clouds and dense smoke.
- **“Nose Level”**: most measure the whole atmosphere, not just the surface.
- **Overpass Time**: polar-orbiting satellites observe a location about once per day at similar local times (geostationary satellites can observe throughout daytime).


NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
I want to investigate how gaseous transportation-related air pollutants like NO$_2$ and CO might vary in different communities throughout the course of the day.

What kind of satellite instrument should I be looking for?

A: Geostationary Multispectral Instrument  
B: Geostationary Hyperspectral Instrument  
C: Polar-Orbiting Multispectral Instrument  
D: Polar-Orbiting Hyperspectral Instrument
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Satellite Data Processing Levels

- **Level 0**: Raw data
- **Level 1**: Geo-referenced raw data
- **Level 2**: Derived geophysical variables (e.g., column concentrations)
- **Level 3**: Data re-mapped to uniform space & time grids (usually with recommended quality controls)
- **Level 4**: Data from multiple sources combined together (e.g., satellite & model)

Source: Data Processing Levels. NASA EarthData.
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Sources: [Data Processing Levels](https://earthdata.nasa.gov), [S-NPP CrIS IMG: Collocated VIIRS level 1 / cloud mask statistical summary V2](https://gesdisc.gsfc.nasa.gov), NASA GES DISC.
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Sources: [Data Processing Levels](https://earthdata.nasa.gov), [Sentinel-SP TROPOMI Tropospheric NO2 1-Orbit L2 5.5km x 3.5km](https://earthdata.nasa.gov), NASA GES DISC.
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Sources: [Data Processing Levels](#), NASA EarthData, [SeaWiFS Deep Blue Aerosol Optical Depth and Angstrom Exponent Monthly Level 3 Data](#), NASA GES DISC.
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Sources: Data Processing Levels, NASA EarthData. FLUID visualization page for GEOS-CF surface Ozone forecast, NASA GMAO.
Satellite Air Quality Data Products for EJ
Relevant Prior ARSET Advanced Training

- ARSET - MODIS to VIIRS Transition for Air Quality Applications
# MODIS and VIIRS

<table>
<thead>
<tr>
<th>MODIS</th>
<th>VIIRS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aqua, Terra</strong></td>
<td><strong>Satellites</strong></td>
</tr>
<tr>
<td>1999, 2002</td>
<td><strong>Launched</strong></td>
</tr>
<tr>
<td>Moderate Resolution Imaging Spectroradiometer</td>
<td><strong>Instrument</strong></td>
</tr>
<tr>
<td>405 - 14385 nm (IR, Visible)</td>
<td><strong>Spectral Range</strong></td>
</tr>
<tr>
<td>36</td>
<td><strong>Spectral Bands</strong></td>
</tr>
<tr>
<td>0.5 – 2 km pixel edge</td>
<td><strong>Spatial Resolution</strong></td>
</tr>
<tr>
<td>1-2 Days</td>
<td><strong>Global Coverage</strong></td>
</tr>
<tr>
<td>~ 10:30, 13:30 LST</td>
<td><strong>Local Overpass Time</strong></td>
</tr>
<tr>
<td><strong>SNPP, NOAA-20, NOAA-21</strong></td>
<td><strong>Visible Infrared Imaging Radiometer Suite</strong></td>
</tr>
<tr>
<td>2011, 2017, 2022</td>
<td><strong>Daily</strong></td>
</tr>
<tr>
<td>~ 12:30, 13:30 LST</td>
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</tbody>
</table>
# MODIS and VIIRS: Air Quality Data Products

<table>
<thead>
<tr>
<th>MODIS</th>
<th>VIIRS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>True Color Image</strong></td>
<td><strong>True Color Image</strong></td>
</tr>
<tr>
<td>MOD/MYD04_L2 (10km)</td>
<td>AERDB_L2_VIIRS (6km)</td>
</tr>
<tr>
<td>MOD/MYD04_3K (3km)</td>
<td>AERDT_L2_VIIRS (6km)</td>
</tr>
<tr>
<td>MCD19A2 (1km)</td>
<td>JRR-AOD (0.75km)</td>
</tr>
<tr>
<td>Gridded (1°)</td>
<td>Gridded (1°)</td>
</tr>
<tr>
<td><strong>Aerosol Optical Depth</strong></td>
<td><strong>Aerosol Optical Depth</strong></td>
</tr>
<tr>
<td>MOD/MYD04A1 (1km)</td>
<td>VNP12IMGTL_NRT</td>
</tr>
<tr>
<td><strong>Fire Detection</strong></td>
<td><strong>Fire Detection</strong></td>
</tr>
<tr>
<td>MOD/MYD04A1 (1km)</td>
<td>VJ114IMGTL_NDT</td>
</tr>
<tr>
<td><strong>Smoke &amp; Dust Detection</strong></td>
<td><strong>JRR-ADP (0.75km)</strong></td>
</tr>
<tr>
<td><strong>MODIS and VIIRS: Air Quality Data Products</strong></td>
<td><strong>MODIS and VIIRS: Air Quality Data Products</strong></td>
</tr>
</tbody>
</table>
Aerosol Optical Depth

MODIS-Aqua  
VIIRS-SNPP

Source: NASA Worldview

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
Aerosol Optical Depth Retrieval Algorithms

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Resolution</th>
<th>Best for Land</th>
<th>Best for Water</th>
<th>Best for Bright Surfaces</th>
<th>Best for Dark Surfaces</th>
<th>Issues</th>
<th>Best for Urban Areas</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep Blue (10km)</td>
<td>MOD/MYD04_L2</td>
<td>Land only</td>
<td>Land &amp; water</td>
<td>Land only, best for bright surfaces</td>
<td>Land &amp; water, best for dark surfaces</td>
<td>Higher resolution, issues in urban areas</td>
<td>Highest resolution, combine Aqua &amp; Terra</td>
<td></td>
</tr>
<tr>
<td>MAIAC (1km)</td>
<td>MCD19A2</td>
<td>Land only</td>
<td>Land &amp; water</td>
<td>Land only, best for bright surfaces</td>
<td>Land &amp; water, best for dark surfaces</td>
<td>Higher resolution, issues in urban areas</td>
<td>Highest resolution, combine Aqua &amp; Terra</td>
<td></td>
</tr>
</tbody>
</table>

Source: NASA Worldview
VIIRS Smoke and Dust Index

Source: NOAA JSTAR Mapper

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
Satellite-Derived Surface PM$_{2.5}$

- Examples of Level 4 products
- Combine satellite data with other information (models, surface monitors) to derive high spatial resolution maps of surface PM$_{2.5}$ (globally or locally)
- annual, monthly, and daily temporal resolution (with different approaches)
- 1km (or sometimes finer) spatial resolution
- May lag significantly behind real-time
- Many datasets available through NASA Socioeconomic Data and Applications Center (SEDAC)

Aerosol Optical Depth (AOD) with Geostationary Instruments

- Current geostationary satellites provide high temporal resolution (~10 min) full-disk imagery
- Multiple satellites form a global constellation for AOD
  - GOES-16 (East US, South America)
  - GOES-18 (West US, Pacific)
  - Himawari-8/9 (Japan)
  - GEO-KOMPSAT-2A (Korea)
  - Fengyun-4 (China)
  - GSAT (India)
  - Meteosat-12 (Europe, Africa)
- Instrument capabilities vary

Source: NOAA Aerosol Watch
Surface PM$_{2.5}$ from Geostationary AOD

**Sources:**
- NOAA Aerosol Watch
- Zhang & Kondragunta (2021) [Daily and Hourly Surface PM$_{2.5}$ Estimation from Satellite AOD](https://doi.org/10.1002/2018MS001355), Earth and Space Science.

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
Relevant Prior ARSET Intermediate Training

- ARSET - Accessing and Analyzing Air Quality Data from Geostationary Satellites
Fire Detection

Thermal Anomalies
• Detection of extreme temperatures
• Indicative of active burning
• Thick smoke can block signal
• May miss small fires

Fire Radiative Power (FRP)
• Rate of emitted radiative energy by a fire

Fire Radiative Energy (FRE)
• Time integrated FRP
• Correlation between FRE and fire emissions

Source: NASA FIRMS, 06 June 2023
Relevant Prior ARSET Intermediate Training

- ARSET - Satellite Observations and Tools for Fire Risk, Detection, and Analysis
- ARSET - Observaciones de Satélites y Herramientas para el Riesgo, Detección y Análisis de Incendios
Upcoming Mission: Multi-Angle Imager for Aerosols (MAIA)

Targetable satellite instrument coordinated with surface PM measurements & health studies

Source: MAIA Website
Relevant Prior ARSET Advanced Training

- ARSET - High Resolution NO2 Monitoring From Space with TROPOMI
# OMI and TROPOMI

<table>
<thead>
<tr>
<th><strong>OMI (NASA)</strong></th>
<th><strong>TROPOMI (ESA)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aura</strong></td>
<td><strong>Sentinel-5P</strong></td>
</tr>
<tr>
<td><strong>July 2004</strong></td>
<td><strong>Launched</strong></td>
</tr>
<tr>
<td><strong>Nadir-Viewing Imaging Spectrometer</strong></td>
<td><strong>Instruments</strong></td>
</tr>
<tr>
<td><strong>Spectral Range</strong></td>
<td><strong>270 nm – 2.3 μm (UV/VIS/NIR/SWIR)</strong></td>
</tr>
<tr>
<td><strong>Spatial Resolution</strong></td>
<td><strong>0.55 nm</strong></td>
</tr>
<tr>
<td><strong>Global Coverage</strong></td>
<td><strong>Daily</strong></td>
</tr>
<tr>
<td><strong>Local Overpass Time</strong></td>
<td><strong>Daily</strong></td>
</tr>
</tbody>
</table>

**OMI (NASA):**
- **Spectral Range:** 264 – 504 nm (UV/VIS)
- **Spatial Resolution:** 0.42 – 0.63 nm
- **Global Coverage:** Daily
- **Local Overpass Time:** ~ 13:45 LST

**TROPOMI (ESA):**
- **Spectral Range:** 270 nm – 2.3 μm (UV/VIS/NIR/SWIR)
- **Spatial Resolution:** 5.5 x 3.5 km² at Nadir
- **Local Overpass Time:** ~ 13:30 LST
## OMI and TROPOMI: Trace Gas Data Products

<table>
<thead>
<tr>
<th>OMI (NASA)</th>
<th>TROPOMI (ESA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropospheric and Total Column NO₂</td>
<td>Tropospheric and Total Column NO₂</td>
</tr>
<tr>
<td>Swath, Gridded (0.25° and 0.1°)</td>
<td>Swath (5.5 km x 3.5km)</td>
</tr>
<tr>
<td>Total Column SO₂</td>
<td>Total Column SO₂</td>
</tr>
<tr>
<td>Swath, Gridded (0.25°)</td>
<td>Swath (5.5 x 3.5 km)</td>
</tr>
<tr>
<td>Total Column HCHO</td>
<td>Tropospheric Column HCHO</td>
</tr>
<tr>
<td>Swath, Gridded (0.1°)</td>
<td>Swath (5.5 x 3.5 km)</td>
</tr>
<tr>
<td>Tropospheric and Total Column O₃</td>
<td>Tropospheric, Total Column O₃, Profiles</td>
</tr>
<tr>
<td>Gridded (0.25°)</td>
<td>Swath (5.5 x 3.5 km)</td>
</tr>
<tr>
<td></td>
<td>Carbon Monoxide (CO)</td>
</tr>
<tr>
<td></td>
<td>Swath (7 km x 5.5 km)</td>
</tr>
<tr>
<td></td>
<td>Methane (CH₄)</td>
</tr>
<tr>
<td></td>
<td>Swath (7 km x 5.5 km)</td>
</tr>
</tbody>
</table>
Ozone

- Negative health impacts for humans, crops, and ecosystems
- Important to tropospheric chemistry
- High stratospheric concentrations (Ozone layer) mask more air-quality-relevant tropospheric concentrations
- Use of satellite Ozone is not recommended for air quality applications at this time.

Source: NASA Ozone Watch
Nitrogen Dioxide

- Surface sources: fire, agricultural burning, transportation, industry, power generation
- High concentrations in the planetary boundary layer (PBL)

OMI: long data record
- OMNO2 Level 2 product
- OMNO2g gridded product
- OMNO2d daily Level 3 Product

TROPOMI: high resolution
- S5P_L2__NO2____HiR Level 2 product
- Available from NASA Earthdata by agreement with ESA

Source: NASA GES DISC

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Formaldehyde

- Precursor for $O_3$; allows indirect estimates for near-surface $O_3$ potential using HCHO/NO$_2$ ratios
  - HCHO/NO$_2$ < 1: VOC-Limited
  - HCHO/NO$_2$ > 2-4: NO$_X$-Limited

OMI: long data record
- OMHCHO Level 2 product
- OMHCHOg gridded products
- OMHCHOd daily Level 3 product

TROPOMI: high resolution
- S5P_L2__HCHO___HiR_2
- Available from NASA Earthdata by agreement with ESA

Source: Souri et al. (2023) Characterization of errors in satellite-based HCHO/NO2 tropospheric column ratios with respect to chemistry, column-to-PBL translation, spatial representation, and retrieval uncertainties. Atmospheric Chemistry & Physics.
Sulfur Dioxide

- Satellites are generally better suited to large sources: volcanoes, coal & oil burning, smelting.

OMI: long data record
- OMSO2 Level 2 product
- OMSO2e gridded product, assumes near-surface emissions: most relevant to air quality applications

TROPOMI: high resolution
- S5P_L2__SO2____HiR
- Available from NASA Earthdata by agreement with ESA

Source: NASA Worldview

TROPOMI SO\textsubscript{2} Plume (lower troposphere) from Mauna Loa Eruption, Nov. 30, 2022
**Carbon Monoxide and Methane**

**CO**
- Major precursor for O$_3$
- Relatively long lifetime (~1-2 months) makes it a useful tracer
- TROPOMI: S5P_L2__CO___HiR

**CH$_4$**
- Potent greenhouse gas
- “Super-emitter” point sources (e.g., natural gas leaks)
- Distributed sources are hard to quantify from the ground (e.g., agriculture)
- TROPOMI: S5P_L2__CH4___HiR

Source: [NOAA JSTAR Mapper](https://www.star.nascom.nasa.gov/)

TROPOMI CO from various wildfires, July 9, 2022
Satellite-Derived Surface Trace Gases

- Examples of Level 4 products
- Combine satellite data with other information (models, surface monitors) to derive high spatial resolution near-surface trace gas concentration
- Annual to daily temporal resolution (with different approaches)
- 1km or finer (50m) spatial resolution
- May lag significantly behind real-time
- Datasets are available through the [NASA Socioeconomic Data and Applications Center (SEDAC)](https://sedac.cio.nasa.gov)

**2010-2012 Average Surface NO\textsubscript{2} from GOME, GOME-2, and SCIAMACHY**

Data in [NASA SEDAC](https://sedac.cio.nasa.gov)
Visualization in [NASA Worldview](https://worldview.earthdata.nasa.gov)

Sources: Di et al. (2020) *Assessing NO2 Concentration and Model Uncertainty with High Spatiotemporal Resolution...* Env. Sci. & Tech.
Larkin et al. (2023) *A global spatial-temporal land use regression model for nitrogen dioxide air pollution*, Frontiers in Env. Sci.
Tropospheric Emissions: Monitoring of POllution (TEMPO)

Proxy TEMPO Tropospheric NO₂ 20130809 1000 UTC

Geostationary instrument providing **hourly trace gas products** over North America
Launched April 7, 2023, Level 2 & 3 data products **expected April 2024**

Sources: Animation provided by Aaron Naeger, TEMPO applications & early adopter program
[TEMPO Website](https://tempo.gsfc.nasa.gov/)

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
I want to track trends in particulate matter from 2000 to 2020, comparing averages across US states to see if different state-level policies have had different impacts on particulate concentrations.

Which of these satellite instruments would be my best choice?

A: MODIS
B: VIIRS
C: OMI
D: TROPOMI
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Which of these satellite instruments would be my best choice?

✓ A: MODIS
B: VIIRS
C: OMI
D: TROPOMI
Accessing & Visualizing Remote Sensing Data
NASA Worldview

- Application that allows the user to:
  - Interactively browse, save, or share satellite imagery layers
  - Download the data
- Some imagery available in near real time (NRT) or within 3 hours of observation

https://worldview.earthdata.nasa.gov/
NASA Worldview

https://worldview.earthdata.nasa.gov/

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
NASA Worldview: True-Color Imagery

[Image: NASA Worldview interface]

https://worldview.earthdata.nasa.gov/

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
NASA Worldview: Compare Multiple Layers

https://worldview.earthdata.nasa.gov/

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
NASA Earthdata Search

- A “one stop shop” for searching and downloading NASA Earth datasets
  - Filter & Search data products by keyword, instrument, processing level, etc.
  - Subset datasets in space and time
  - Generate lists of file names for download

https://search.earthdata.nasa.gov/search
NASA Earthdata Search: Select & Download TROPOMI Data

https://search.earthdata.nasa.gov/search

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
NASA Giovanni

- Allows the user to work with datasets without needing to download them
  - Select & subset Level 3 & 4 (gridded) NASA data products
  - Perform simple analysis (spatial & temporal averaging, differences)
  - Plot results (e.g., area colormaps, time series, scatterplots, correlation plots)

https://giovanni.gsfc.nasa.gov/giovanni/
NASA Giovanni

Choose Plot or Analysis Type

Choose Date and Time

Choose Region of Interest

Help/Info

Filter Datasets

Keyword Search

Dataset Details (Units, Resolution, Coverage)

Add Datasets for Analysis

https://giovanni.gsfc.nasa.gov/giovanni/

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
NASA Giovanni: Recurring Average Map

https://giovanni.gsfc.nasa.gov/giovanni/
NASA Giovanni: Time Series

https://giovanni.gsfc.nasa.gov/giovanni/

NASA ARSET – Satellite Data for Air Quality Environmental Justice and Equity Applications
Part 2: Summary
Summary

• Satellite remote sensing data can complement surface monitoring and other data sources to help fill in global and local data gaps in air quality information.

• Atmospheric column quantities (e.g., AOD) can relate to surface air quality parameters (e.g., PM$_{2.5}$) but are not the same; patterns and trends observed by satellites should be validated with ground-based data where possible.

• Spatial and/or temporal resolution and coverage of satellite data products varies, making different products suitable for different applications.

• For environmental justice applications, spatial and temporal resolution of satellite datasets should match or be finer than the desired scale of analysis.

• NASA provides resources for accessing and analyzing satellite datasets online.
Looking Ahead to Part 3

- Interactive Exercises for using Satellite and Demographic Data
  - EJSCREEN
  - Python

- Optional Activity
  - Use NASA Worldview and/or Giovanni to look at your hometown or an area of interest to you and overlay some of the data products we discussed today.
  - Try to find an interesting air quality event for the area and see how it shows up in the satellite data. What did you expect to see? What surprised you?
  - If you registered for the HAQAST Forum, feel free to post what you find there!
  - This is an optional exercise and is NOT part of the required homework.
Homework and Certificates

• Homework:
  – One homework assignment
  – Opens on 06/09/2023
  – Access from the training webpage
  – Answers must be submitted via Google Forms
  – Due by 20/09/2023

• Certificate of Completion:
  – Attend all three live webinars (attendance is recorded automatically)
  – Complete the homework assignment by the deadline
  – You will receive a certificate via email approximately two months after completion of the course.
Contact Information

Trainers:
• Carl Malings
  – carl.a.malings@nasa.gov

• ARSET Website
• Follow us on Twitter!
  – @NASAARSET
• ARSET YouTube

Visit our Sister Programs:
• DEVELOP
• SERVIR
Resources

- **NASA Worldview** (Visualize satellite data online)
- **NASA Earthdata Search** (Search for & download satellite data)
- **NASA Giovanni** (Analyze level 3 & 4 data online)
- **NASA HAQAST** (Health & Air Quality Applied Sciences Team)
  - Guide to getting started with satellite data
  - Health and Air Quality Community Forum
- **NASA Air Quality Data Pathfinder** (see next slide)
- **NASA GSFC Air Quality Observations from Space**
- **NASA SEDAC** (Socioeconomic Data and Applications Center)
- **Prior ARSET Health & Air Quality Trainings**
Air pollution is one of the largest global environmental and health threats. NASA provides data resources to better understand the movement of pollutants and the impact of events leading to poor air quality. This Pathfinder helps you access, and leverage data acquired from NASA’s satellite, airborne, and ground-based missions and campaigns.

Available Data Types:
• Aerosols
• Trace Gases (e.g., Nitrogen Dioxide, Sulfur Dioxide, Carbon Monoxide, etc.)
• Weather (e.g., Air Temperature, Clouds, Precipitation, etc.)
• Land Surface (e.g., Soil Moisture, Surface Reflectance, Topography, etc.)
• Human Dimensions

Data are from satellites, airborne and ground-based platforms, and models, including:
• AIRS
• AMSR2
• GPM
• MODIS
• OLI/TIRS
• OMI
• OMPS
• SMAP
• TROPOMI
• VIIRS
• GEOS
• MERRA-2

Visit the EARTHDATA Air Quality Data Pathfinder for more information:
• Commonly Used Datasets for Air Quality Research and Applications
• Tools for Using Data
• Resources for Applying and Connecting NASA Data
• GIS Resources
• Tips for Getting Help and Connecting with NASA experts
• Tutorials and more!
Thank You!