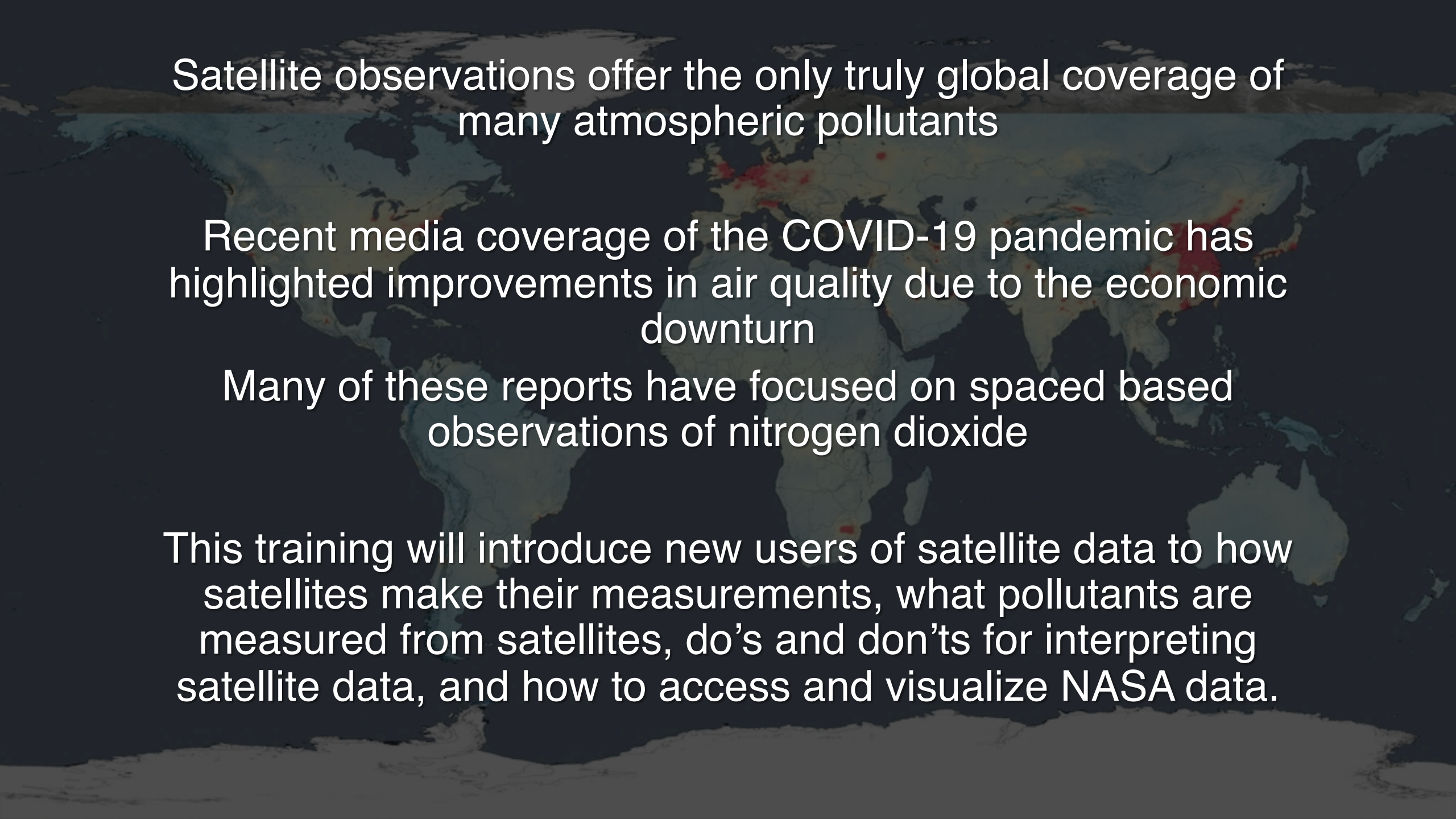


# Measuring Nitrogen Dioxide from Space

Melanie Follette-Cook, Ana Prados, and Pawan Gupta

An Inside Look at how NASA Measures Air Pollution, May 26 and 28, 2020

A world map with a dark, semi-transparent overlay. The map shows various regions highlighted in red and orange, primarily concentrated in East Asia, South Asia, and parts of Europe and Africa, representing areas of high air pollution or specific satellite observations.

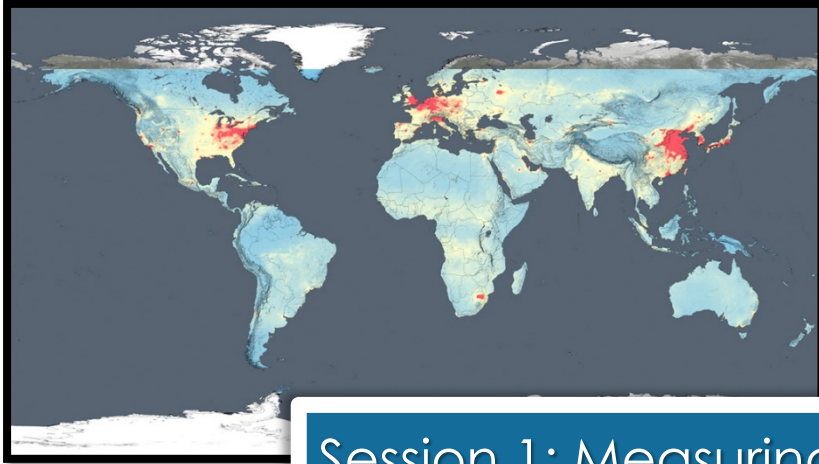
Satellite observations offer the only truly global coverage of many atmospheric pollutants

Recent media coverage of the COVID-19 pandemic has highlighted improvements in air quality due to the economic downturn

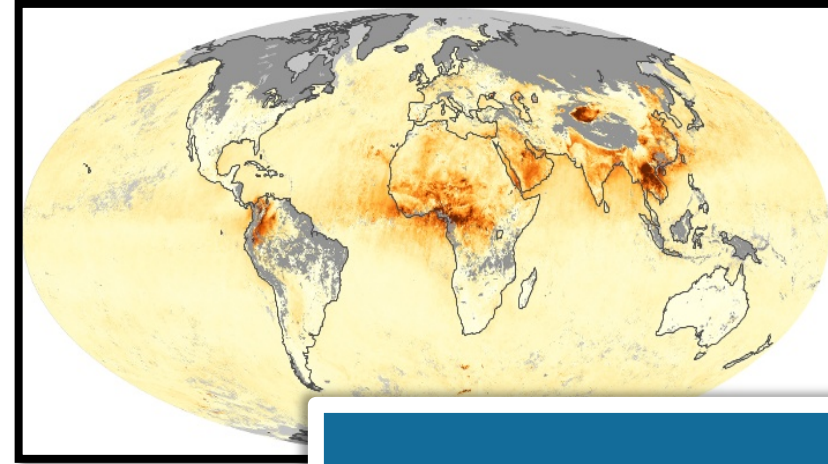
Many of these reports have focused on space based observations of nitrogen dioxide

This training will introduce new users of satellite data to how satellites make their measurements, what pollutants are measured from satellites, do's and don'ts for interpreting satellite data, and how to access and visualize NASA data.

# Webinar Agenda



Session 1: Measuring  
Nitrogen Dioxide from  
Space



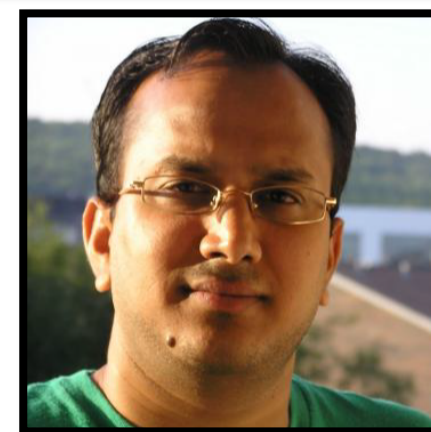
Session 2: Measuring  
Aerosols from Space



Melanie Follette-Cook  
NASA's Applied Remote Sensing Training Program



Ana Prados



Pawan Gupta



# ARSET Overview

## The Applied Remote Sensing Training Program

ARSET provides cutting edge remote sensing education through online and in-person trainings. These trainings are offered in a variety of formats that fit learners' needs and cover a variety of satellites, sensors, and applications.



[Website](#)

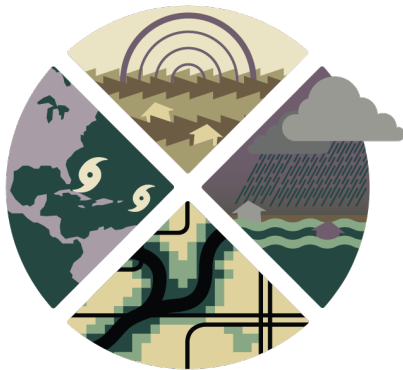
[YouTube](#)

[Twitter](#)

Air Quality



Disasters



Land



Water



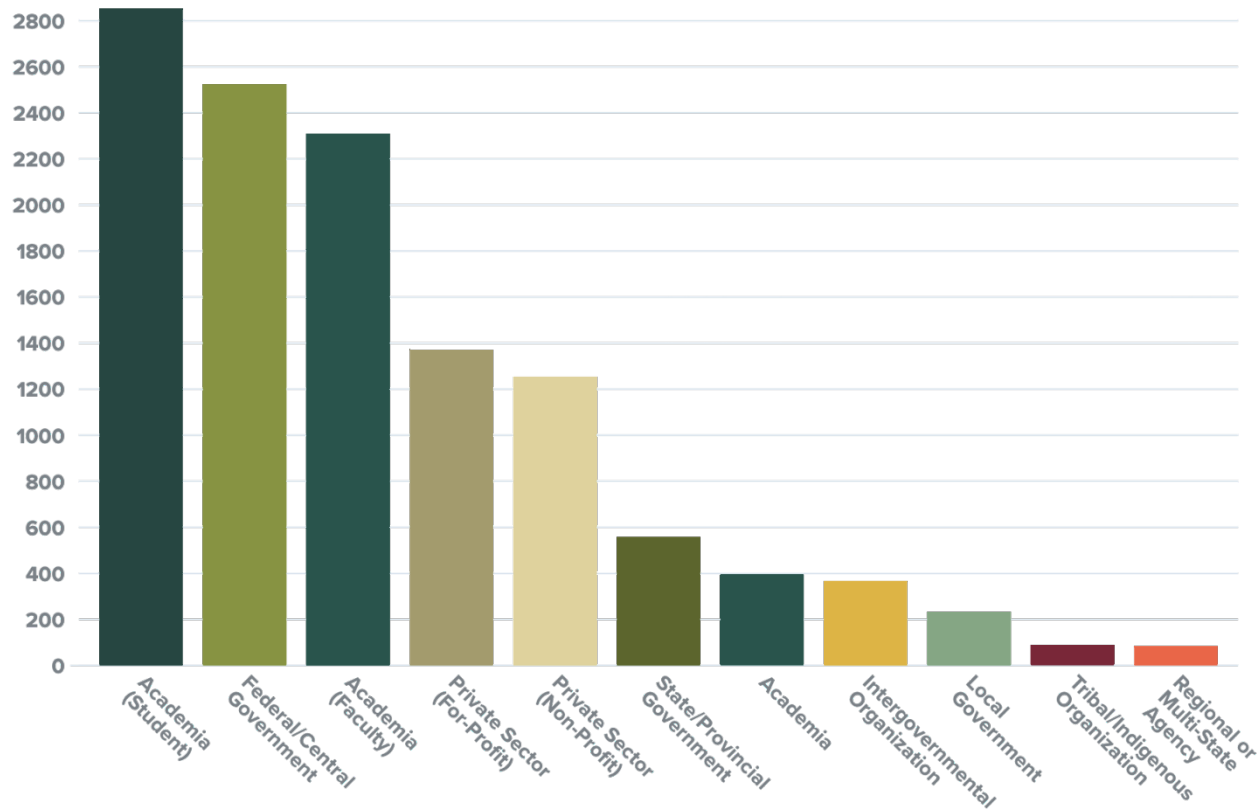
[Sign up for  
our mailing  
list!](#)



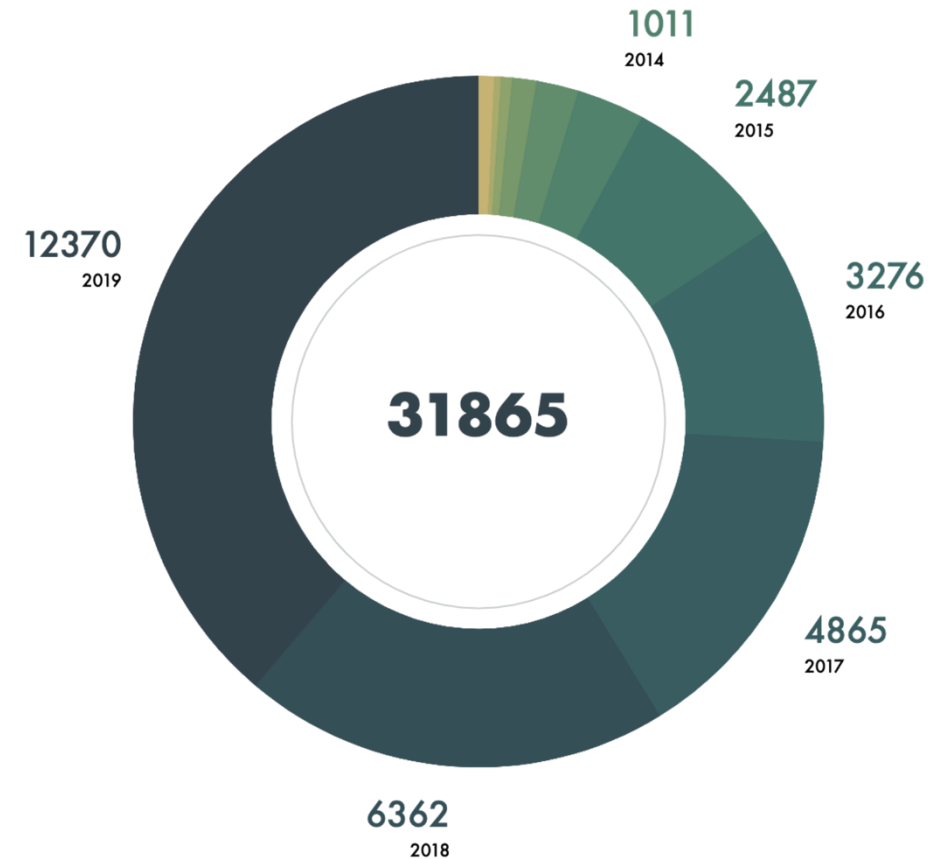
# ARSET Overview

## Notable Statistics

### Sector Breakdown



### Participation by Year



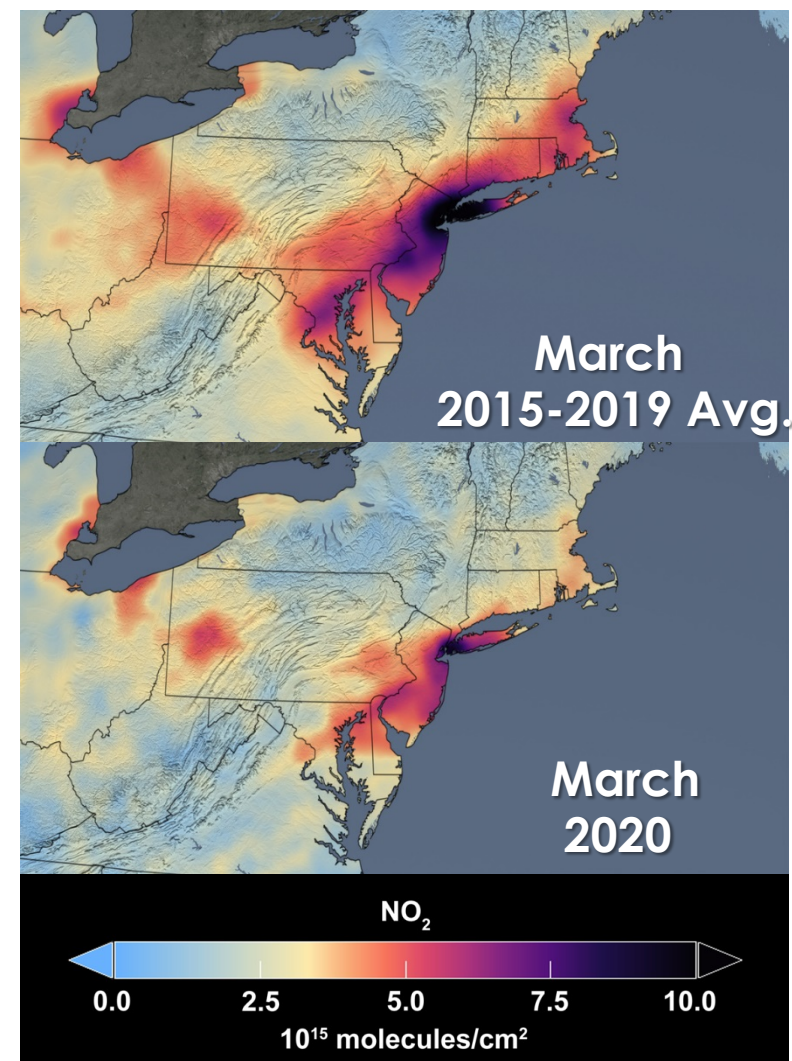
# Missions Covered by ARSET



# Learning Objectives

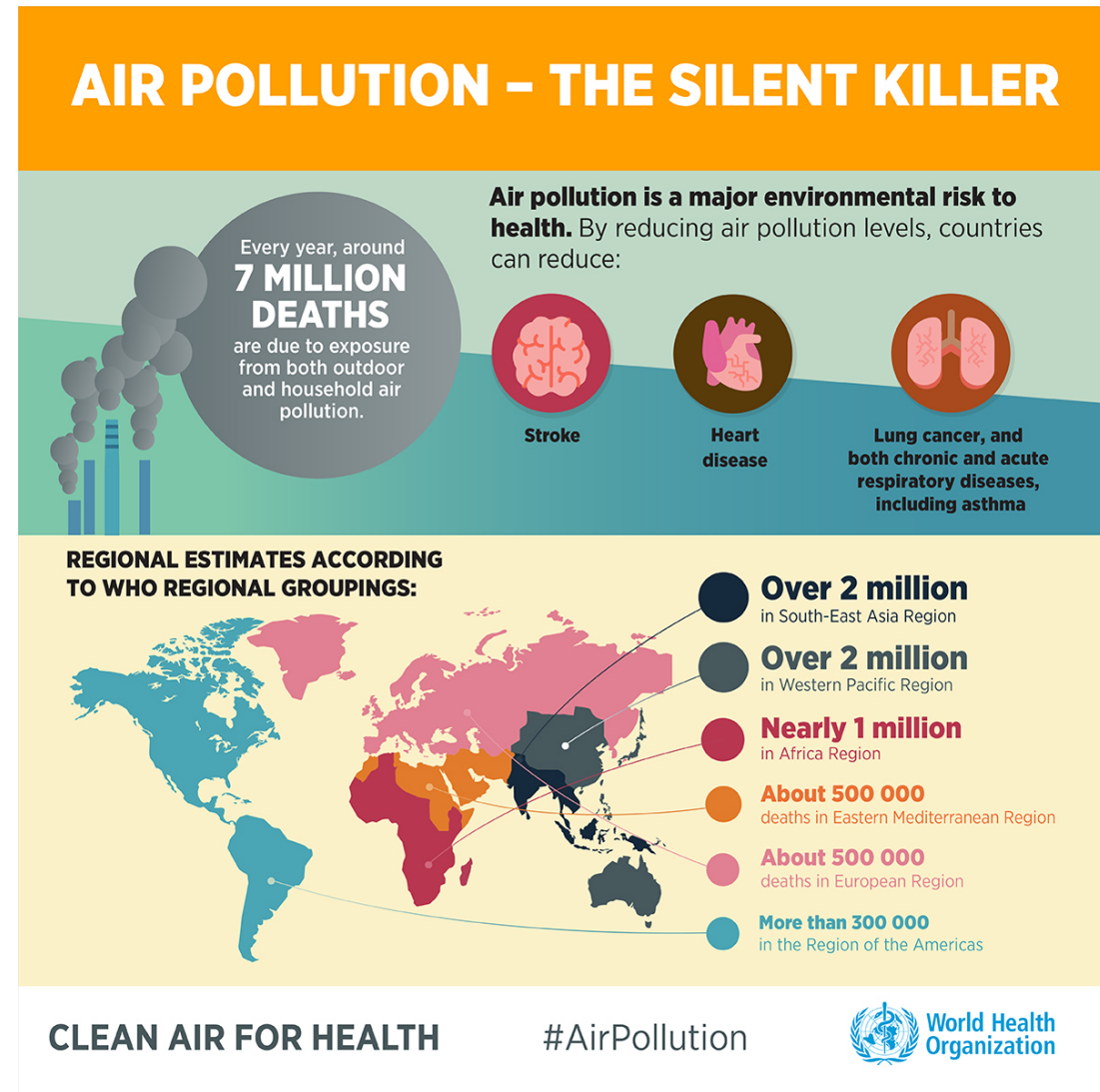
By the end of this presentation, you will be able to:

- Understand what satellites measure
- Explain what plots like these are showing
- Describe the capabilities and limitations of satellite NO<sub>2</sub> observations
- Find and download satellite imagery for NO<sub>2</sub>



# Global Burden of Air Pollution

- Air pollution was responsible for 4.2 million deaths in 2016.
  - 7.6% of all deaths in 2016
- 91% of the world's population lives in a region where air pollution levels exceed WHO guidelines.
- Some of these regions are the most poorly monitored.
- Satellite data can help quantify the impact on human health.



Source: <https://www.who.int/health-topics/air-pollution>





# Space-Based Observations Relevant for Air Quality

- **Gases**

- Ozone (O<sub>3</sub>)
- Carbon Monoxide (CO)
- Nitrogen Dioxide (NO<sub>2</sub>)
- Sulfur Dioxide (SO<sub>2</sub>)
- Greenhouse Gases (CO<sub>2</sub>, Methane)

Today's presentation focuses on **NO<sub>2</sub>**

- **Particles/Aerosols**

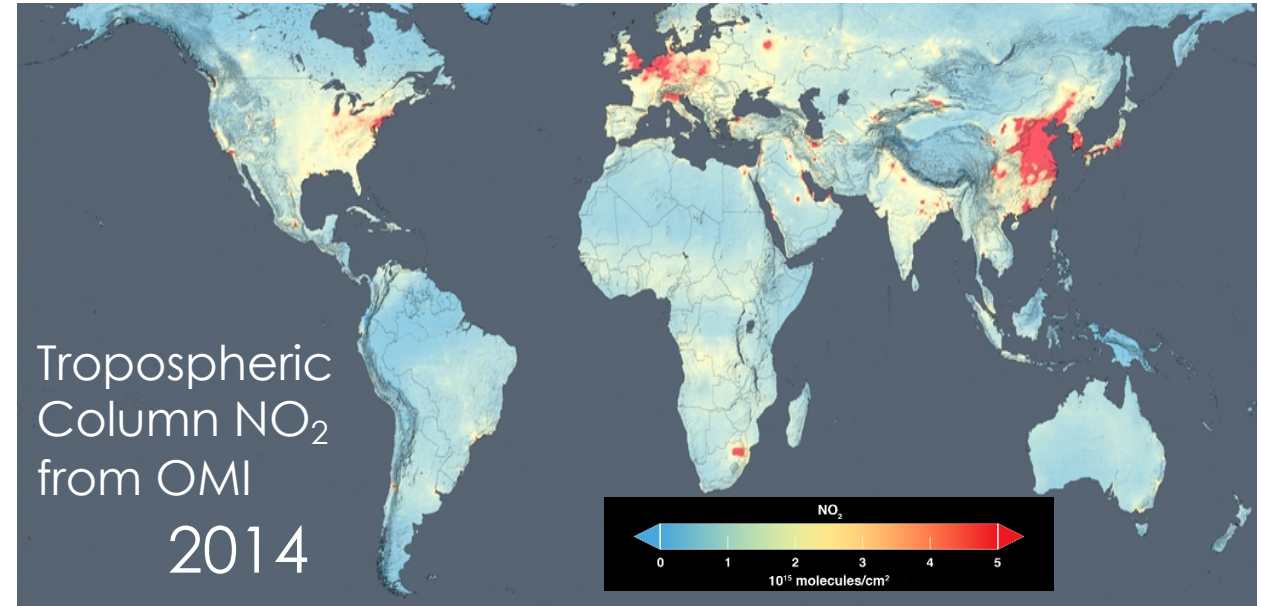
- True Color Imagery
- Aerosol Optical Depth

- **Fire Detection**



# Why does NASA measure NO<sub>2</sub>?

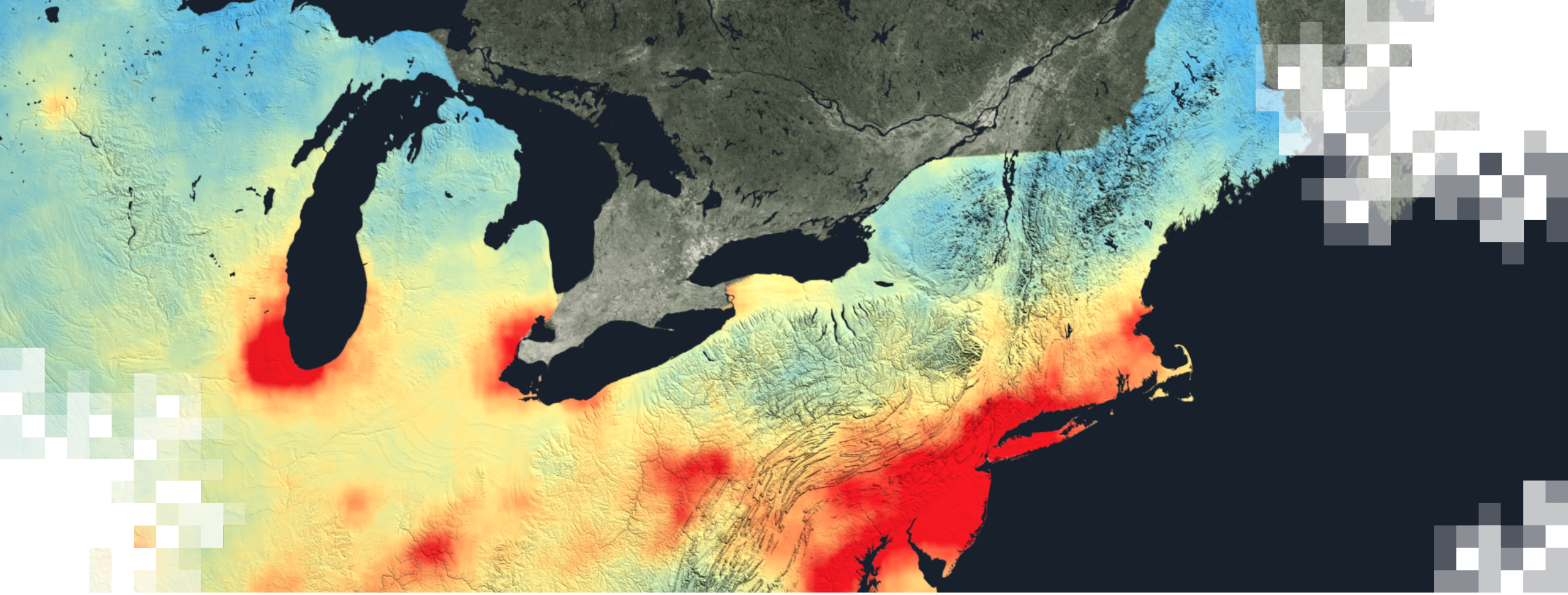
- NO<sub>2</sub> is a criteria pollutant regulated by the U.S. EPA (and in many other countries) and can be harmful to humans.
- Produces ozone, another pollutant
- Produces acid rain, which is detrimental to ecosystems
- Sources of NO<sub>2</sub>:
  - Lightning, fires, soils, combustion of fossil fuels (e.g., cars, power plants, manufacturing)



<https://svs.gsfc.nasa.gov/4412>

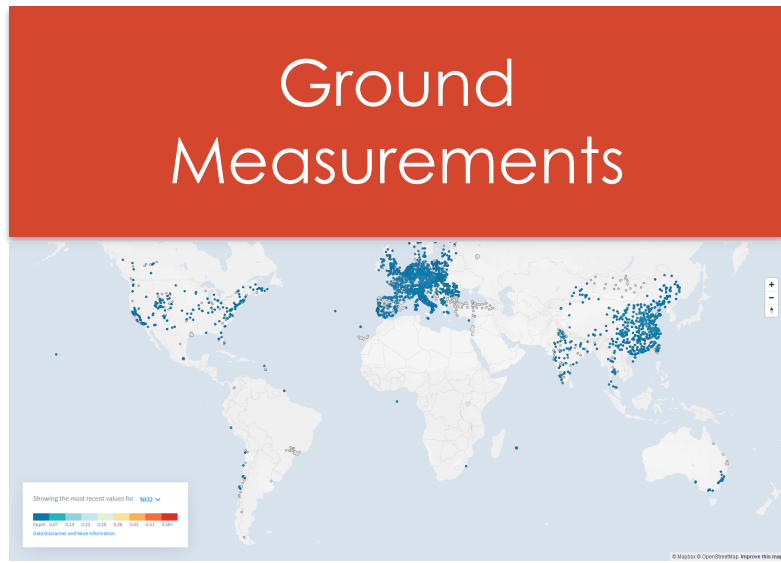
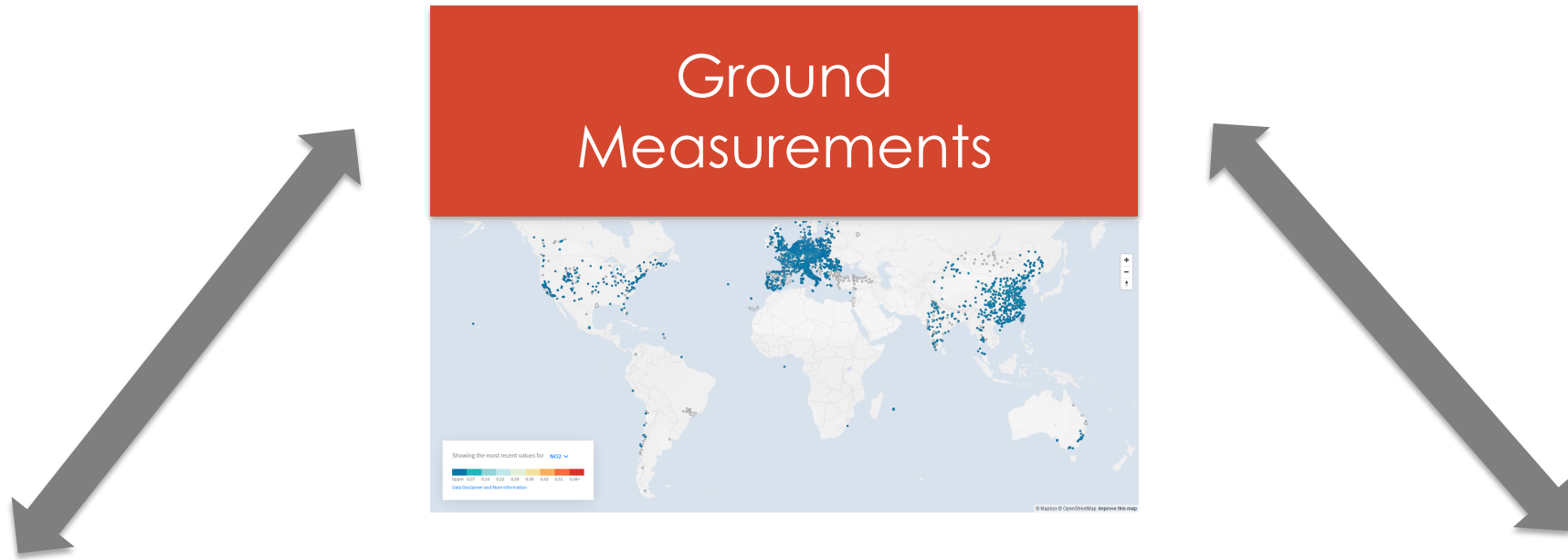
Most of the NO<sub>2</sub> pollution is at ground level, where ecosystems and people live and breathe.





# Remote Sensing Basics

# Air Pollution Monitoring



Air & Space Observations



Models

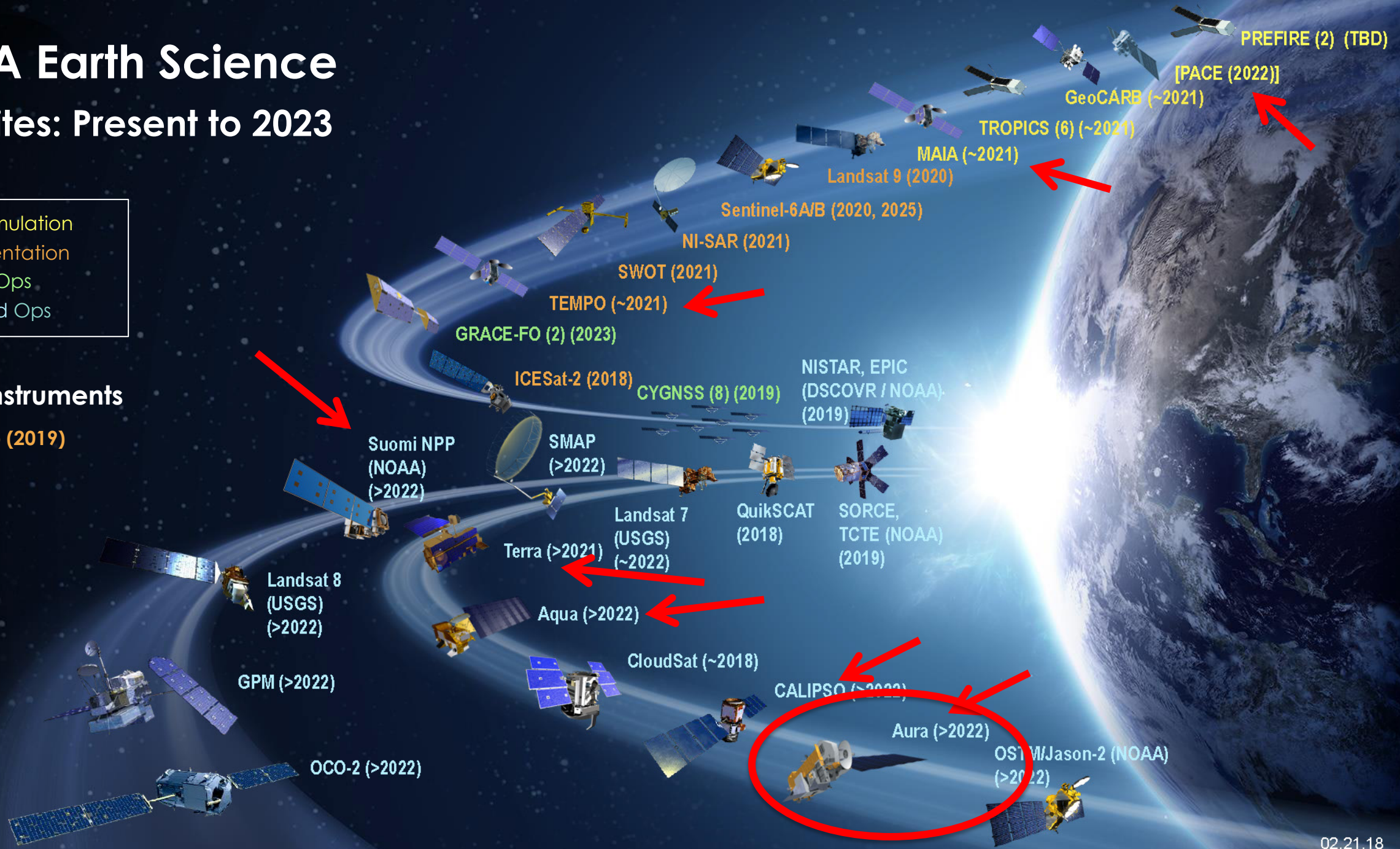


# NASA Earth Science Satellites: Present to 2023

- (Pre)Formulation
- Implementation
- Primary Ops
- Extended Ops

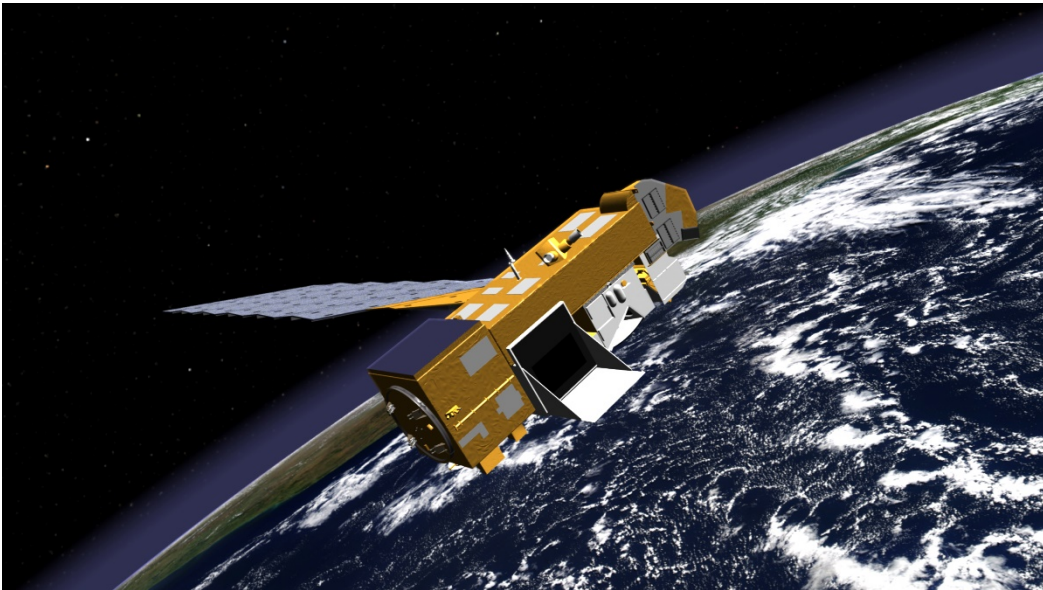
## JPSS-2 Instruments

OMPS-Limb (2019)

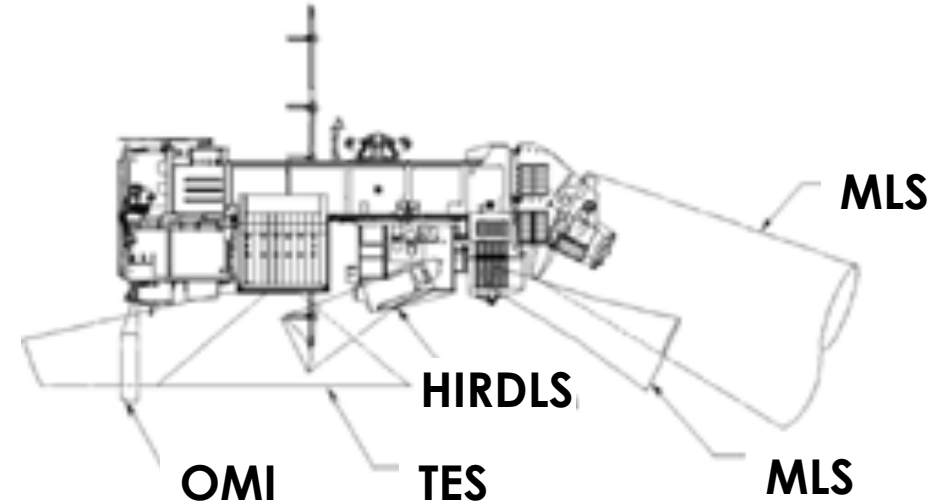


# Satellites vs. Instruments

1. NASA **satellites** carry one or more instruments.
2. Satellite **instruments** provide observations of the Earth and atmosphere.
3. The Aura Satellite, launched in 2004, carries the OMI instrument (among others).
4. OMI measures NO<sub>2</sub>! More on that later.



**Aura Satellite**



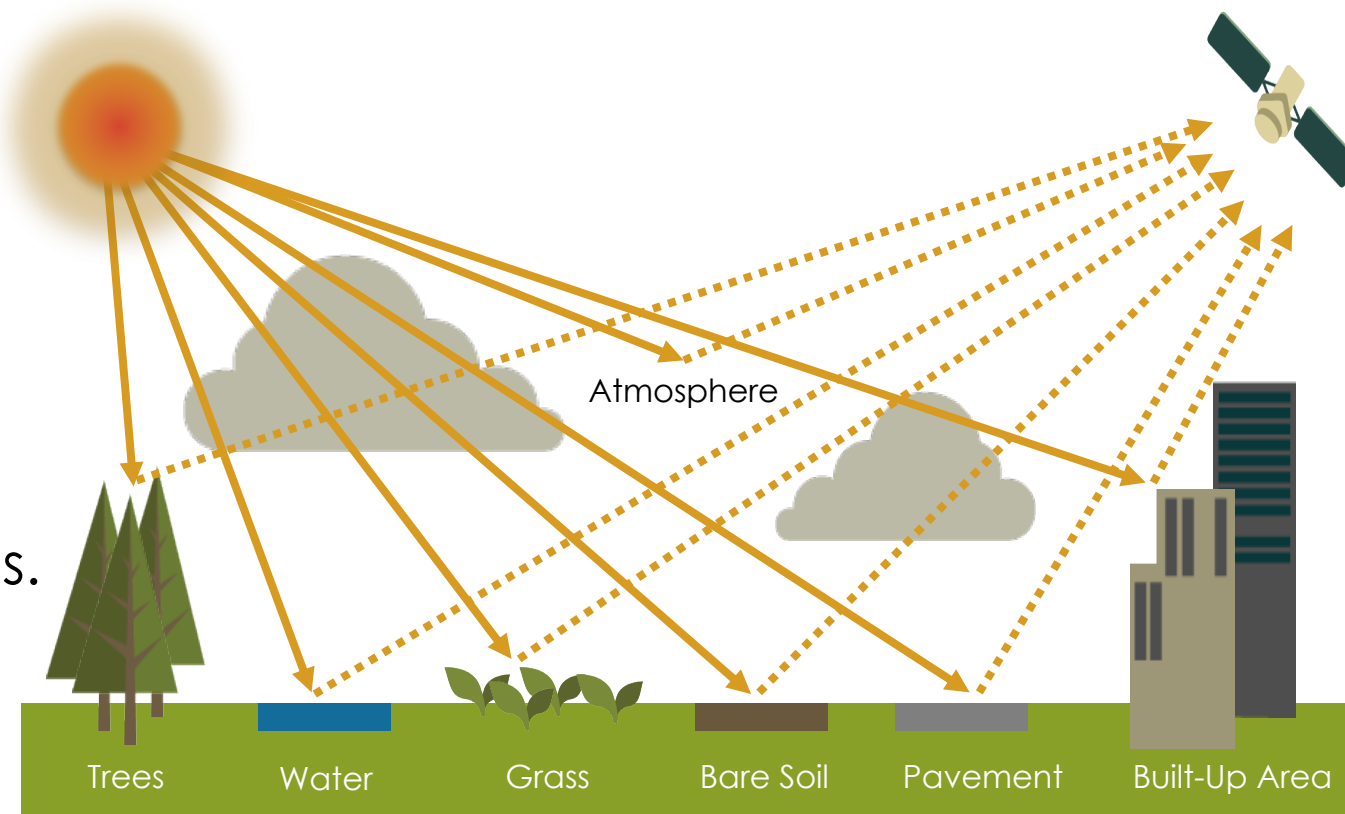
# What is remote sensing?

Collecting information about an object without being in direct physical contact with it.



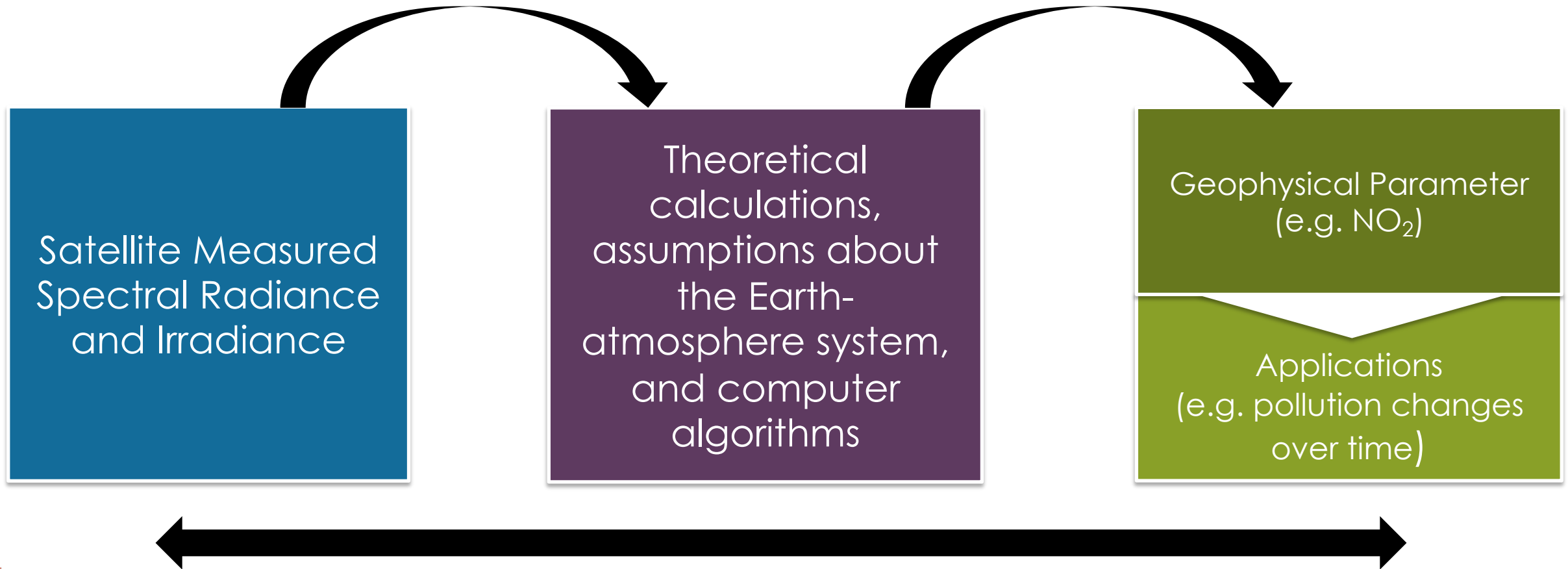
# What do satellite instruments measure?

- The intensity of reflected and emitted radiation to space is influenced by the surface and atmospheric conditions.
- Satellites instruments measure this reflected and emitted radiation, so they contain information about the surface and atmospheric conditions.
- We know the distinct absorption spectra of each trace gas.
- We can identify a “spectral fingerprint” for each atmospheric constituent.





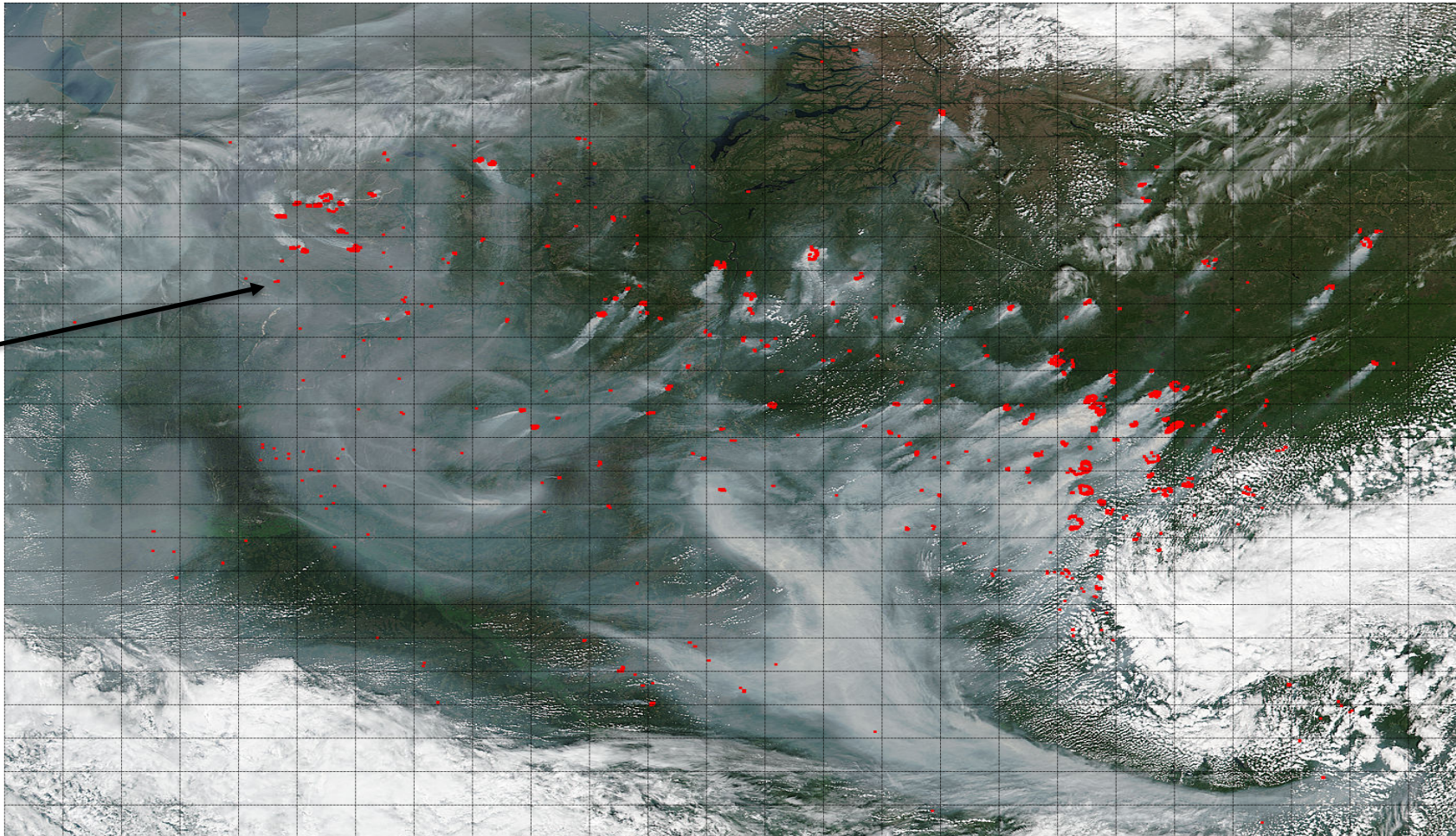
# How do we get from satellite measurements to images, and then to observed changes in air pollution over time?



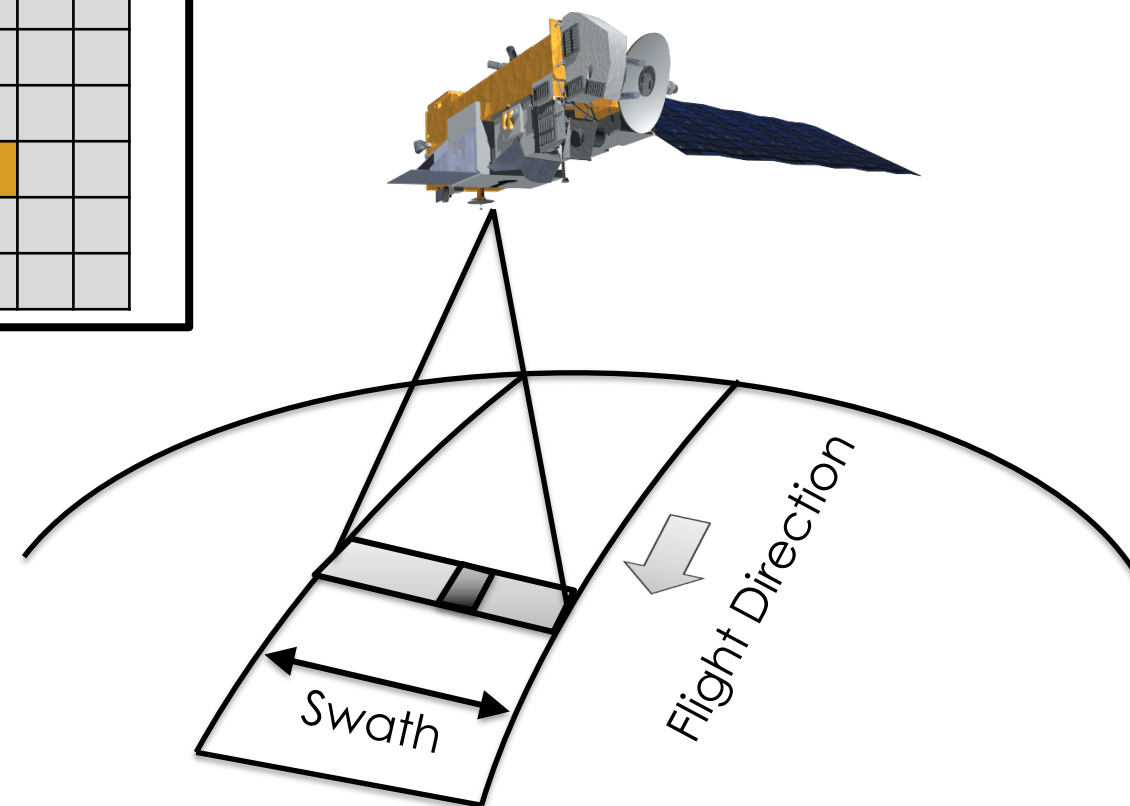
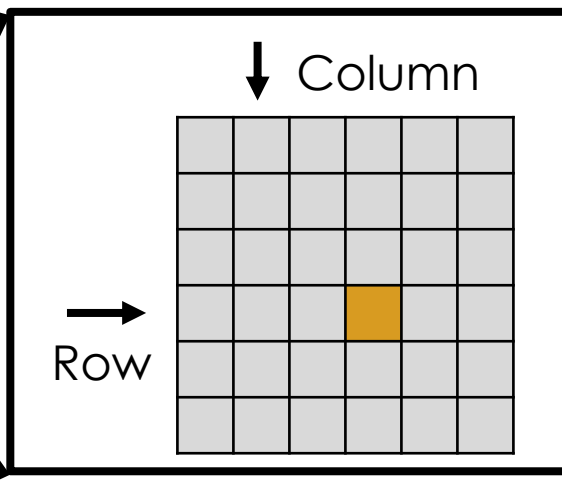
# “A Picture is Worth a Thousand Words”

A satellite picture is worth ~~a~~ **millions of data points.**

A geo-physical number



# Pixel – The Smallest Unit of an Image

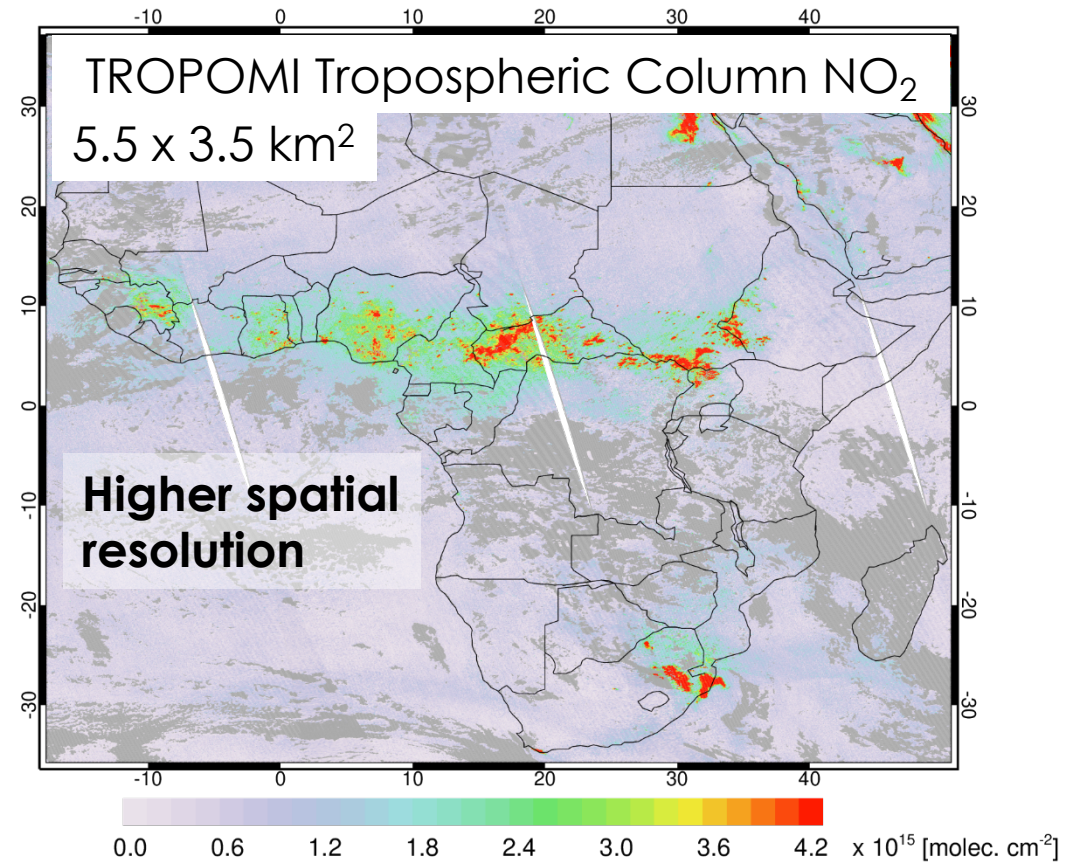
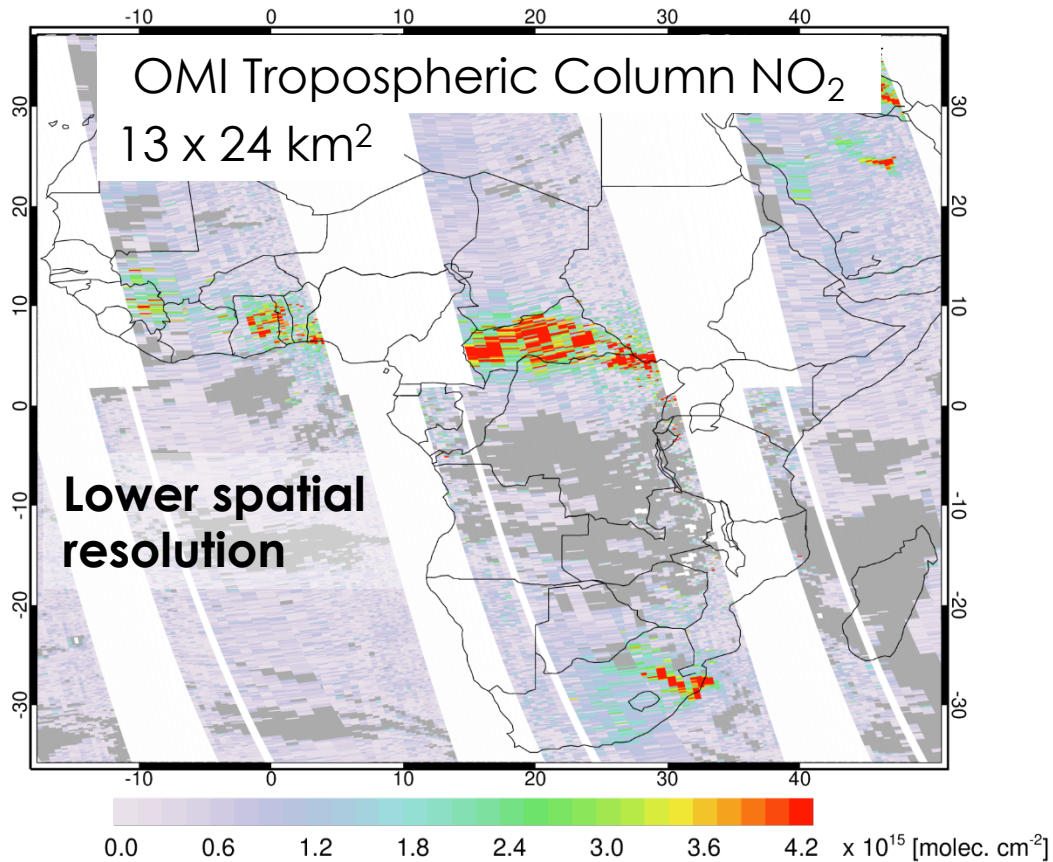


- An image is made up individual picture elements – called *pixels* – arranged in columns in rows.
- Each pixel represents an area on the Earth's surface and has a unique value.
- **Spatial resolution** is defined by the size of a pixel.

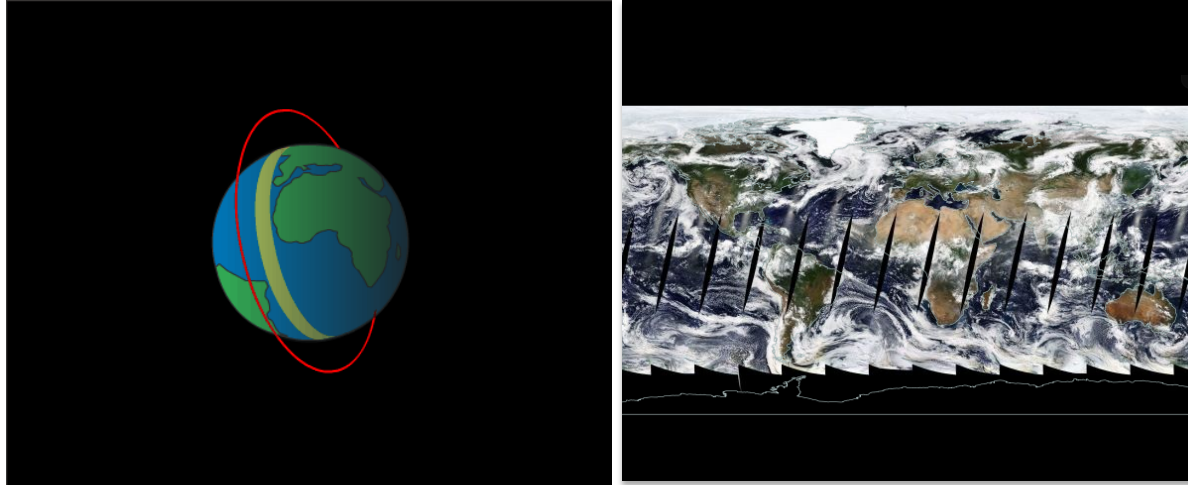


# Why is spatial resolution important?

Higher resolution means that we can identify more features.



# Where do satellites make measurements?

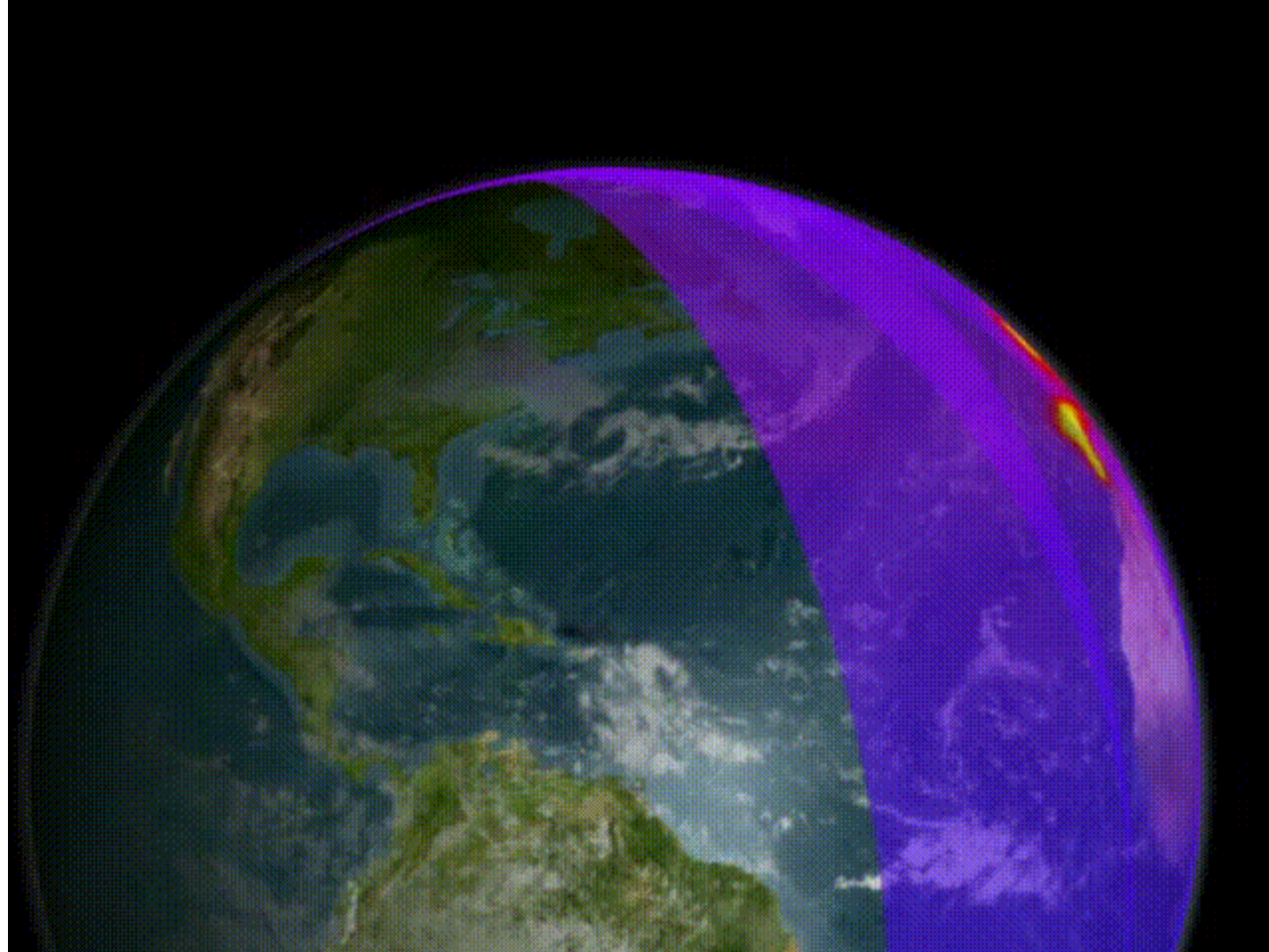


## Polar Orbit

- Fixed, circular orbit above Earth
- ~600-1,000 km above Earth
- Passes overhead at about the **same local solar time** each day
- ***Can provide global coverage***



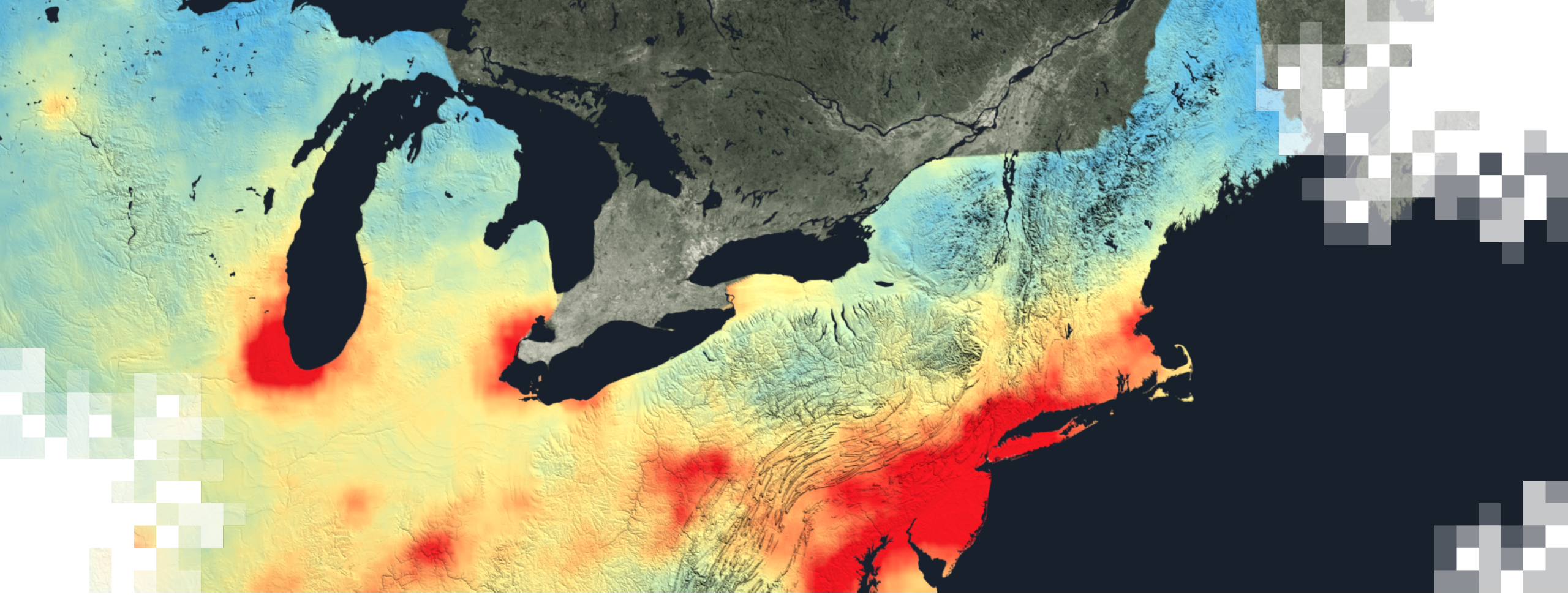
# Aura Collecting Observations from Polar Orbit



# How frequently do satellites provide observations?

- If the swath width of an instrument is large enough, polar orbiting satellites can provide a snapshot of global images every day.
- If the instrument's swath width leaves gaps between orbits, global coverage can take longer than one day (OMI provides global coverage in 1-2 days).





Ozone Monitoring Instrument (OMI)



# Ozone Monitoring Instrument (OMI)

- Launched July 15, 2004
  - NASA EOS Aura Satellite
  - 740 wavelength bands
  - 1:45 p.m. equatorial crossing time
  - Spatial resolution: 13x24 km<sup>2</sup> (but larger near the edges of the swath)
  - Temporal resolution: Global coverage in 1-2 days
- Types of Measurements
    - Total Column O<sub>3</sub>
    - Tropospheric Column O<sub>3</sub>
    - Aerosol optical depth (in UV)
    - Column Formaldehyde
    - Column NO<sub>2</sub>
    - **Tropospheric column NO<sub>2</sub>**
    - Column SO<sub>2</sub>



OMI data are freely available.

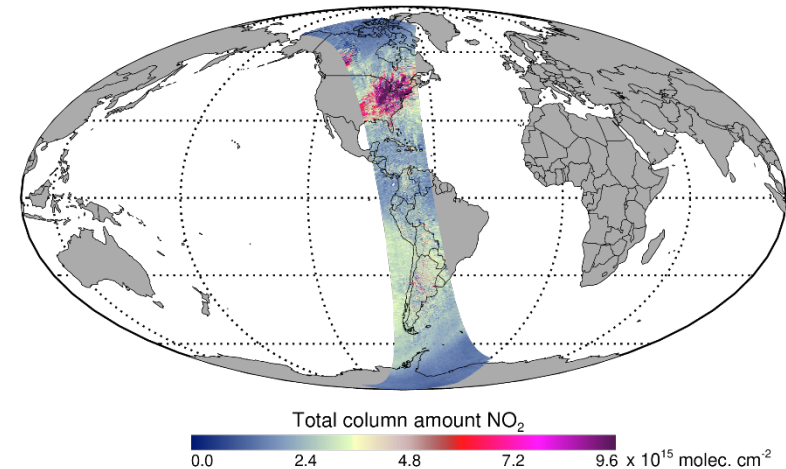


# OMI Nitrogen Dioxide (NO<sub>2</sub>) Data: Native Resolution

- OMI NO<sub>2</sub> data is available in its *native resolution* (also known as Level 2) at the GES DISC. Search for OMNO2.
- Each orbit = 1 OMI data file
- For advanced users, more information about OMI Level 2 data is freely available from ARSET's Advanced NO<sub>2</sub> webinar: <https://arset.gsfc.nasa.gov/airquality/webinars/advanced-NO2-2019>
- A readme file can be found here: [https://disc.gsfc.nasa.gov/datasets/OMNO2\\_003/summary](https://disc.gsfc.nasa.gov/datasets/OMNO2_003/summary)
- Level 2 data and images can typically be accessed within a day or two.

## OMNO2 Level 2 Native Resolution

Aura OMI OMNO2 (17:47 UTC October 11, 2006)



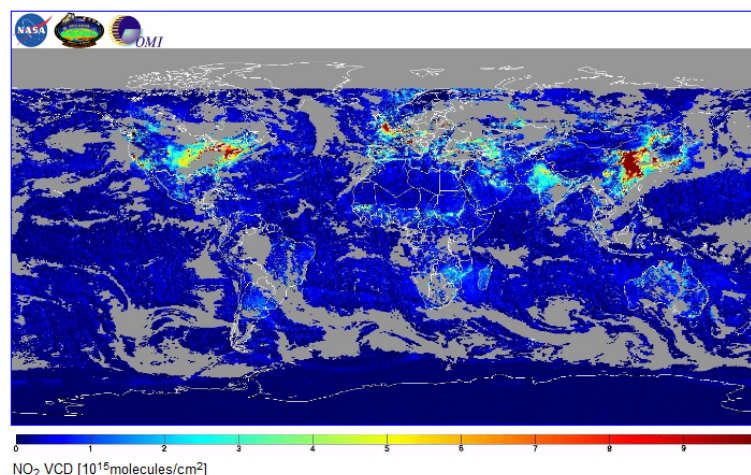
<https://disc.gsfc.nasa.gov/>



# OMI Data: Gridded Products

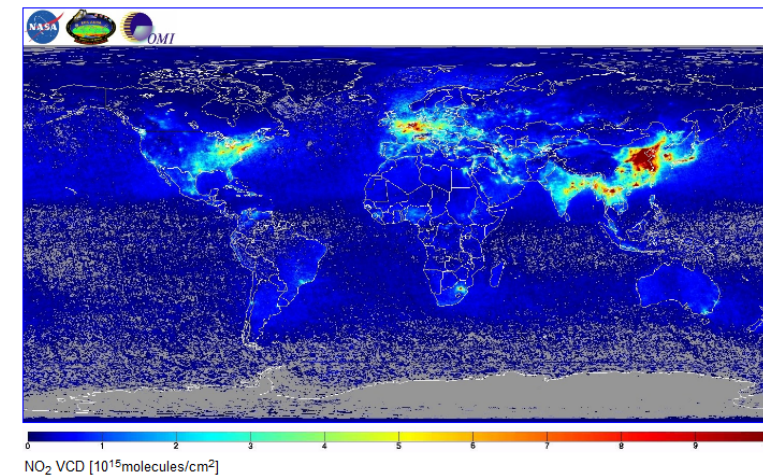
- NASA also provides OMI data on *uniform grids* (also known as Level 3).
- These can take a little longer to be available (few days).

OMNO2d Level 3 Gridded  
(0.25° x 0.25°)  
Daily, monthly



Daily - <https://disc.gsfc.nasa.gov/>  
(txt, hdf, netcdf)  
Monthly - <https://avdc.gsfc.nasa.gov/>  
(available txt, hdf5)

OMNO2d\_HR Level 3 Gridded  
(0.1° x 0.1°)  
Daily, monthly



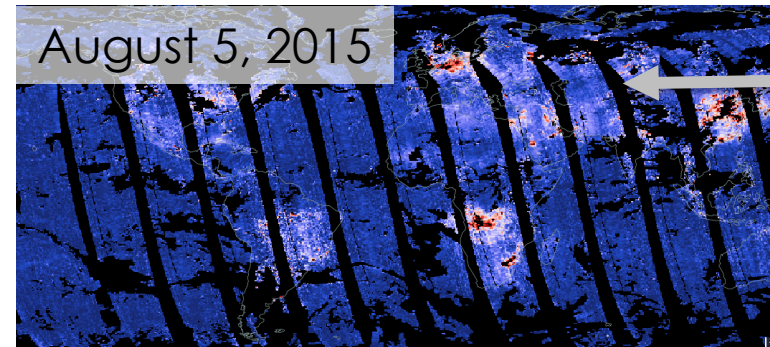
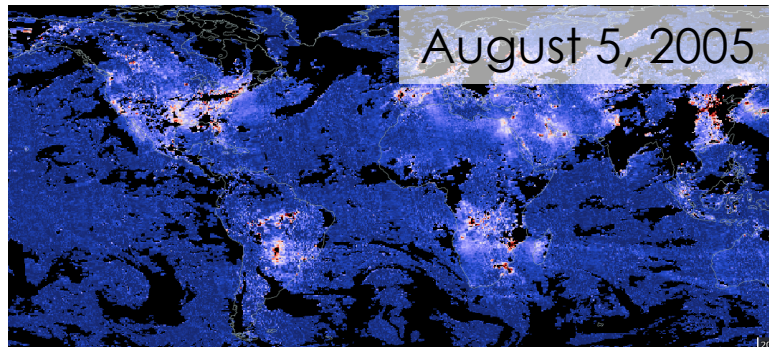
[https://avdc.gsfc.nasa.gov/pub/  
data/satellite/Aura/OMI/V03/L3/  
OMNO2d\\_HR/](https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L3/OMNO2d_HR/)  
Daily: hdf5  
Monthly: txt, netcdf



# Important Considerations When Using OMI NO<sub>2</sub> Data

- There has been 50% data loss from OMI since 2008 (the OMI row anomaly).
- If using native resolution Level 2 data, an advanced user must apply additional filters or quality flags contained in the data files.
- In gridded (Level 3) data, these quality flags have typically been applied.
- Disadvantages of Gridded Data: Can be coarser resolution, and loss of some information due to averaging of data from various pixels in order to generate the Level 3 grid.

OMI Tropospheric Column NO<sub>2</sub>



Loss of data  
due to row  
anomaly

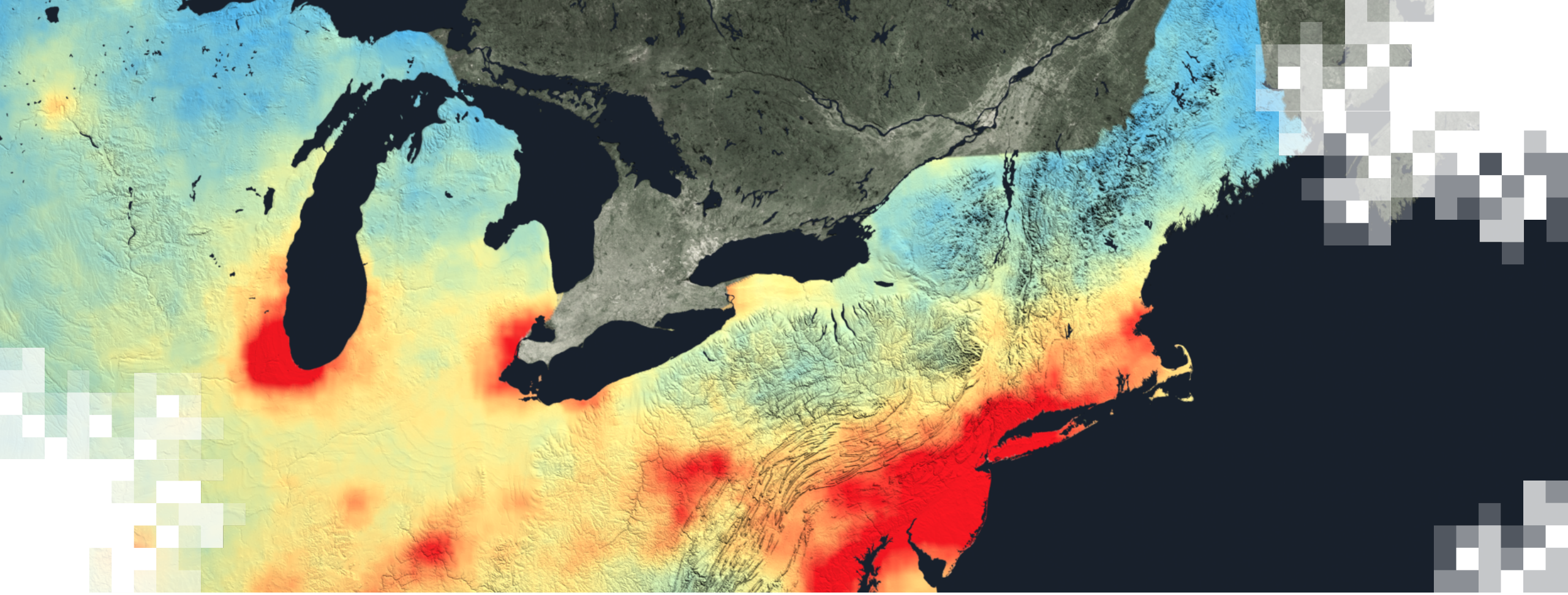


# What other satellite instruments measure NO<sub>2</sub>?

## TROPOMI

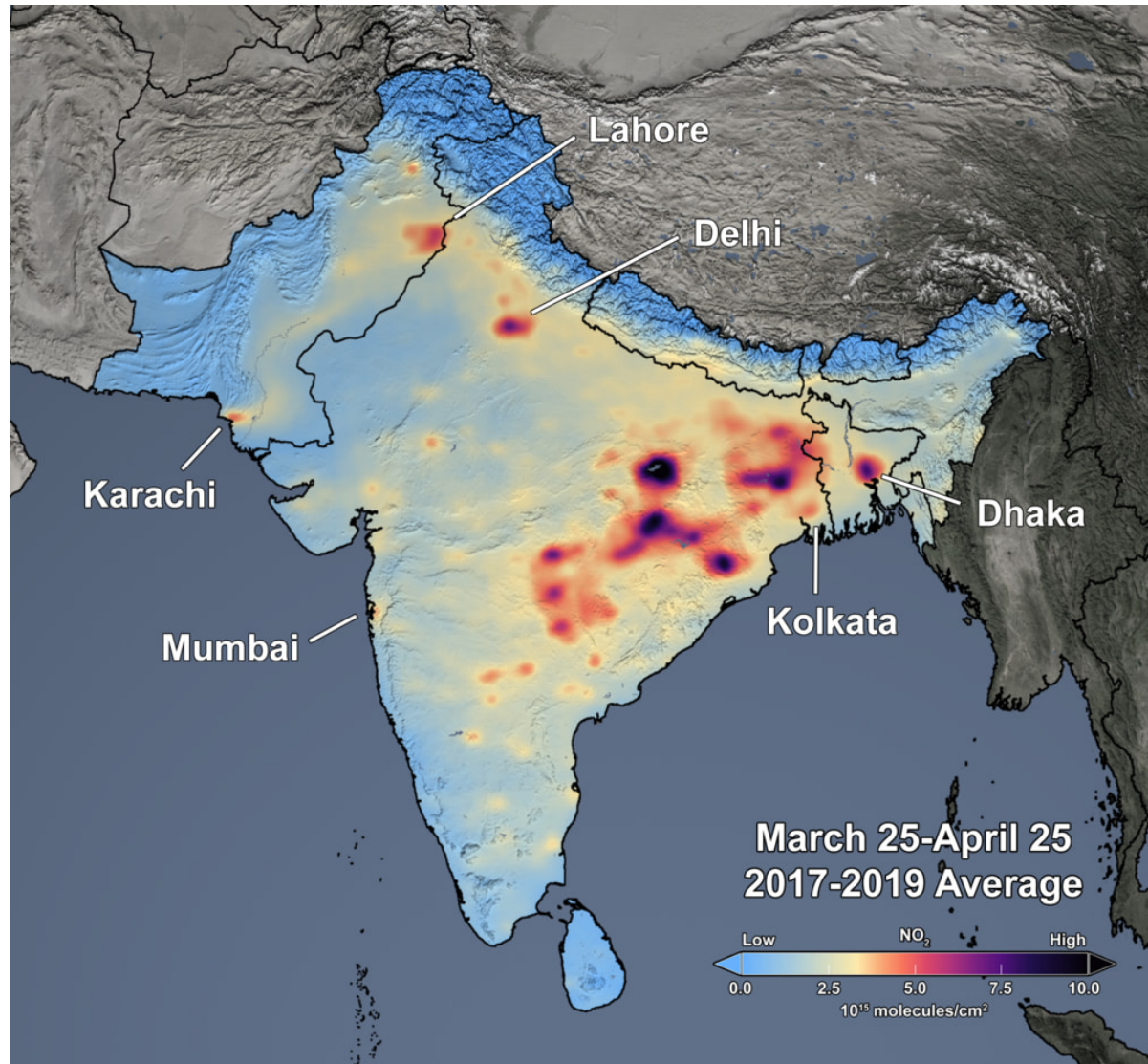
- Since March 2020, there have been numerous media reports showing global changes in NO<sub>2</sub> from the TROPOMI instrument.
- This is an instrument on the Sentinel-5P satellite from the European Space Agency.
- Also provides global coverage
- Higher spatial resolution than OMI: 5.5x3.5 km
- Shorter historical record (launched in 2017)
- To learn more about TROPOMI, you can listen to the recording of this ARSET training:
  - <https://arset.gsfc.nasa.gov/airquality/webinars/advanced-NO2-2019>



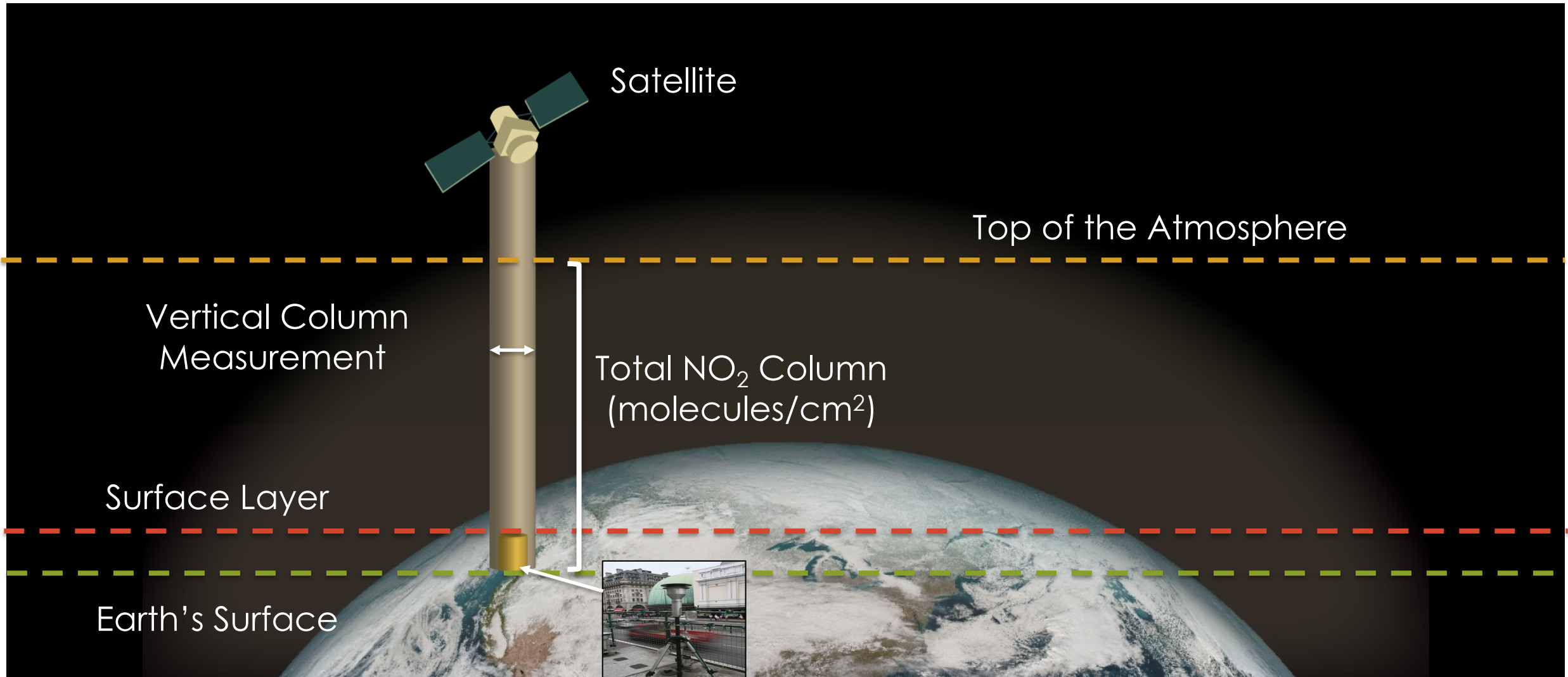


## Basics of NO<sub>2</sub> Image Interpretation

# What does this image mean, and what features can I see?



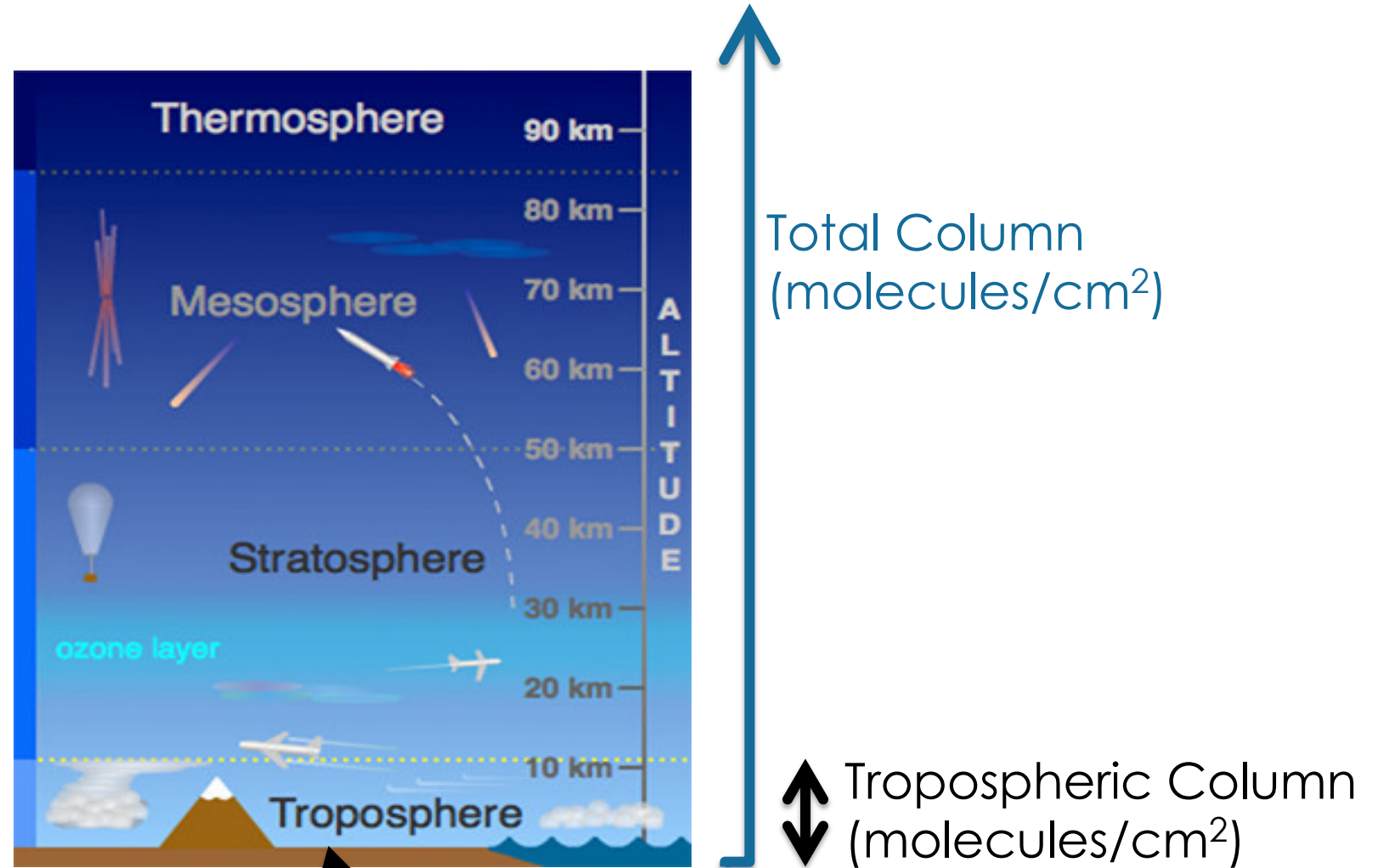
# Satellite vs. Ground-Based Instruments





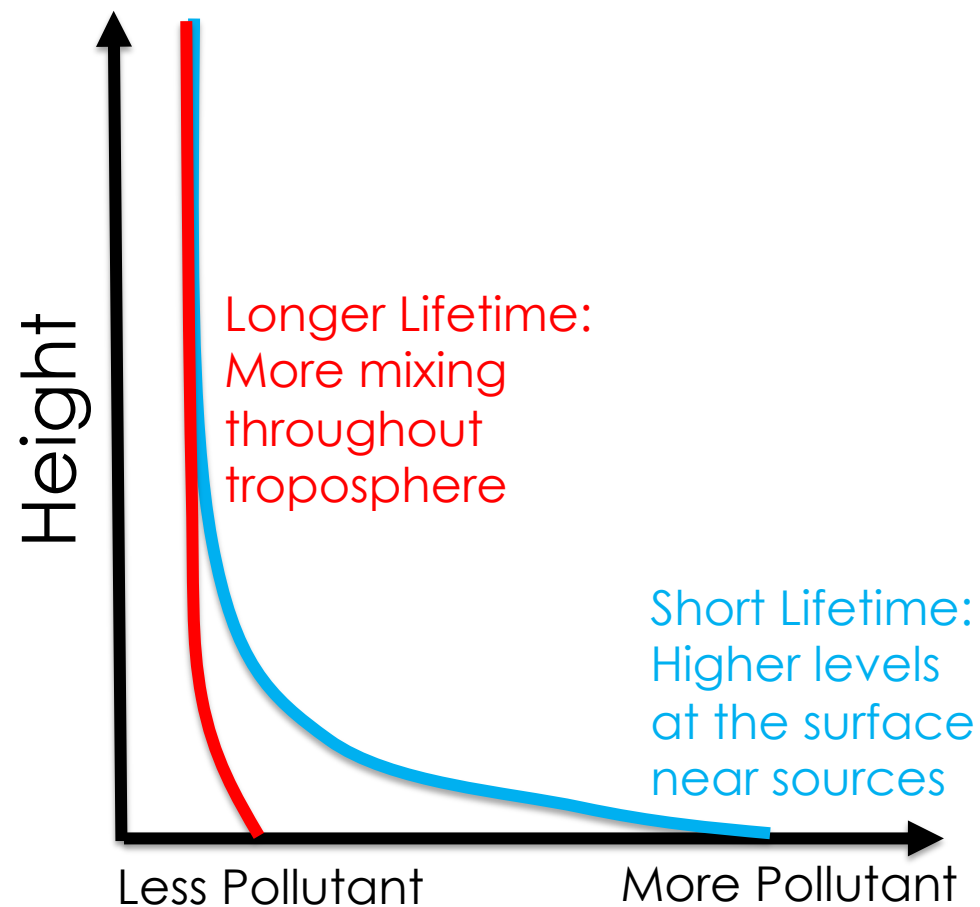
# The Total Column is Made Up of Atmospheric Layers

- The atmosphere is made up of layers; each one has distinct characteristics.
- We are going to focus on the *troposphere*.
  - Where we live
  - Lowest layer
  - Almost all weather and clouds occur here



# What can a tropospheric column tell me about the surface?

- Using information about pollution sources and atmospheric chemistry, we can infer information about the vertical distribution of a pollutant, including the amount near the surface.
- Where are the pollutant sources?
  - Most  $\text{NO}_2$  is emitted at the surface (e.g. vehicles, electrical generation).
- How long does it stay in the atmosphere?
  - Near the surface,  $\text{NO}_2$  is relatively short lived (a few hours), so pollution levels are much higher around a source.



# Changes in the NO<sub>2</sub> Column Can Give Us Information about Changes at the Surface

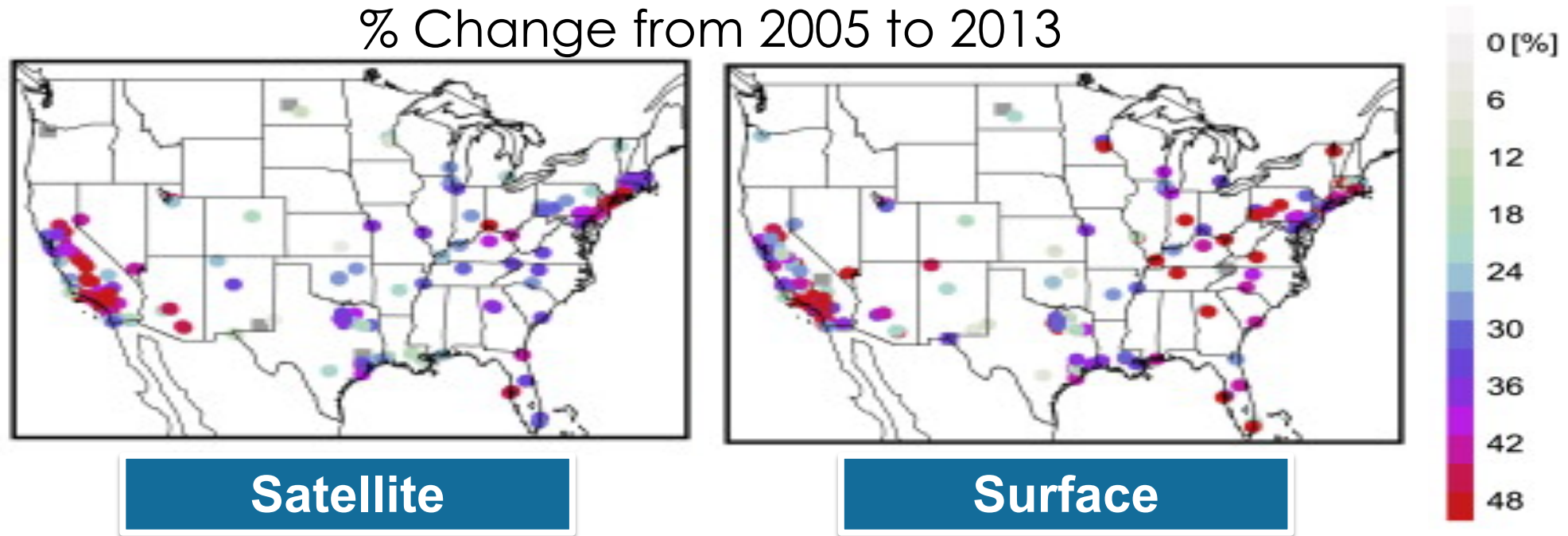
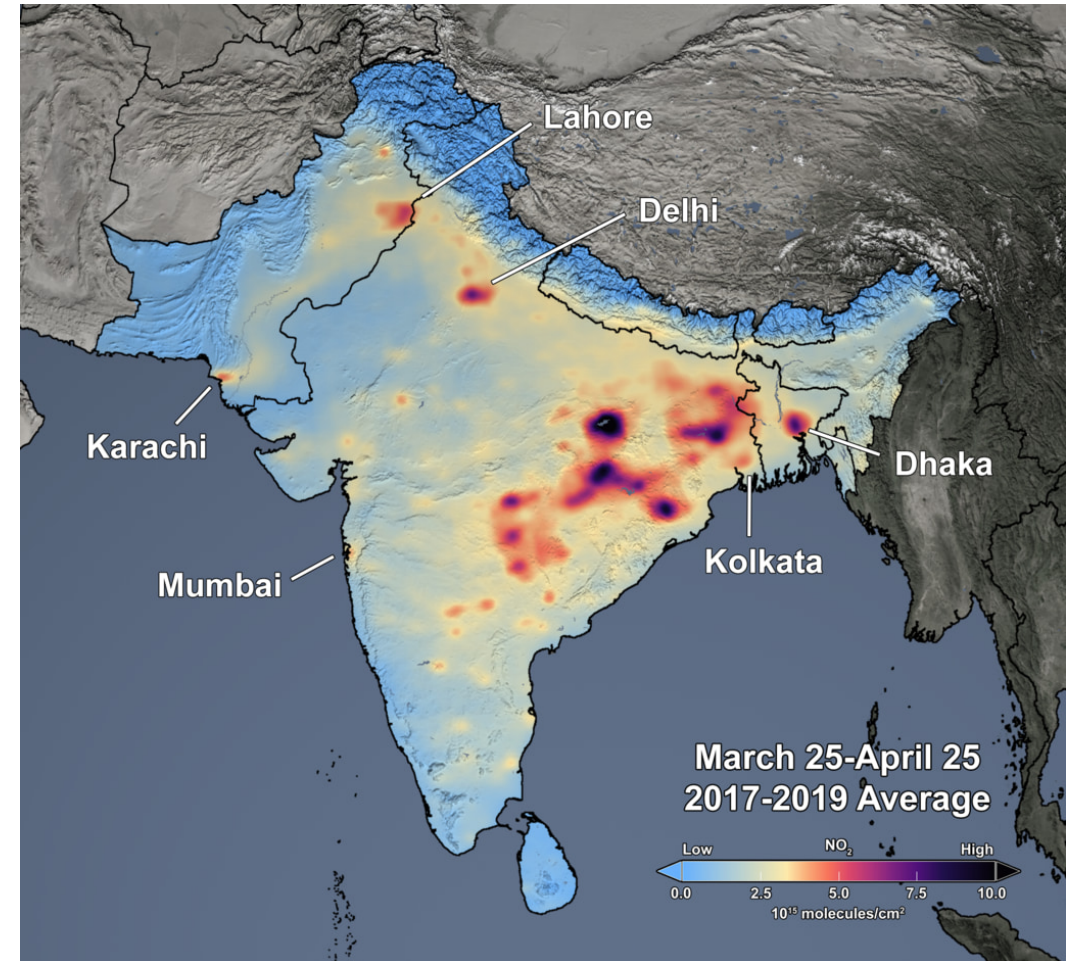


Image Credit: Lamsal et al. (2015)



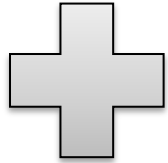
# What does this image mean, and what features can I see?

- The color bar indicates the amount of NO<sub>2</sub> from the surface to the top of the tropopause (molecules/cm<sup>2</sup>).
- If processed and interpreted carefully, NO<sub>2</sub> levels observed from OMI serve as an effective proxy for NO<sub>2</sub> levels at the surface.
- This image has been produced by averaging daily data over a 30-day period over three years (2017-2019).
- OMI NO<sub>2</sub> imagery captures features at local to regional scales.
  - Fine enough to resolve individual power plants and large cities



# What determines the amount of NO<sub>2</sub> at ground level?

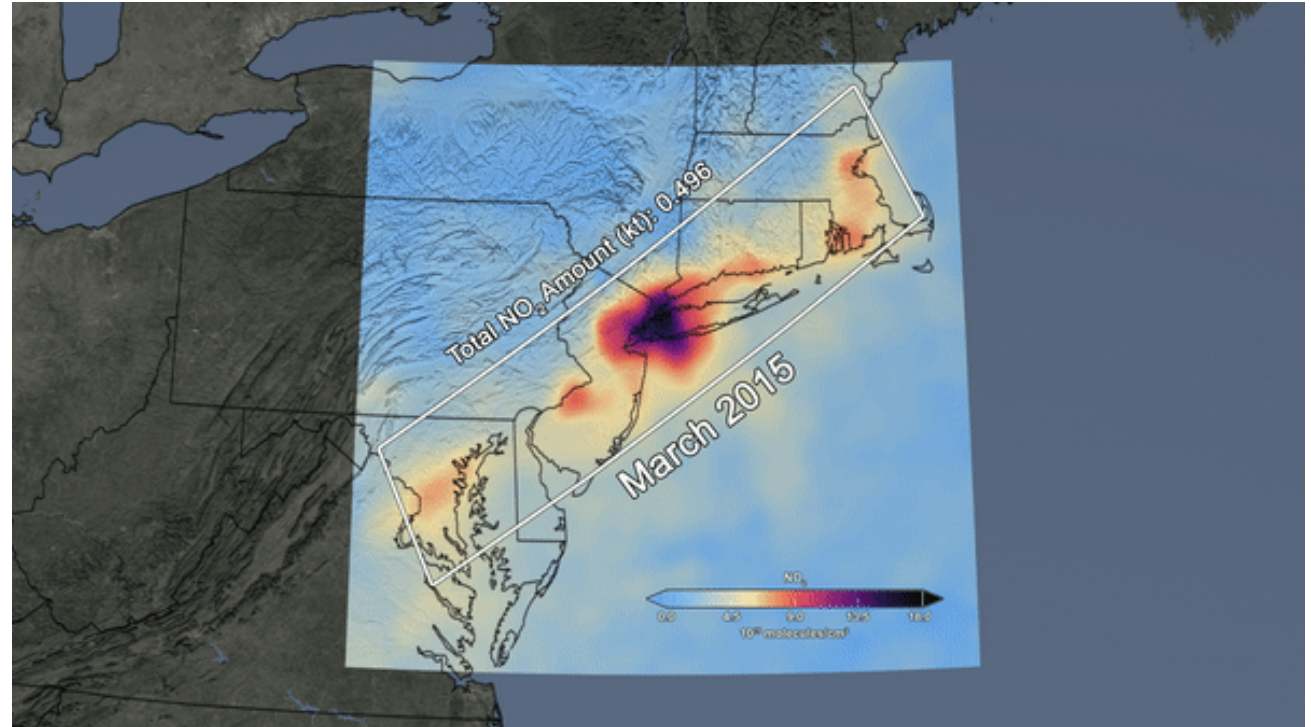
Emissions



Chemistry



Weather



# What determines the amount of NO<sub>2</sub> at ground level?

## Emissions

Emissions can vary depending on fuel type and conditions, and have both natural and man-made sources:

- Gasoline, diesel (vehicles)
- Coal and natural gas (electrical generation)
- Lightning and fires

What can change emissions?

- Increased use of renewable energy
- Air quality or climate-change policy or regulation
- Unexpected changes
  - Economic recession
  - Natural disasters
  - Lockdown due to COVID-19
  - Sudden policy interventions (e.g. Beijing Olympics)

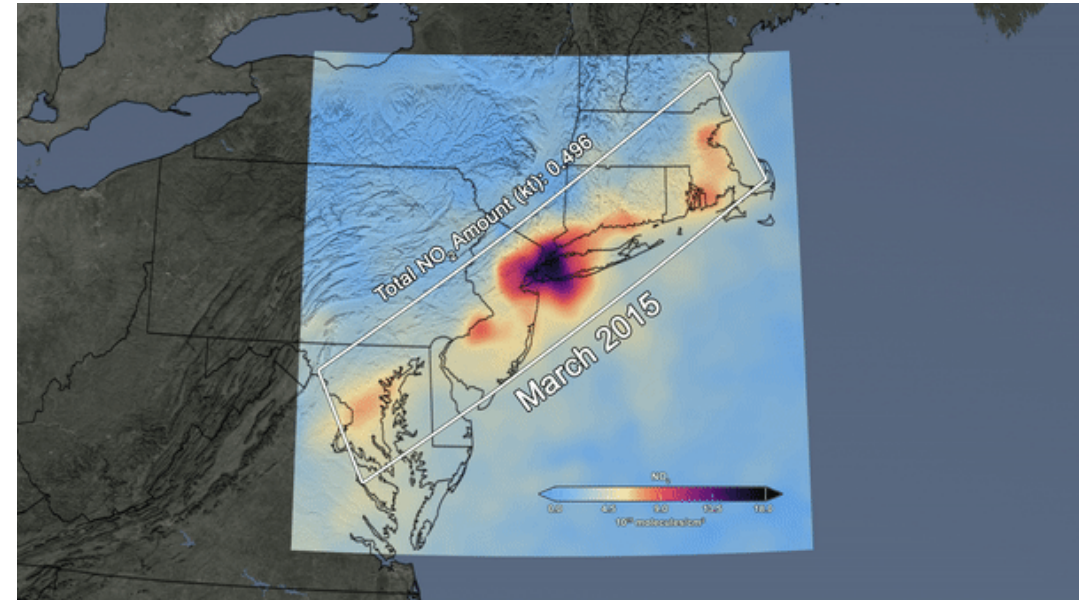


# What determines the amount of NO<sub>2</sub> at ground level?

## Chemistry

There are always emissions of NO<sub>2</sub> and other pollutants into the atmosphere, but after they are emitted, they undergo chemical reactions that determine their lifetimes (how long they stay in the atmosphere). The speed of these chemical reactions can change depending on factors such as the temperature and amount of sunlight.

One way we account for seasonal changes in temperature is by looking at the same period over different years.



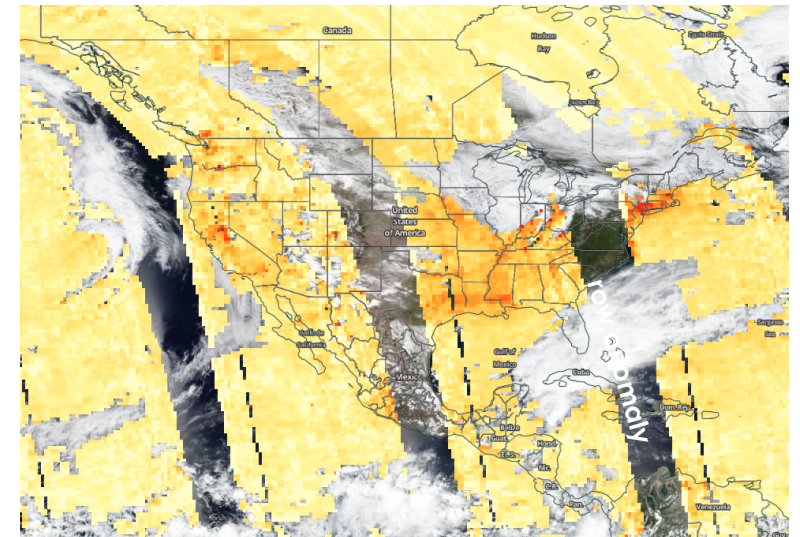
# What determines the amount of NO<sub>2</sub> at ground level?

## Weather

Weather varies from year to year and can impact the amount of NO<sub>2</sub> at the surface.

- *Winds*: Winds can disperse emissions, changing NO<sub>2</sub> levels depending on wind direction and speed
- *Temperature, Clouds*: Higher temperatures and/or more sunlight can speed up NO<sub>2</sub> chemistry in the air.
- Clouds can also interfere with an instrument's ability to "see" all the way to the surface.
- *Rain*: Rain can wash away pollutants, cleaning the air and lowering pollutant levels.

OMI Tropospheric Column NO<sub>2</sub>  
May 10, 2020

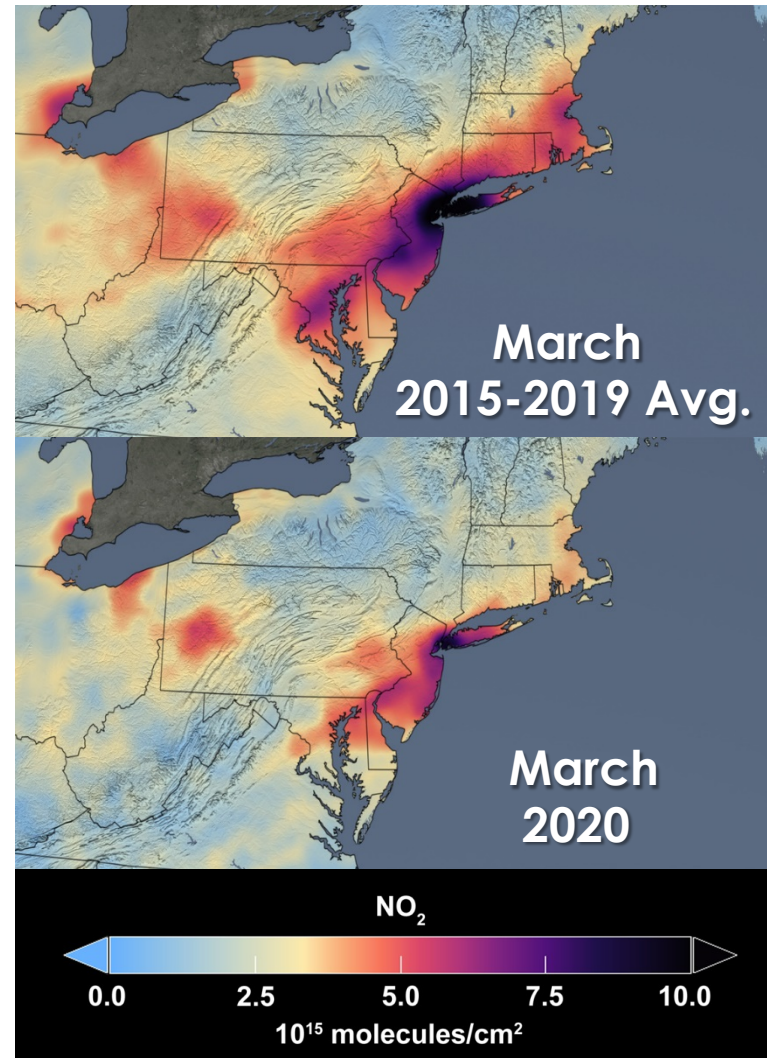


(+ VIIRS true color imagery)





# So what can we see from this image?



# So what can we see from this image?

What quantity are we looking at?

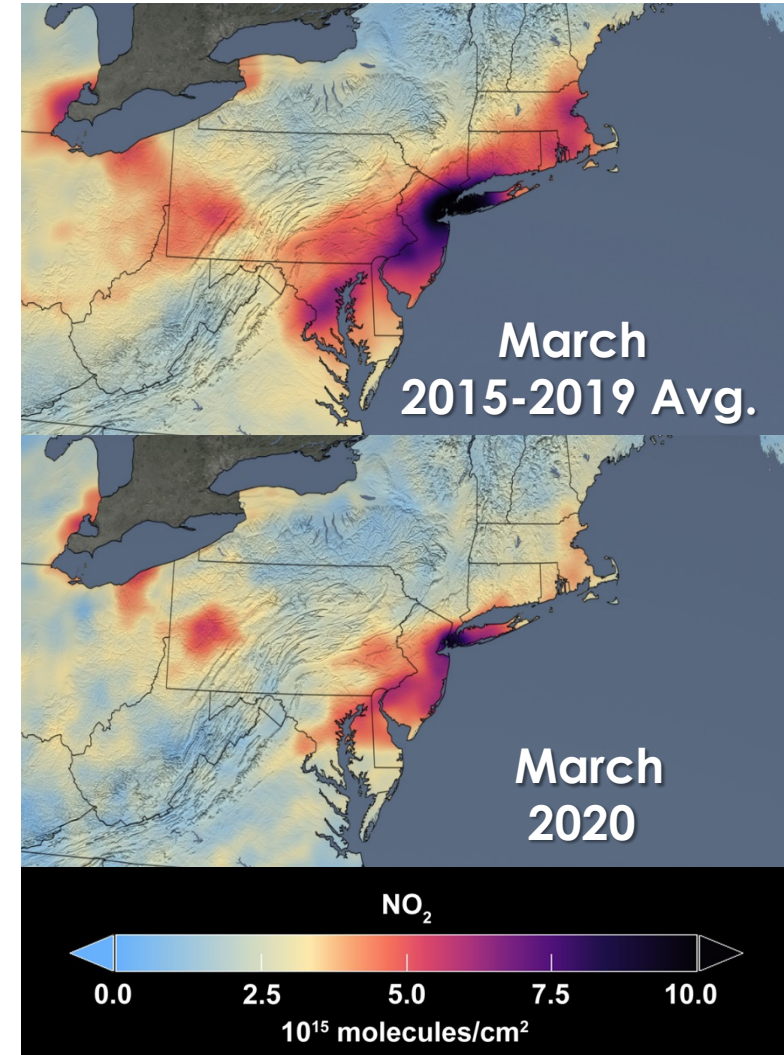
*Tropospheric Column NO<sub>2</sub>*

Is this image for one day?

*No, these images show averages of daily data over a month.*

Is this data gridded? Or at the native resolution of the satellite?

*This image was made using gridded data. This data is produced by NASA and involves carefully averaging and filtering the native resolution data from the satellite.*



# So what can we see from this image?

Is this a map of  $\text{NO}_2$  at the surface, where people breathe?

*No, this is a map of tropospheric column  $\text{NO}_2$ , which is the total amount of  $\text{NO}_2$  from the surface to the top of the troposphere.*

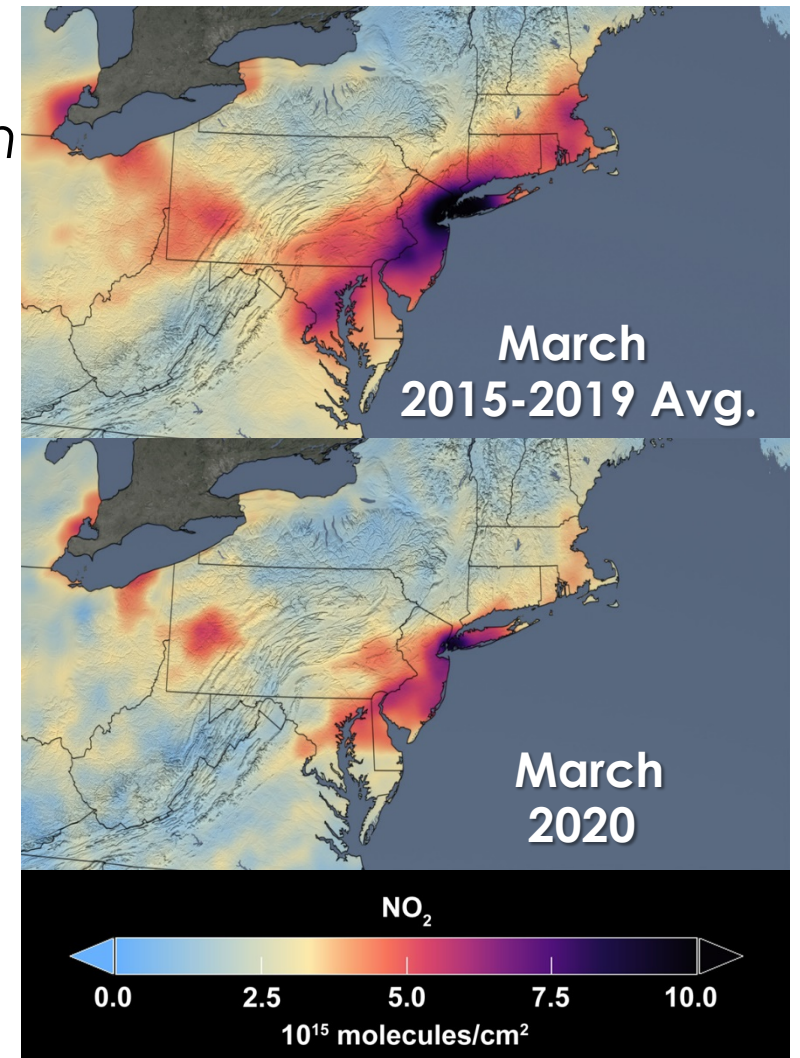
Can changes in the tropospheric column tell me information about changes at the surface?

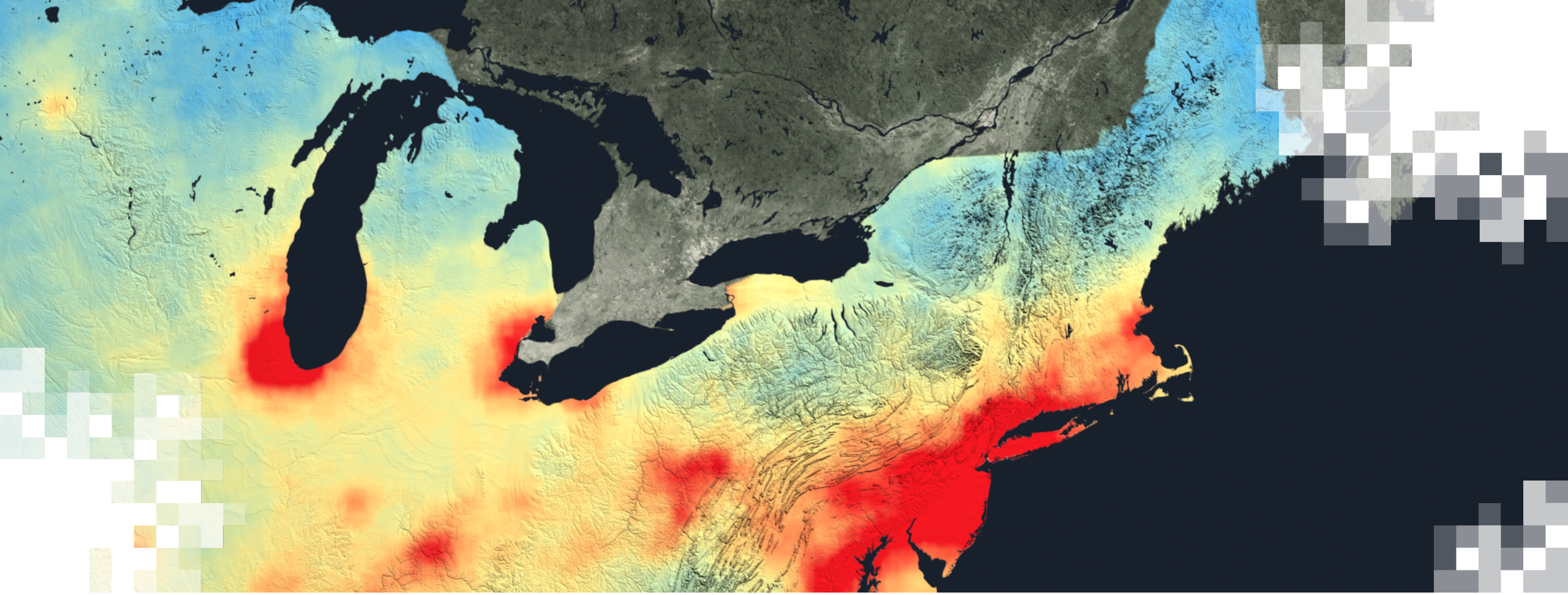
*Yes, sources of  $\text{NO}_2$  are primarily at the surface, and its lifetime is short, leading to high values near sources.*

Are all the changes between the top and bottom image due to the lockdown in response to COVID-19?

*No, the amount of  $\text{NO}_2$  depends on:  
emissions + chemistry + weather*

*Calculating the change in  $\text{NO}_2$  from the lockdown requires careful and rigorous scientific analysis.*





## Practical Uses of NO<sub>2</sub> Satellite Images and Data

# Practical Uses of NO<sub>2</sub> Satellite Images and data

- **Monitoring changes in pollution from fossil fuels due to:**
  - Air quality or climate-change policy or regulation
  - Changes in the economic output - as long as the the world's economies are mostly driven by fossil fuels (e.g. lockdown due to COVID-19)
  - Increased use of renewable energy
- **Detection of point source emissions:** e.g. power plants, tar sands, smelters
- **Satellite-model inter-comparisons:** used by agencies such as the US EPA
- **Assimilation into air quality models:** to improve air quality forecasts
- **Proxy for co-emitted pollutants,** such as greenhouse gases (CO<sub>2</sub>)



# OMI Detects NO<sub>2</sub> Changes in Pollution Over Time

Between 2005 and 2018, air quality regulation led to large decreases in NO<sub>2</sub>.

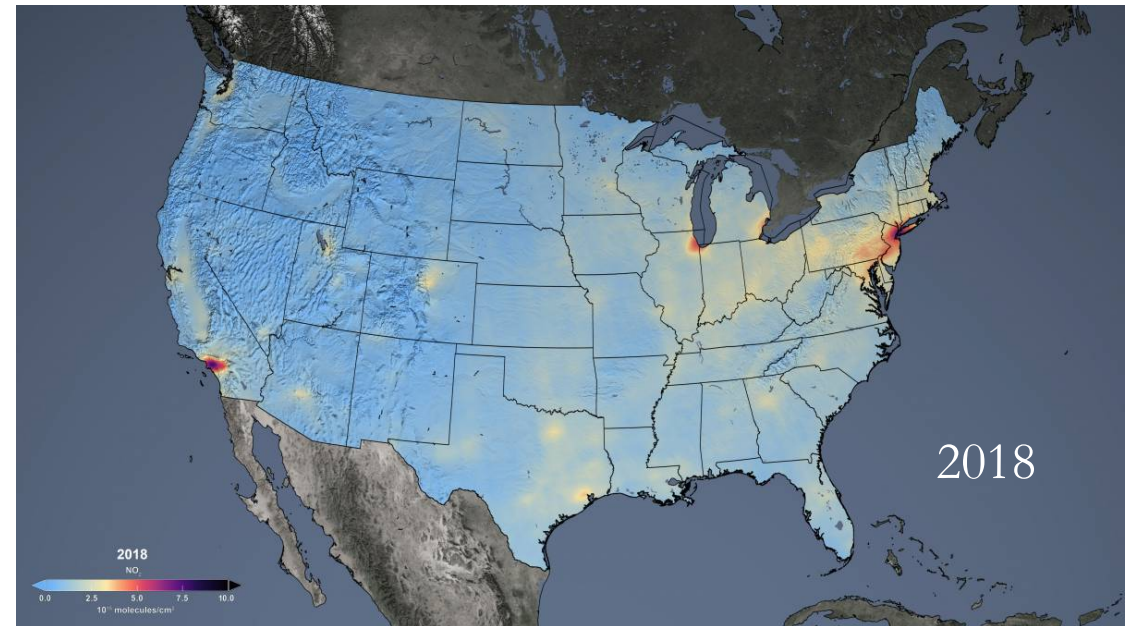
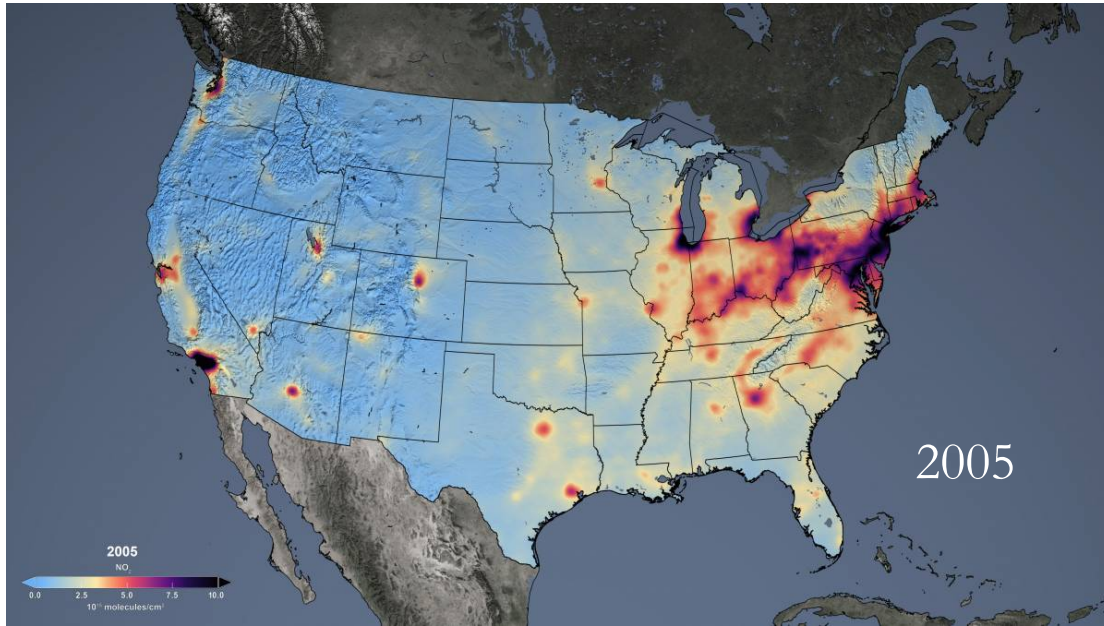
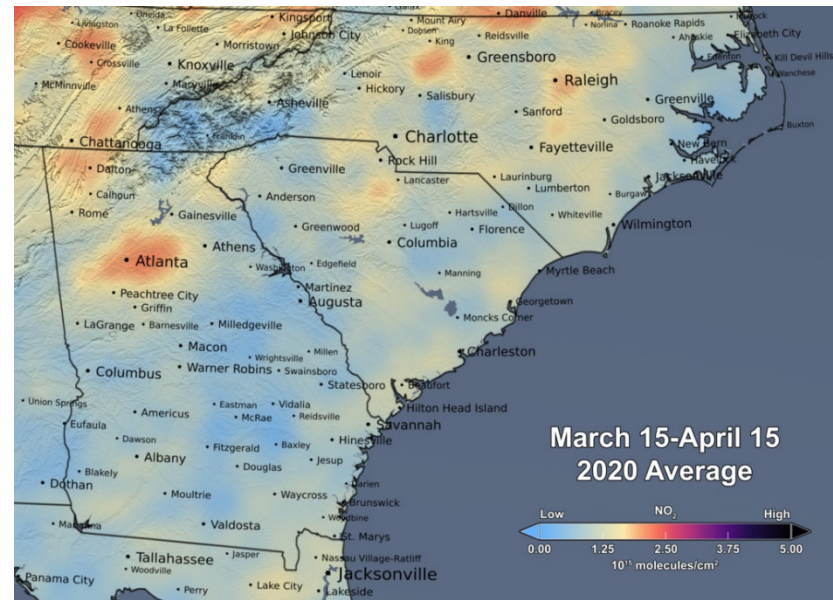
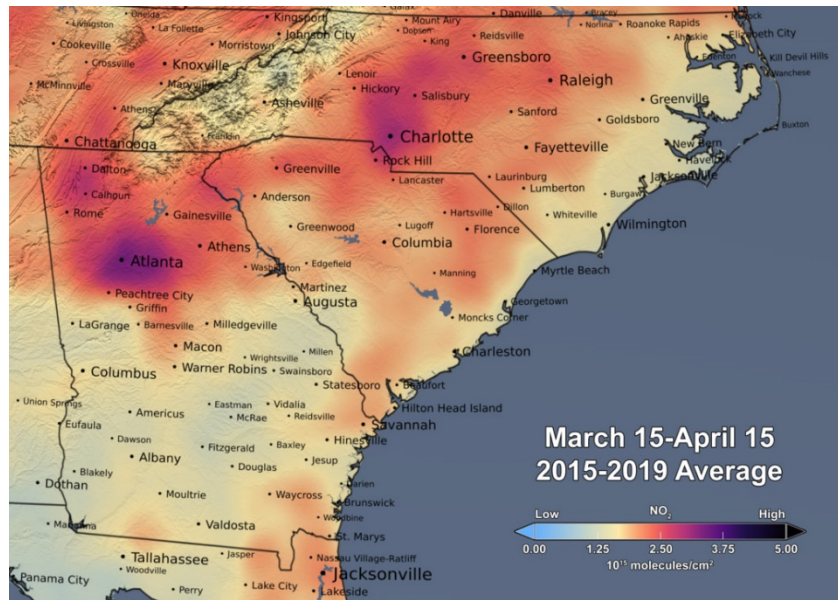


Image Credit: B. Duncan

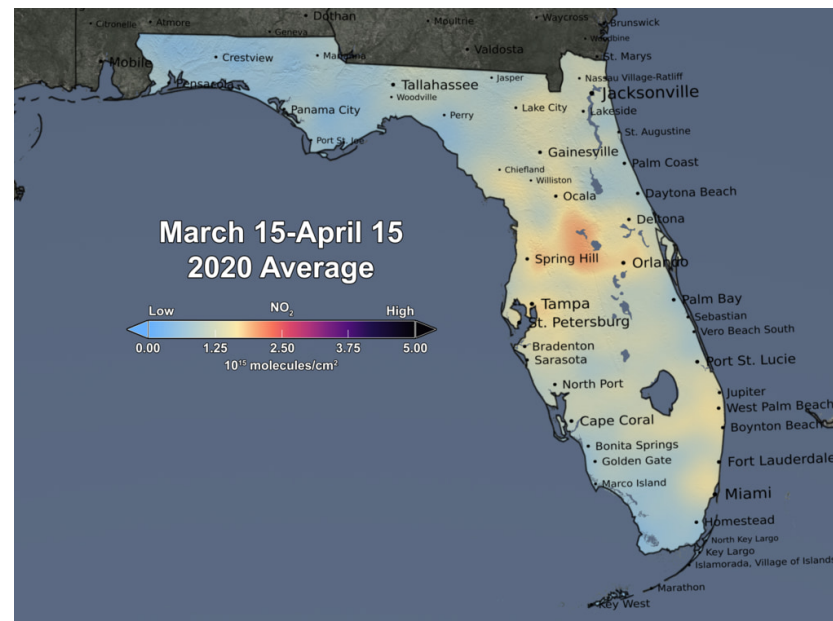
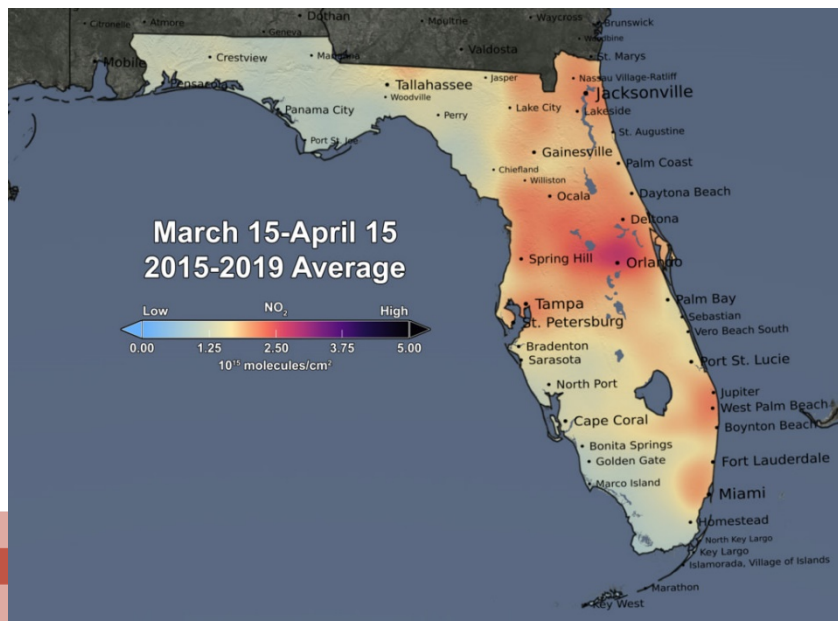
NASA's Applied Remote Sensing Training Program



# Recent decreases in NO<sub>2</sub> are lower than an average of the previous four years.



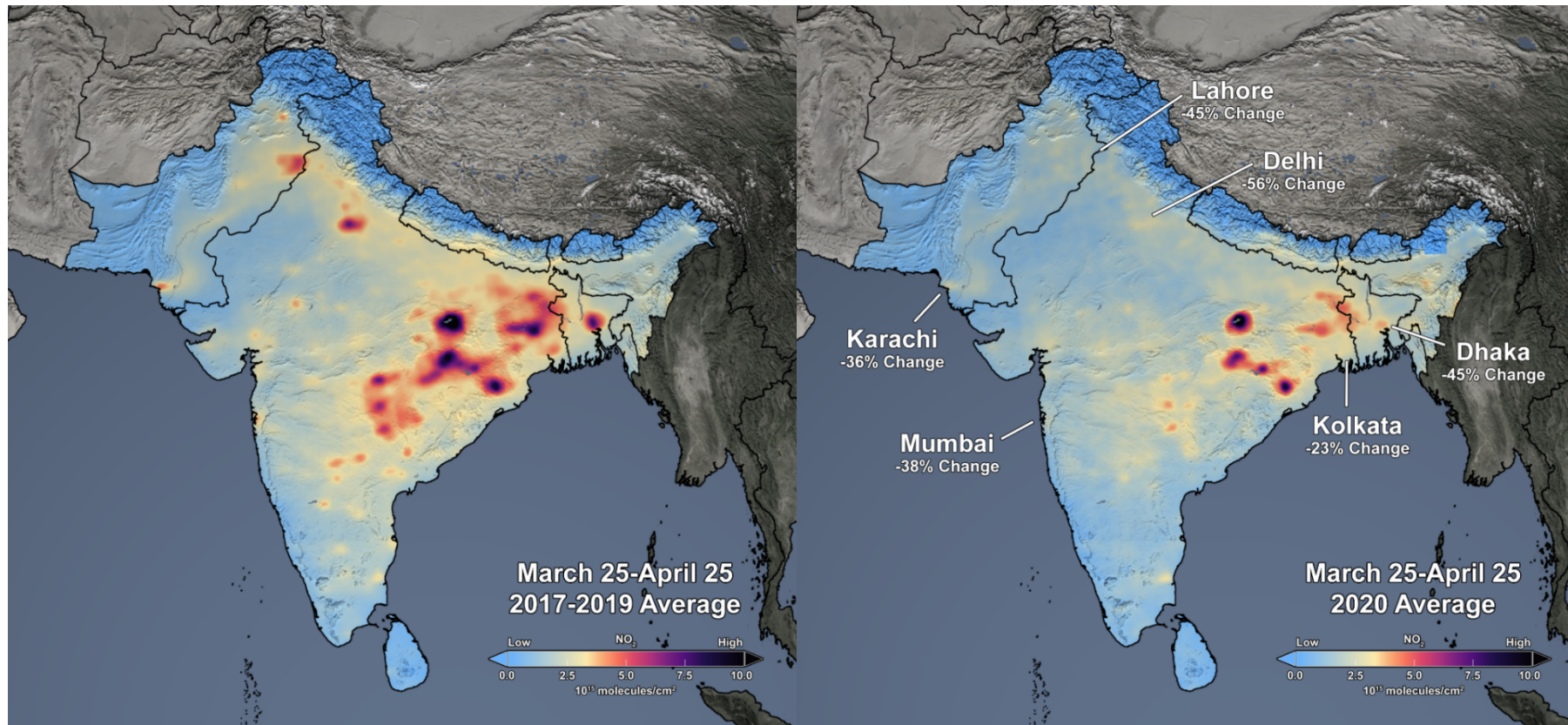
NO<sub>2</sub> levels from March 15 – April 15 of 2020 were 30-40% lower than the average from 2015-2019



The images were released in April and May and are available at <https://svs.gsfc.nasa.gov/4810>. More details can be found at <https://airquality.gsfc.nasa.gov>.



# Recent decreases in NO<sub>2</sub> are lower than an average of the previous four years.

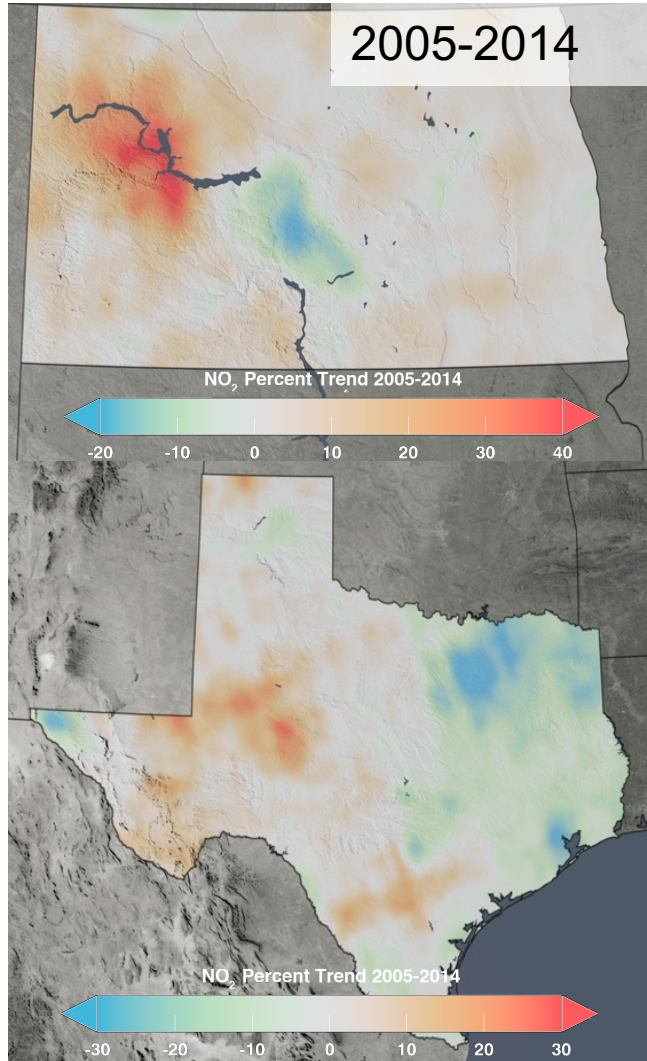


In South Asia, NO<sub>2</sub> levels from March 25 – April 25 of 2020 were 30-60% lower than the average from 2017-2019, with some of the highest reductions in densely populated areas with the strictest stay-at-home orders.

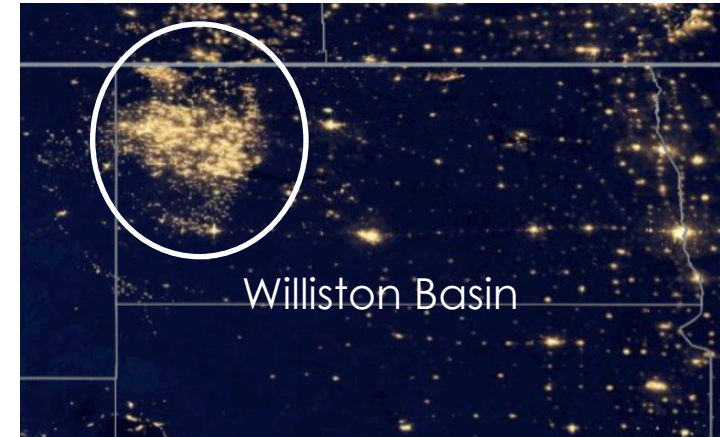




# OMI Detects NO<sub>2</sub> Increases from Oil and Natural Gas Activities



North  
Dakota



Suomi NPP VIIRS Lights at Night

Texas

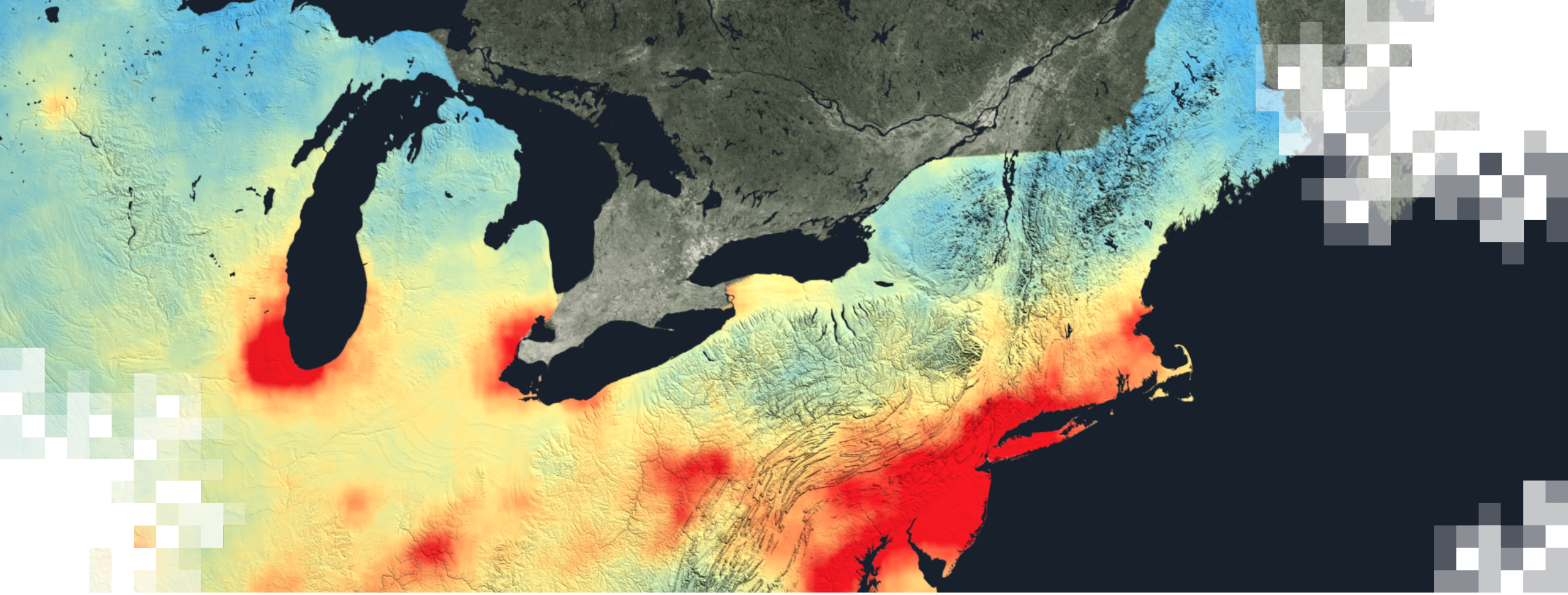


# Data from OMI has been used to estimate surface level NO<sub>2</sub>

- Using information from an atmospheric chemistry model, tropospheric column NO<sub>2</sub> from OMI has been used to estimate surface level NO<sub>2</sub>.
- Estimates are available as monthly means.
- **Note:** This is a research product and not an official NASA product.

Time Period	2005-2016
Available Product	Monthly Mean
Instruments	OMI
Product Resolution	0.1° x 0.1°
Website	<a href="https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L4/OMI_Surface_NO2/Monthly/">https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L4/OMI_Surface_NO2/Monthly/</a>



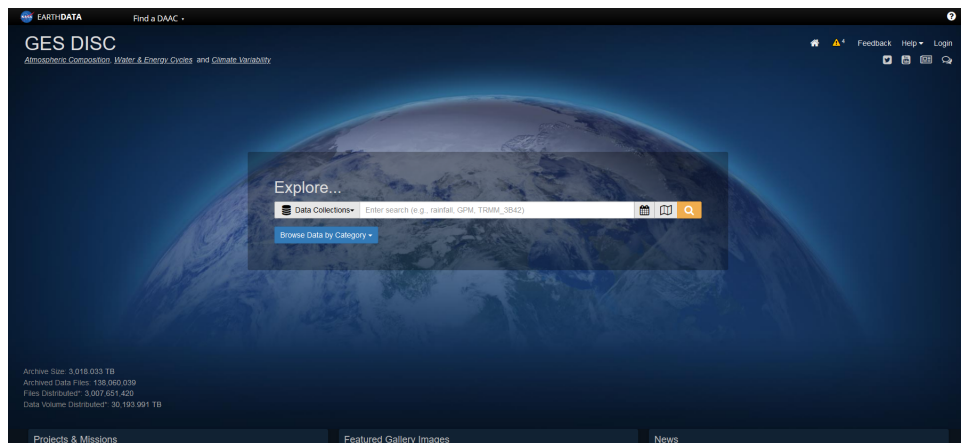


How do I access NO<sub>2</sub> data and images?

# OMI Data

## Gridded and Native Resolution Data

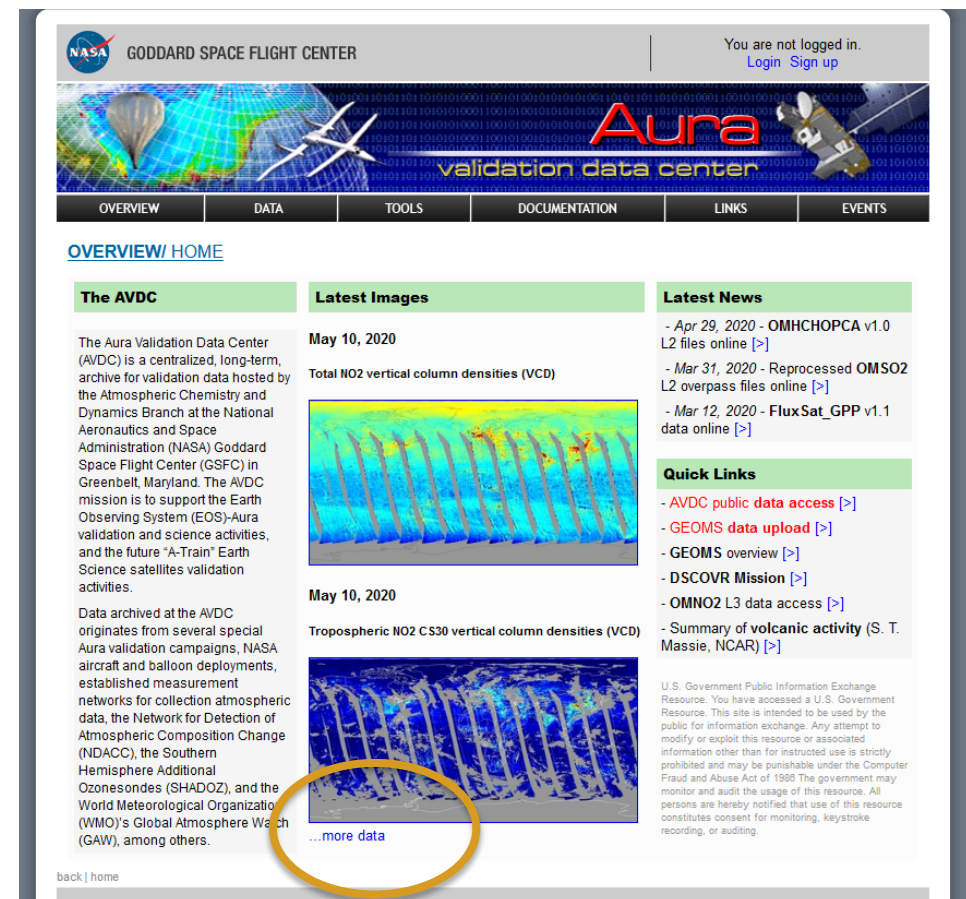
<https://disc.gsfc.nasa.gov/>



Sign up for an Earthdata account to download data

## Gridded Data and Images

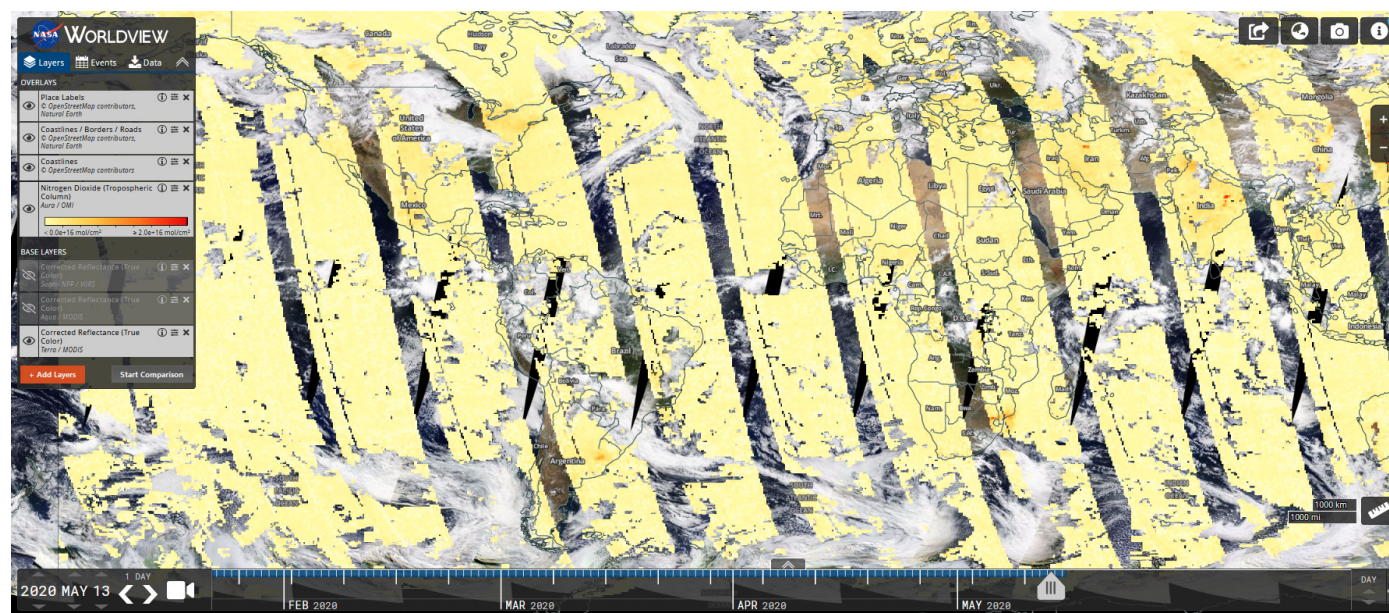
<https://avdc.gsfc.nasa.gov/>



# NASA Worldview

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

- 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 three hours of observation
- This tool will be explored during Thursday's webinar.

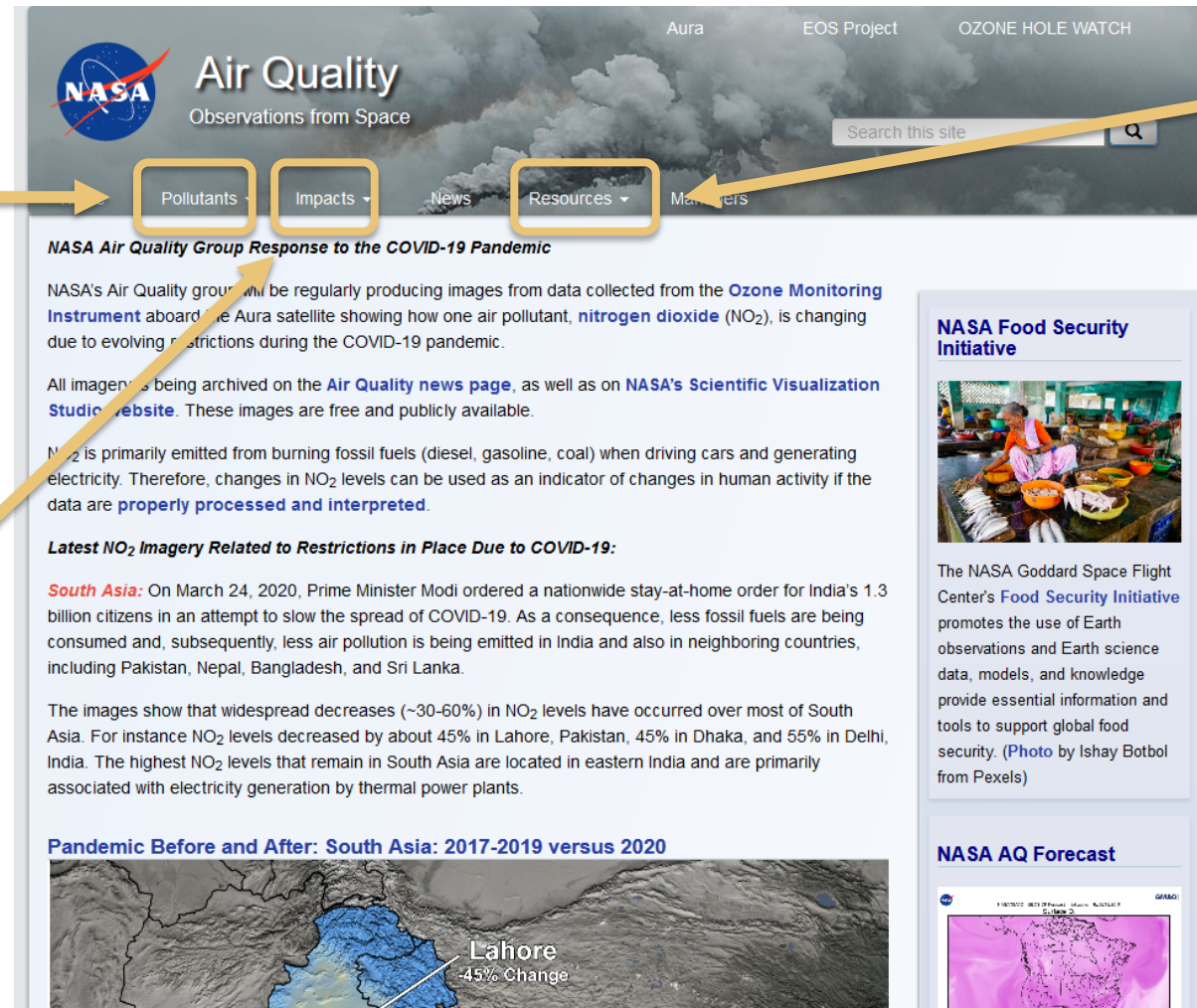


# NASA Goddard Space Flight Center (GSFC) Air Quality Website

<https://airquality.gsfc.nasa.gov/>

*Pollutants*  
Lots of info,  
ready-made  
images &  
animations

*Impacts*  
Overview of how air  
pollution affects  
human health &  
agriculture



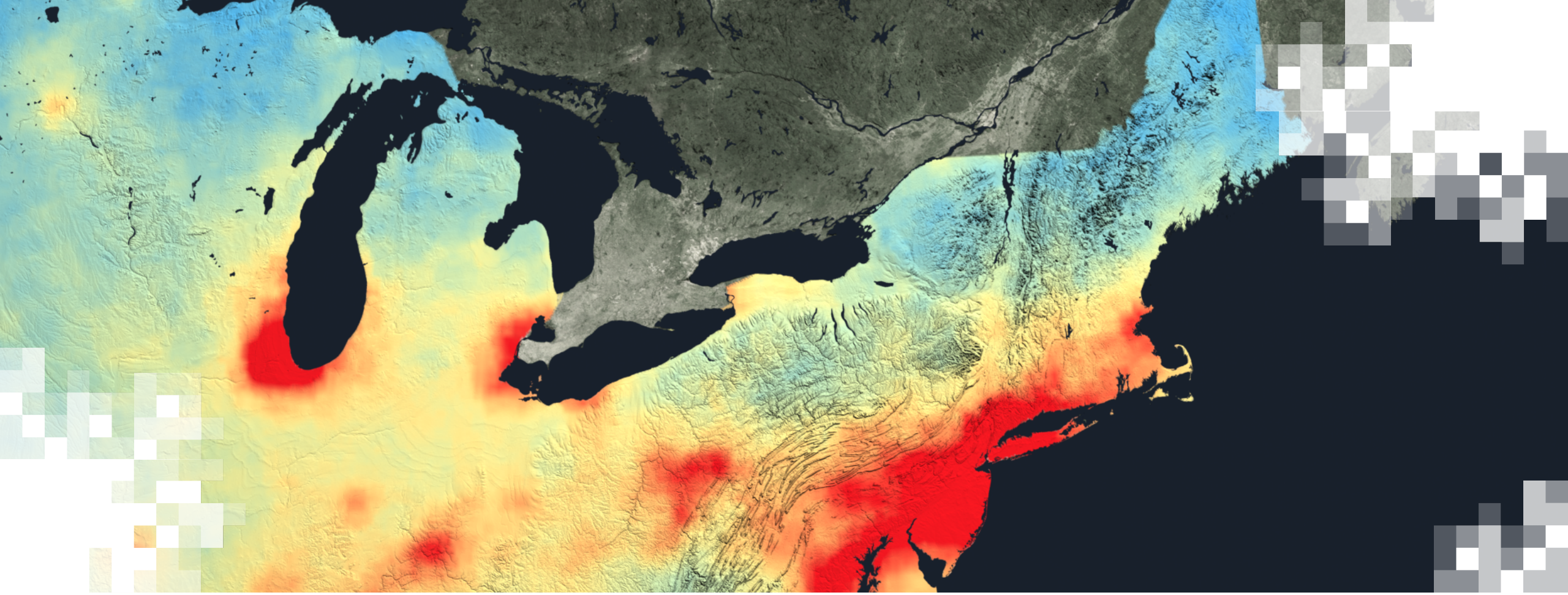
## Resources

- Webtools & data
- Factsheets
- AQ websites
- Outreach

## Sidebar: links to NASA Programs

- Food Security
- AQ Forecasts
- ARSET
- HAQAST
- Applied Sciences





Giovanni -  
The Bridge Between Data and Science:  
An Online Visualization and Analysis Tool

# NASA Giovanni

- *All steps of this demonstration are in the training materials*
- You do not need to do these steps as I do them, but if you want to follow along as I do it, please use this site: <https://disc-beta.gsfc.nasa.gov/giovanni/>
- If you have a question, we can address it during the Q&A, or feel free to email me after the webinar





Visit <https://urs.earthdata.nasa.gov/users/new>



## EARTHDATA LOGIN

### Register for an Earthdata Login Profile

#### Profile Information

**Username:** •

**Password:** •

**Password Confirmation:** •

• Required field

#### **Username must:**

- Be a Minimum of 4 characters
- Be a Maximum of 30 characters
- Use letters, numbers, periods and underscores
- Not contain any blank spaces
- Not begin, end or contain two consecutive special characters( . \_ )

#### **Password must contain:**

- Minimum of 8 characters
- One Uppercase letter
- One Lowercase letter
- One Number



# Time Averaged Maps: Step 1

- Go to the Giovanni website: <http://giovanni.gsfc.nasa.gov/giovanni/>

The screenshot shows the NASA Giovanni website interface. At the top, there is a navigation bar with the NASA logo, 'EARTHDATA', and a search bar for 'Find a DAAC'. The main header features the 'GIOVANNI' logo and the tagline 'The Bridge Between Data and Science v 4.33'. A yellow banner at the top of the main content area reads 'MODIS-Aqua SST Version 2019.0 data now available in Giovanni ... [1 of 1 messages] Read More'. Below this, the 'Select Plot' section has radio buttons for 'Maps: Time Averaged Map \*', 'Comparisons: Select...', 'Vertical: Select...', 'Time Series: Select...', and 'Miscellaneous: Select...'. The 'Select Date Range (UTC)' section includes input fields for 'YYYY-MM-DD.' and 'HH:mm', with a 'Valid Range: 1948-01-01 to 2020-05-12' note. The 'Select Region (Bounding Box or Shape)' section has a text input field and a 'Format: West, South, East, North' label. The 'Select Variables' section shows a list of 'Observations' (Model (925), Observation (570)) and 'Disciplines' (Aerosols (195), Atmospheric Chemistry (78), Atmospheric Dynamics (423), Cryosphere (12), Hydrology (684)). It also displays 'Number of matching Variables: 0 of 1495' and 'Total Variable(s) included in Plot: 0', along with a 'Keyword' search field. At the bottom, there is a footer with contact information, a 'Reset' button, and a prominent green 'Plot Data' button.



# Time Averaged Maps: Step 2

- Under **Select Plot**, go to **Maps** and select **Time Averaged Map**

The screenshot shows the NASA Giovanni web interface. At the top, there is a navigation bar with the NASA logo, 'EARTHDATA', and a search bar for 'Find a DAAC'. Below this is the 'GIOVANNI' logo and the tagline 'The Bridge Between Data and Science v 4.33'. There are links for 'Feedback', 'Help', and 'Login'. A yellow banner at the top of the main content area reads 'MODIS-Aqua SST Version 2019.0 data now available in Giovanni ... [1 of 1 messages] Read More'. The 'Select Plot' section is highlighted with a red circle, and the 'Maps: Time Averaged Map' option is selected. Below this, there are several dropdown menus for 'Comparisons', 'Vertical', 'Time Series', and 'Miscellaneous'. The 'Select Date Range (UTC)' section has input fields for 'YYYY-MM-DD.' and 'HH:mm', with a 'Valid Range: 1948-01-01 to 2020-05-12' displayed below. The 'Select Region (Bounding Box or Shape)' section has a text input field and a 'Format: West, South, East, North' label. The 'Select Variables' section has two expandable menus: 'Observations' (with 'Model (925)' and 'Observation (570)' options) and 'Disciplines' (with 'Aerosols (195)', 'Atmospheric Chemistry (78)', 'Atmospheric Dynamics (423)', 'Cryosphere (12)', and 'Hydrology (684)' options). A search bar for variables is also present. At the bottom, there is a footer with the NASA logo, 'Responsible NASA Official: Angela Li', 'Web Curator: M. Hegde', 'Privacy', 'Powered By', and 'Contact Us' links. A 'Reset' button and a green 'Plot Data' button are also visible.



# Time Averaged Maps: Step 2

- Under **Measurement**, select **NO<sub>2</sub>**

The screenshot shows the NASA EarthData GIOVANNI interface. At the top, it says "NASA EARTHDATA" and "Find a DAAC". The main header is "GIOVANNI The Bridge Between Data and Science v 4.33" with links for "Feedback", "Help", and "Login".

The "Select Variables" section is active. It shows a search bar with "Number of matching Variables: 0 of 1495" and "Total Variable(s) included in Plot: 0". Below the search bar are three main categories:

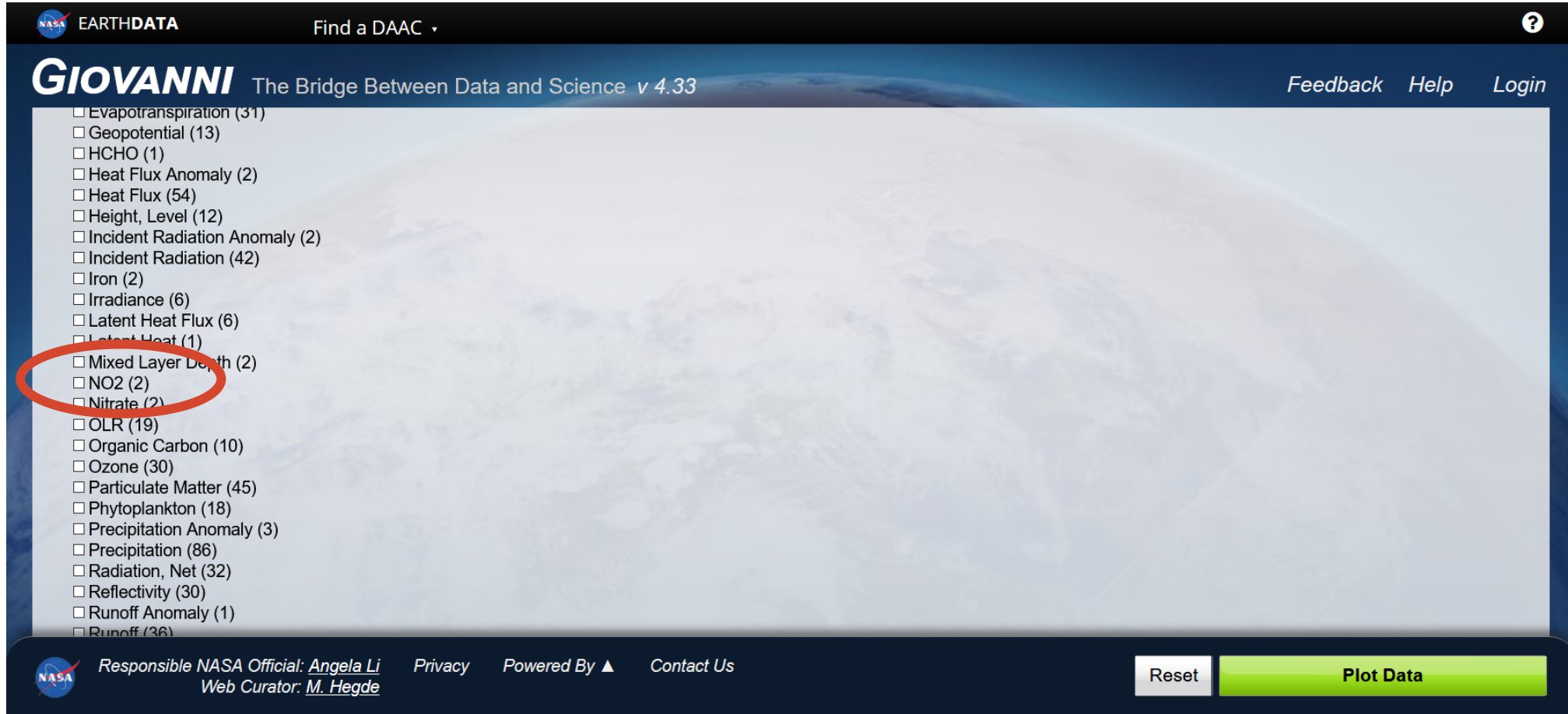
- Observations**:
  - Model (925)
  - Observation (570)
- Disciplines**:
  - Aerosols (195)
  - Atmospheric Chemistry (78)
  - Atmospheric Dynamics (423)
  - Cryosphere (12)
  - Hydrology (684)
  - Ocean Biology (56)
  - Oceanography (68)
  - Water and Energy Cycle (756)
- Measurements** (circled in red):
  - Aerosol Index (6)
  - Aerosol Optical Depth (8)
  - Air Pressure Anomaly (1)
  - Air Pressure (37)
  - Air Temperature Anomaly (2)
  - Air Temperature (77)
  - Albedo (26)
  - Altitude (8)

A red arrow points downwards from the "Measurements" section with the text "Scroll down". At the bottom of the interface, there are links for "Responsible NASA Official: Angela Li" and "Web Curator: M. Hegde", along with "Privacy", "Powered By", and "Contact Us". There are also "Reset" and "Plot Data" buttons.



# Time Averaged Maps: Step 2

- Under **Measurement**, select **NO<sub>2</sub>**



The screenshot shows the NASA GIOVANNI web interface. At the top, there is a navigation bar with the NASA logo, 'EARTHDATA', and a search box labeled 'Find a DAAC'. Below this, the 'GIOVANNI' logo is displayed with the tagline 'The Bridge Between Data and Science v 4.33'. To the right of the logo are links for 'Feedback', 'Help', and 'Login'. A large list of data measurements is shown on the left side, each with a checkbox and a count in parentheses. The 'NO2 (2)' option is circled in red. At the bottom of the interface, there is a footer with the NASA logo, 'Responsible NASA Official: Angela Li', 'Privacy', 'Powered By', and 'Contact Us'. On the right side of the footer, there are two buttons: 'Reset' and 'Plot Data'.

**Measurement List:**

- Evapotranspiration (31)
- Geopotential (13)
- HCHO (1)
- Heat Flux Anomaly (2)
- Heat Flux (54)
- Height, Level (12)
- Incident Radiation Anomaly (2)
- Incident Radiation (42)
- Iron (2)
- Irradiance (6)
- Latent Heat Flux (6)
- Latent Heat (1)
- Mixed Layer Depth (2)
- NO<sub>2</sub> (2)
- Nitrate (2)
- OLR (19)
- Organic Carbon (10)
- Ozone (30)
- Particulate Matter (45)
- Phytoplankton (18)
- Precipitation Anomaly (3)
- Precipitation (86)
- Radiation, Net (32)
- Reflectivity (30)
- Runoff Anomaly (1)
- Runoff (36)



# Time Averaged Maps: Step 3

- Select NO<sub>2</sub> Tropospheric Column (30% Cloud Screened) (OMNO2d\_v003)

The screenshot shows the NASA GIOVANNI web interface. At the top, it says "NASA EARTHDATA Find a DAAC" and "GIOVANNI The Bridge Between Data and Science v 4.33". There are links for "Feedback", "Help", and "Login".

**Select Plot:** "Maps: Time Averaged Map" is selected. Other options include "Comparisons", "Vertical", "Time Series", and "Miscellaneous".

**Select Date Range (UTC):** The date range is currently empty, with a message "Please specify a start date." and a "Valid Range: 2004-10-01 to 2020-05-10".

**Select Region (Bounding Box or Shape):** The region selection area is empty.

**Select Variables:** A sidebar on the left lists categories: Observations, Disciplines, and Measurements. The "NO2 Tropospheric Column (30% Cloud Screened) (OMNO2d v003)" variable is selected in the main table.

**Number of matching Variables: 2 of 1495 Total Variable(s) included in Plot: 1**

	Variable	Units	Source	Temp.Res.	Spat.Res.	Begin Date	End Date
<input type="checkbox"/>	<a href="#">NO2 Total Column (30% Cloud Screened) (OMNO2d v003)</a>	1/cm2	OMI	Daily	0.25 °	2004-10-01	2020-05-10
<input checked="" type="checkbox"/>	<a href="#">NO2 Tropospheric Column (30% Cloud Screened) (OMNO2d v003)</a>	1/cm2	OMI	Daily	0.25 °	2004-10-01	2020-05-10

At the bottom, there are links for "Responsible NASA Official: Angela Li" and "Web Curator: M. Hegde", along with "Privacy", "Powered By", and "Contact Us". There are "Reset" and "Plot Data" buttons.



# Time Averaged Maps: Step 4

- Set the date range as **April 1, 2005** to **April 30, 2005**

The screenshot shows the NASA Giovanni web interface. At the top, it says "EARTHDATA" and "Find a DAAC". The main header is "GIOVANNI The Bridge Between Data and Science v 4.33". There are links for "Feedback", "Help", and "Log out (melanie\_cook)". A yellow banner at the top says "MODIS-Aqua SST Version 2019.0 data now available in Giovanni ... [1 of 1 messages] Read More".

The "Select Plot" section has a dropdown menu set to "Maps: Time Averaged Map \*". Other options include "Comparisons: Select...", "Vertical: Select...", "Time Series: Select...", and "Miscellaneous: Select...".

The "Select Date Range (UTC)" section is circled in red. It shows a date range from "2005 -04 -01 00 : 00" to "2005 -04 -30 23 : 59". Below this, it says "Valid Range: 2004-10-01 to 2020-05-10".

The "Select Region (Bounding Box or Shape)" section is empty.

The "Select Variables" section has two categories: "Observations" and "Disciplines". Under "Observations", there are checkboxes for "Model (925)" and "Observation (570)". Under "Disciplines", there are checkboxes for "Aerosols (195)", "Atmospheric Chemistry (78)", "Atmospheric Dynamics (423)", "Cryosphere (12)", "Hydrology (684)", "Ocean Biology (56)", "Oceanography (68)", and "Water and Energy Cycle (756)".

The "Number of matching Variables: 0 of 1495" and "Total Variable(s) included in Plot: 1" are displayed. A search bar is present with "Search" and "Clear" buttons.

	Variable	Units	Source	Temp.Res.	Spat.Res.	Begin Date	End Date
<input checked="" type="checkbox"/>	NO2 Tropospheric Column (30% Cloud Screened) (OMNO2d v003)	1/cm2	OMI	Daily	0.25 °	2004-10-01	2020-05-10

At the bottom, there are links for "Responsible NASA Official: Angela Li" and "Web Curator: M. Hegde". There are also links for "Privacy", "Powered By", and "Contact Us". At the bottom right, there are buttons for "Reset", "Plot Data", and "Go to Results".



# Time Averaged Maps: Step 5

- Select your region either by typing in coordinates, or by clicking **Show Map** and drawing a box (about 10 x 10 degrees) around your area of interest.
- If you pick too large of an area or time period, it will take a long time for your image to be created.
- Click on **Plot Data** (green button) in the lower right-hand corner.

The screenshot shows the GIOVANNI web interface. At the top, it says "EARTHDATA Find a DAAC" and "GIOVANNI The Bridge Between Data and Science v 4.33". There are links for "Feedback", "Help", and "Log out (melanie\_cook)". A yellow banner at the top reads "MODIS-Aqua SST Version 2019.0 data now available in Giovanni ... [1 of 1 messages] Read More".

The "Select Plot" section has a dropdown menu set to "Maps: Time Averaged Map". Below it are several "Select" dropdowns for Comparisons, Vertical, Time Series, and Miscellaneous.

The "Select Date Range (UTC)" section shows a date range from "2005 -04 -01 00:00" to "2005 -04 -30 23:59". A "Valid Range: 2004-10-01 to 2020-05-10" is displayed below. A "Show Map" button with a map icon and a red arrow pointing to it is located to the right of the date range.

The "Select Variables" section has two expandable categories: "Observations" and "Disciplines". Under "Observations", "Model (925)" and "Observation (570)" are listed. Under "Disciplines", various categories like "Aerosols (195)", "Atmospheric Chemistry (78)", etc., are listed.

A table shows the "Number of matching Variables: 0 of 1495" and "Total Variable(s) included in Plot: 1". The table has columns for Variable, Units, Source, Temp.Res., Spat.Res., Begin Date, and End Date. One variable is listed: "NO2 Tropospheric Column (30% Cloud Screened) (OMINO2d v003)" with units "1/cm2", source "OMI", temporal resolution "Daily", spatial resolution "0.25 °", and date range "2004-10-01" to "2020-05-10".

At the bottom right, there are three buttons: "Reset", "Plot Data" (highlighted in green), and "Go to Results".

This screenshot is similar to the one above, but it shows a map of the United States. A bounding box is drawn around a region in the central US, with a red arrow pointing to it. The map shows latitude and longitude lines. The "Show Map" button from the previous screenshot is now a small "x" icon in the top right corner of the map window.

The "Plot Data" button at the bottom right is circled in red.





# Time Averaged Maps: Step 6

You can:

- Change the color scale, max, and min under the **Layers >> Options** button on the top right of the map.
- Download your image (png, GeoTIFF, or kmz) or the data shown (netcdf), by clicking “Download” on the left menu.

The screenshot shows the GIOVANNI web interface. A 'Map Options' dialog box is open over a map of the United States. The dialog box contains the following settings:

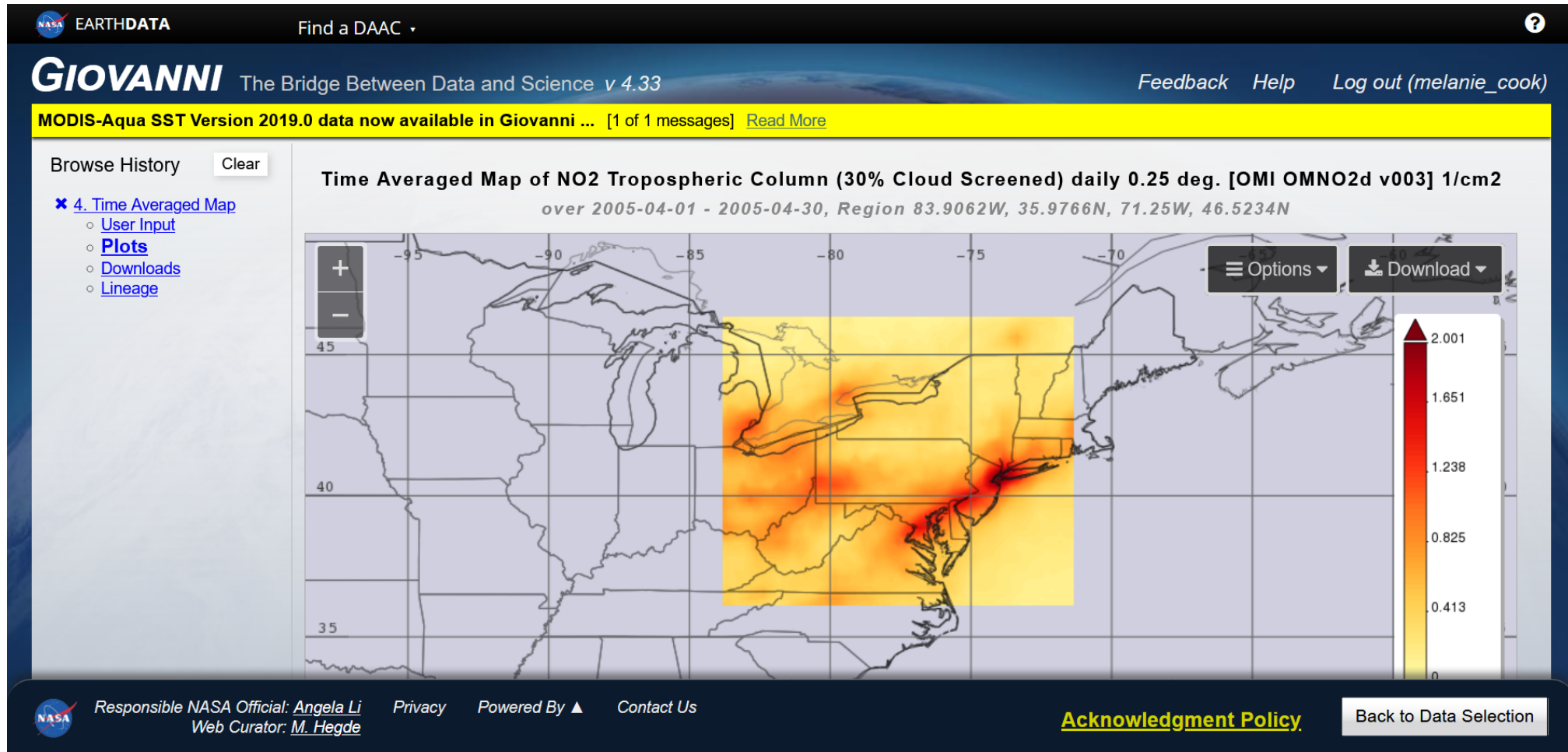
- Data Range:** Minimum: 0, Maximum: 2.00000005e+1 (circled in red)
- Palette:** View All Palettes, New-Orange-Red (Seq), 65
- Smoothing:** On (radio button selected, circled in red)
- Projection:** Equidistant Cylindrical
- Scaling:** Linear (radio button selected)
- Buttons:** Restore Defaults, Re-Plot (circled in red)

The background map shows a color scale for NO2 Tropospheric Column, ranging from 0 to 2.001. The interface includes a 'Download' button on the right and a 'Back to Data Selection' button at the bottom right.

- Change the maximum to 1.00 e+16
- Turn ‘Smoothing’ to On
- Click ‘Re-Plot’

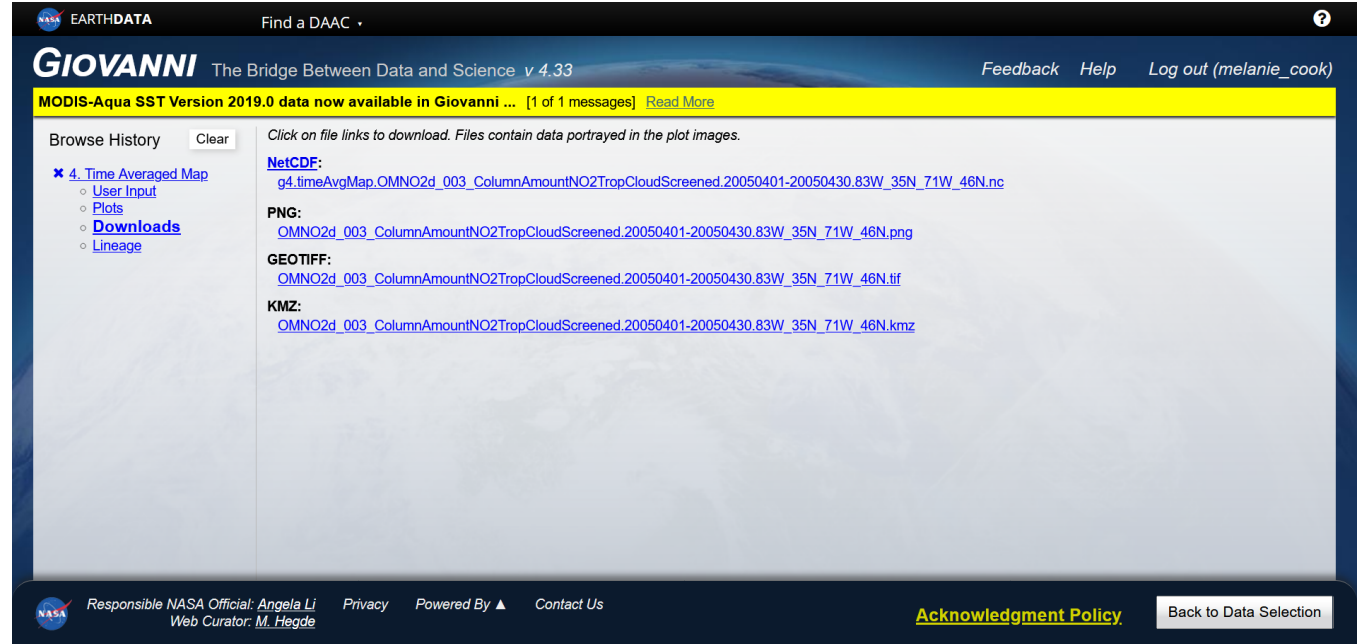


# Time Averaged Maps: Step 6



# Time Averaged Maps: Step 7

- In the panel on the left, under **Time Averaged Map**, click the **Downloads** link.
- Here you can download the maps in .png or GeoTIFF format, or the data in NetCDF format.



The screenshot shows the GIOVANNI web interface. At the top, it says "NASA EARTHDATA" and "Find a DAAC". The main header is "GIOVANNI The Bridge Between Data and Science v 4.33" with links for "Feedback", "Help", and "Log out (melanie\_cook)". A yellow banner reads "MODIS-Aqua SST Version 2019.0 data now available in Giovanni ... [1 of 1 messages] Read More". Below this is a "Browse History" panel with a "Clear" button and a list: "4. Time Averaged Map" (expanded), "User Input", "Plots", "Downloads" (highlighted), and "Lineage". The main content area has a heading "Click on file links to download. Files contain data portrayed in the plot images." and lists download options: "NetCDF:" with a link to a .nc file, "PNG:" with a link to a .png file, "GEOTIFF:" with a link to a .tif file, and "KMZ:" with a link to a .kmz file. The footer includes "Responsible NASA Official: Angela Li", "Web Curator: M. Hegde", "Privacy", "Powered By", "Contact Us", "Acknowledgment Policy", and a "Back to Data Selection" button.



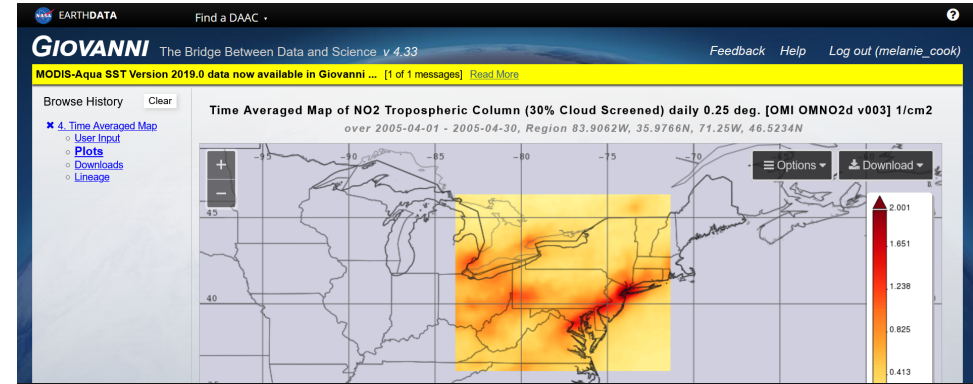
# Time Averaged Maps: Step 8

- Click the **Back to Data Selection** button in the lower right and keep all parameters the same, except change the range to **April 1, 2015 to April 30, 2015**, or look at 2020, and plot the map again.

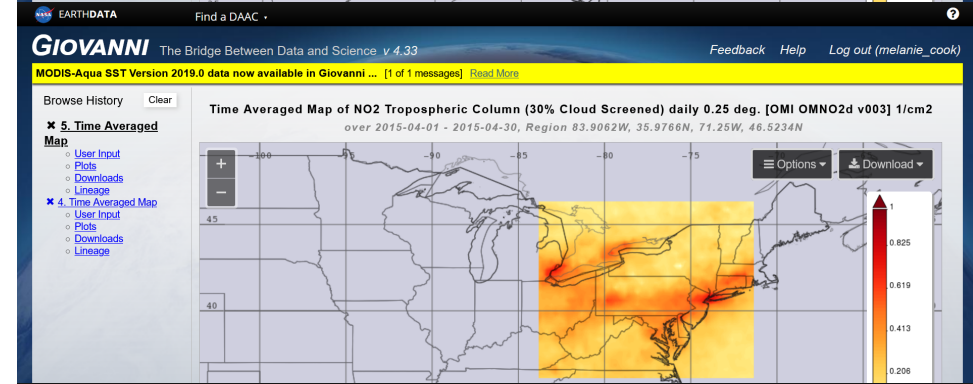
You can quickly access previous plots from the left menu.



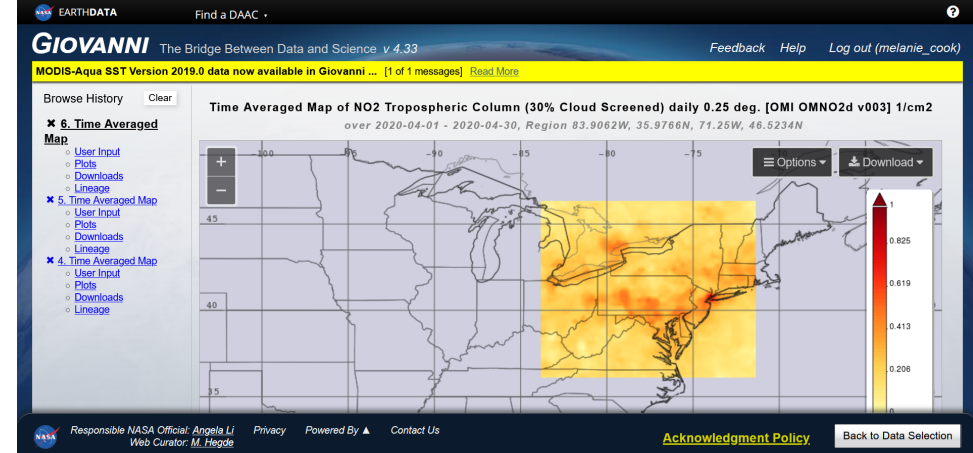
2005



2015



2020



# Want to Learn More?

- ARSET offers more advanced air quality trainings. You can learn:
  - How to use Python to read NO<sub>2</sub> data files at native satellite resolution to create customized images and analysis, and extract data for particular locations.
  - About new, geostationary satellites that provide unprecedented temporal resolution (new images every 5 minutes!).
- Attend a future in person course (sign up for our listserv here), or review all of the materials from past in-person trainings:  
<https://arset.gsfc.nasa.gov/airquality/workshops>  
listserv: <https://lists.nasa.gov/mailman/listinfo/arset>
- Listen to our freely available past recorded trainings:
  - Advanced NO<sub>2</sub> webinar:  
<https://arset.gsfc.nasa.gov/airquality/webinars/advanced-NO2-2019>
  - High Temporal Resolution Air Quality Observations from Space:  
<https://arset.gsfc.nasa.gov/airquality/webinars/2018-geospatial>

