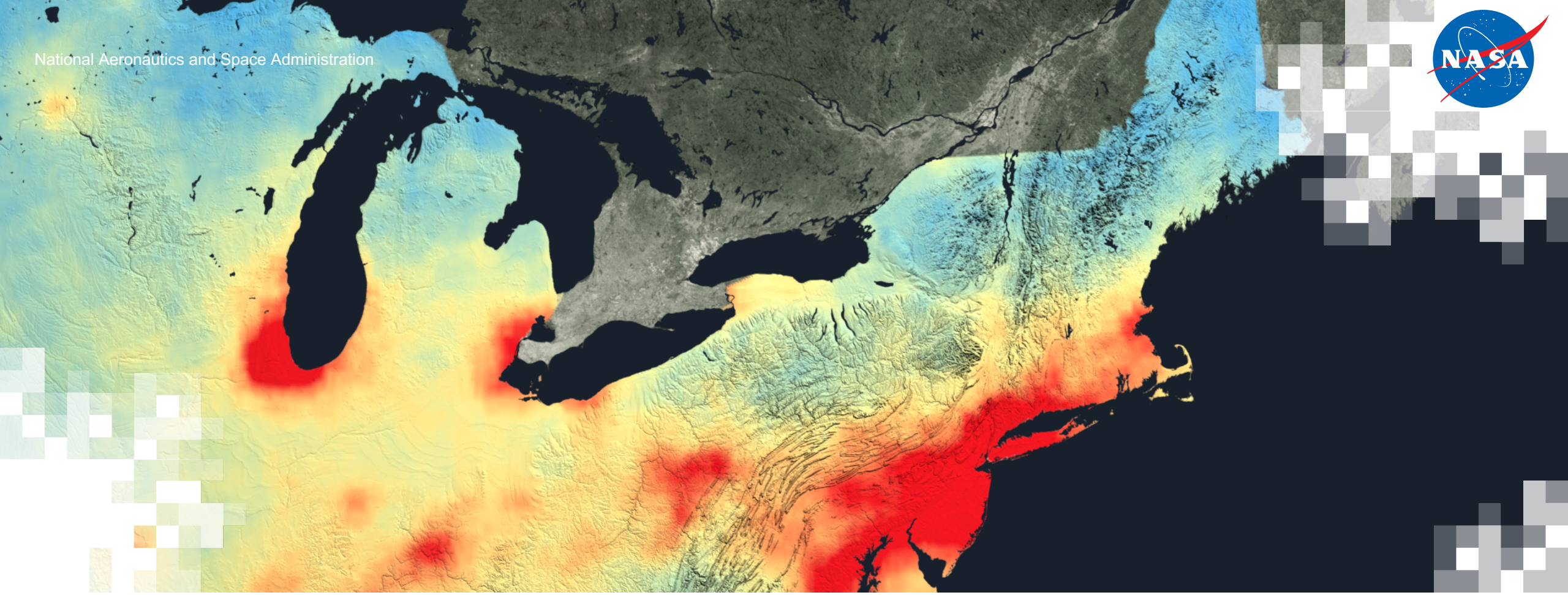



# Measuring Nitrogen Dioxide from Space

Melanie Follette-Cook, Ana Prados, and Pawan Gupta

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

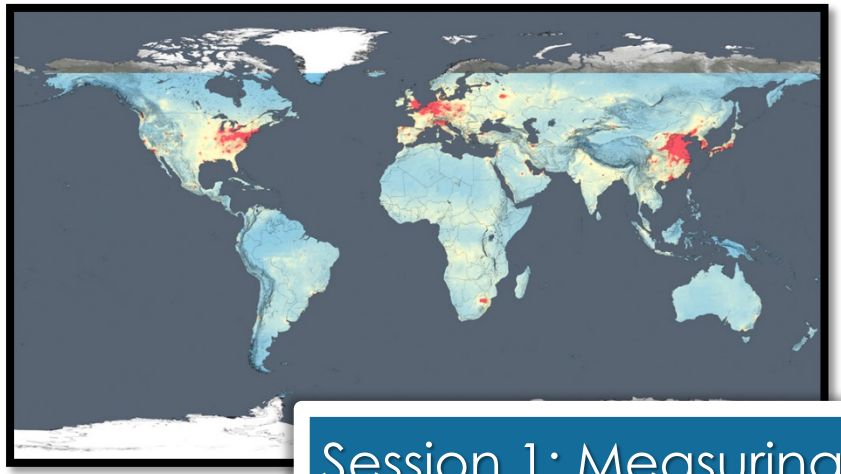
Satellite observations offer the only truly global coverage of many atmospheric pollutants

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

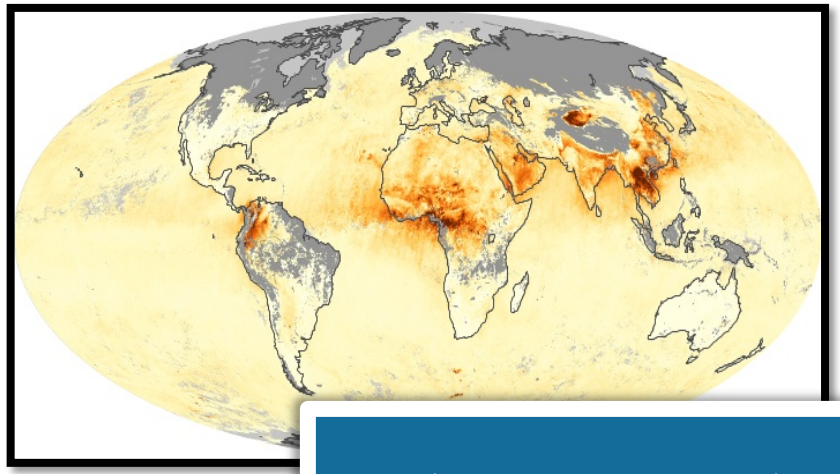
Many of these reports have focused on spaced based observations of nitrogen dioxide

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



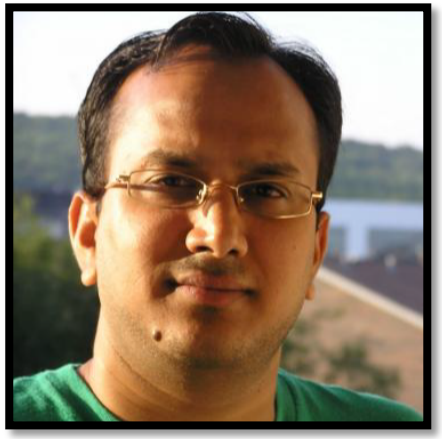
Session 1: Measuring Nitrogen Dioxide from Space



Session 2: Measuring Aerosols from Space


Melanie Follette-Cook

Ana Prados



Pawan Gupta

# ARSET Overview

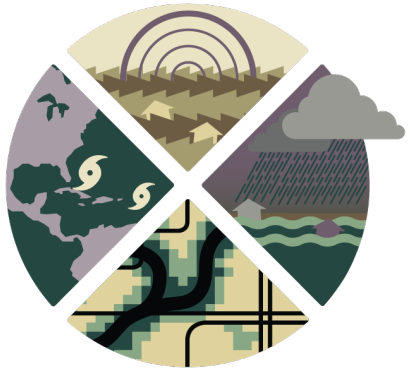
## The Applied Remote Sensing Training Program

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

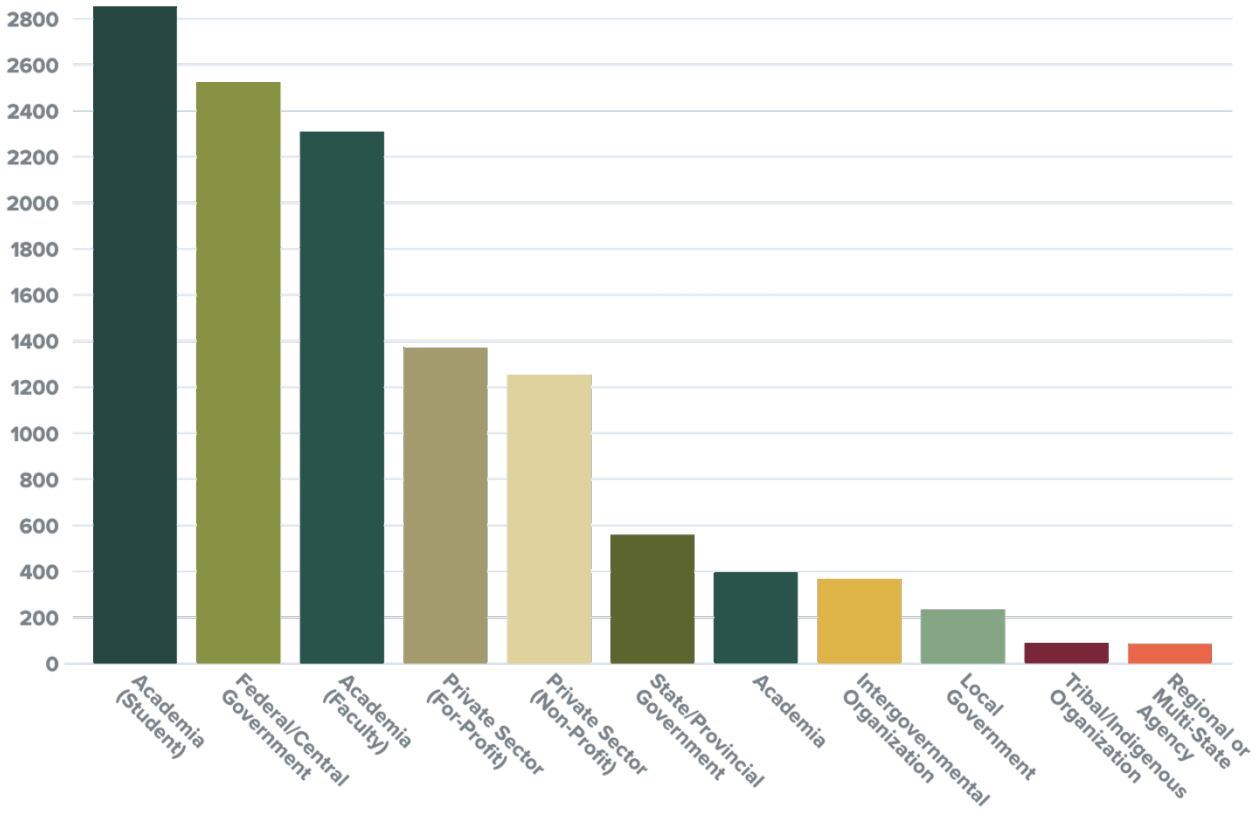
Water

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

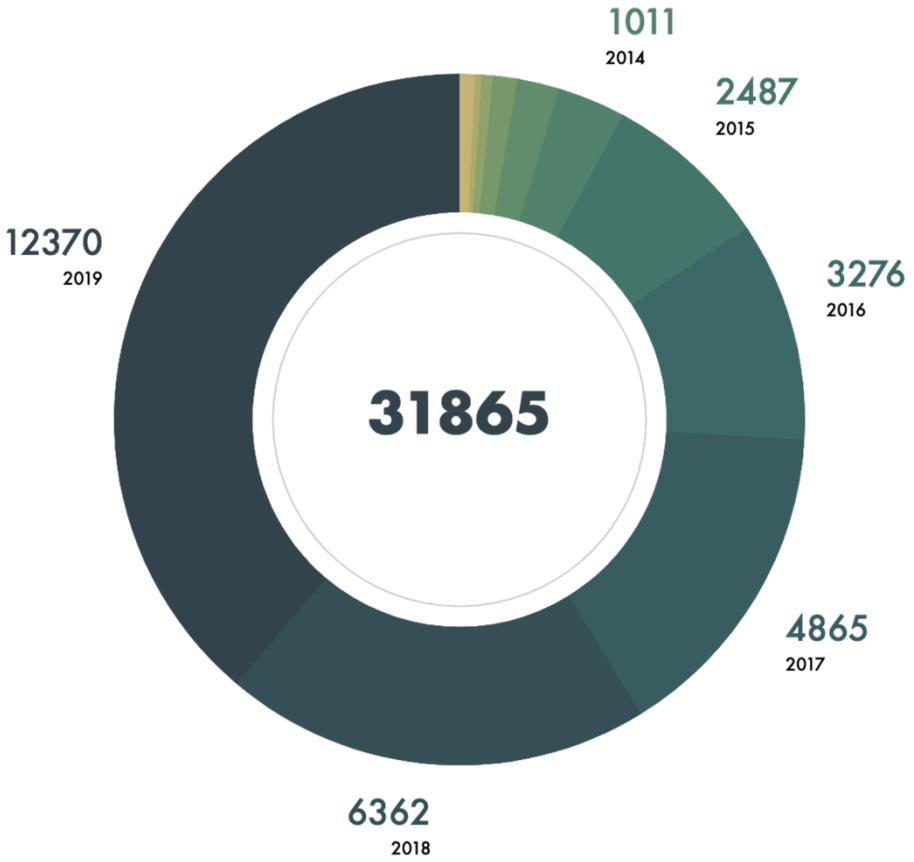
# ARSET Overview

## Notable Statistics

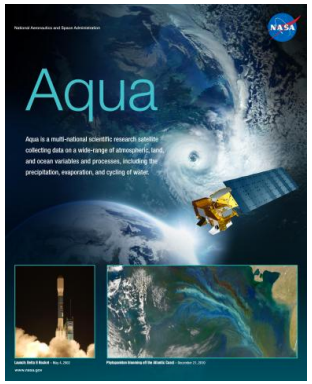
### Sector Breakdown

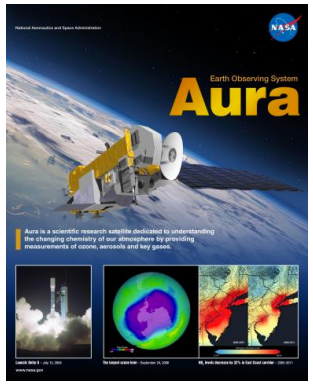


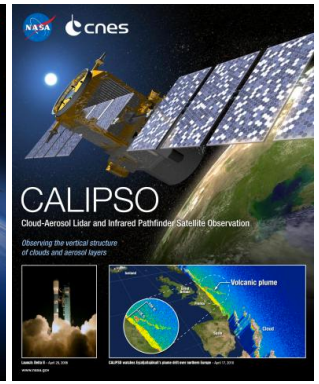

### Participation by Year

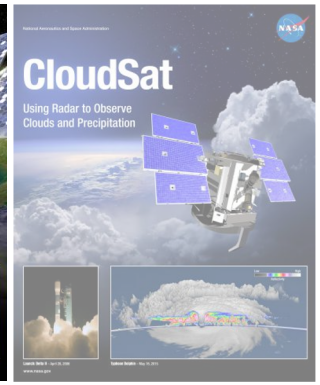


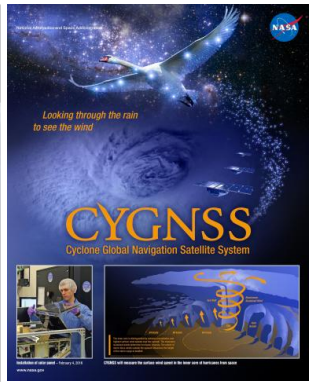
# Missions Covered by ARSET

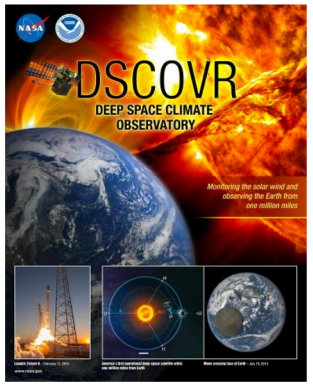


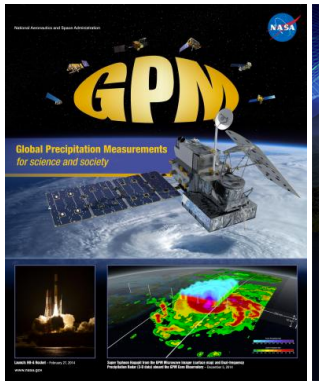



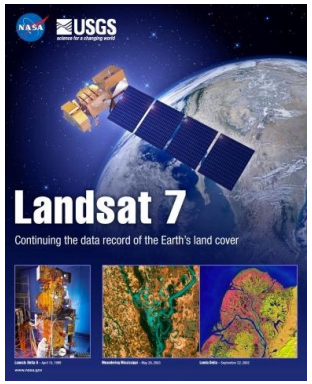



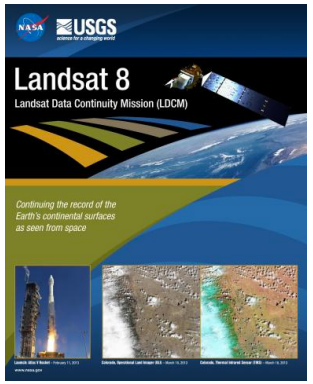



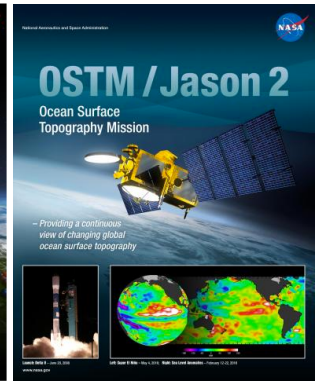



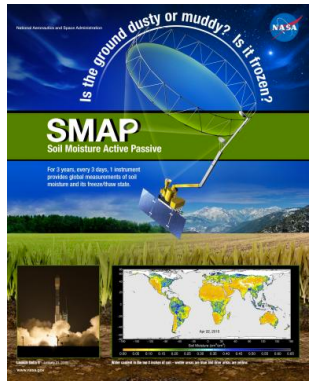


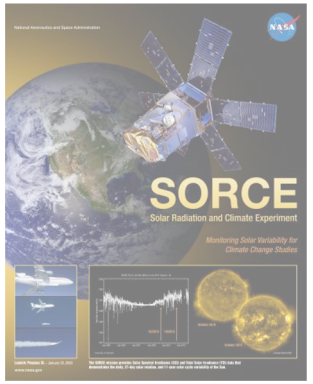


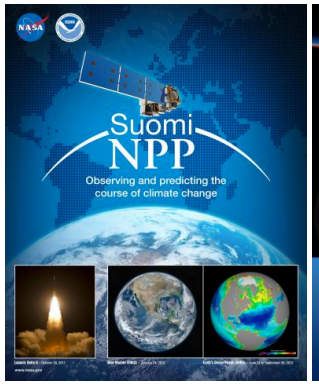



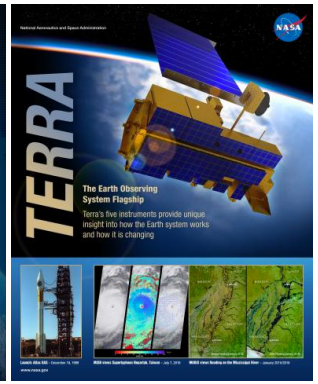




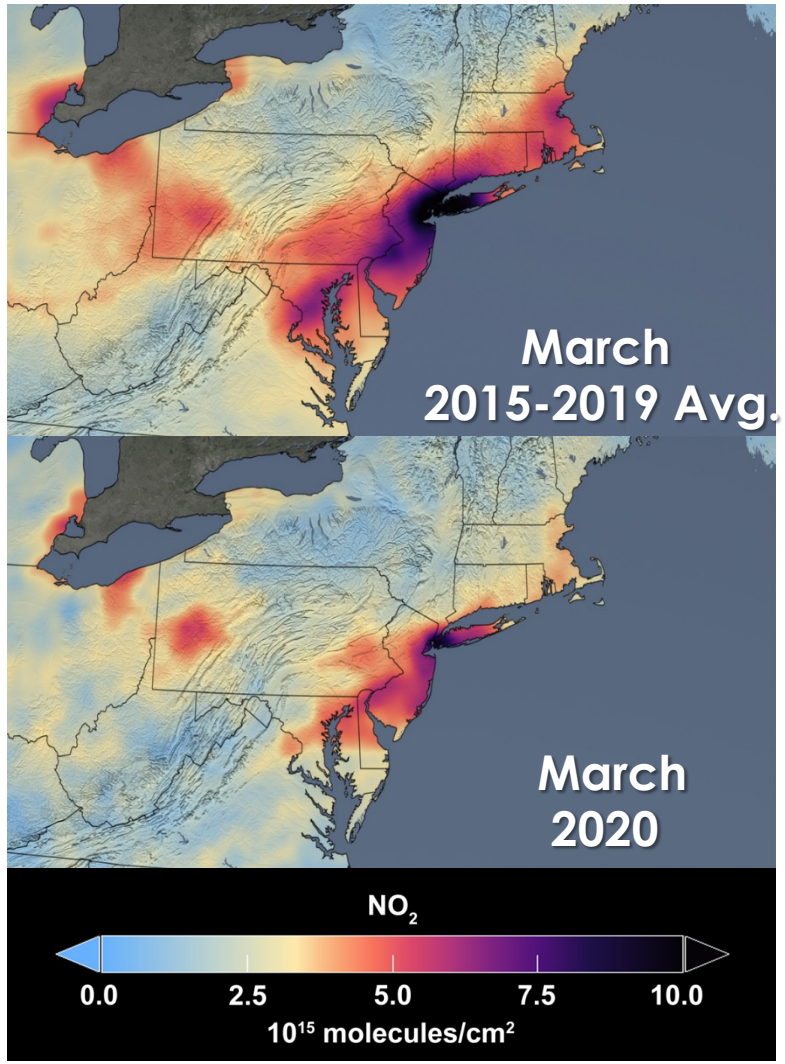



# Learning Objectives

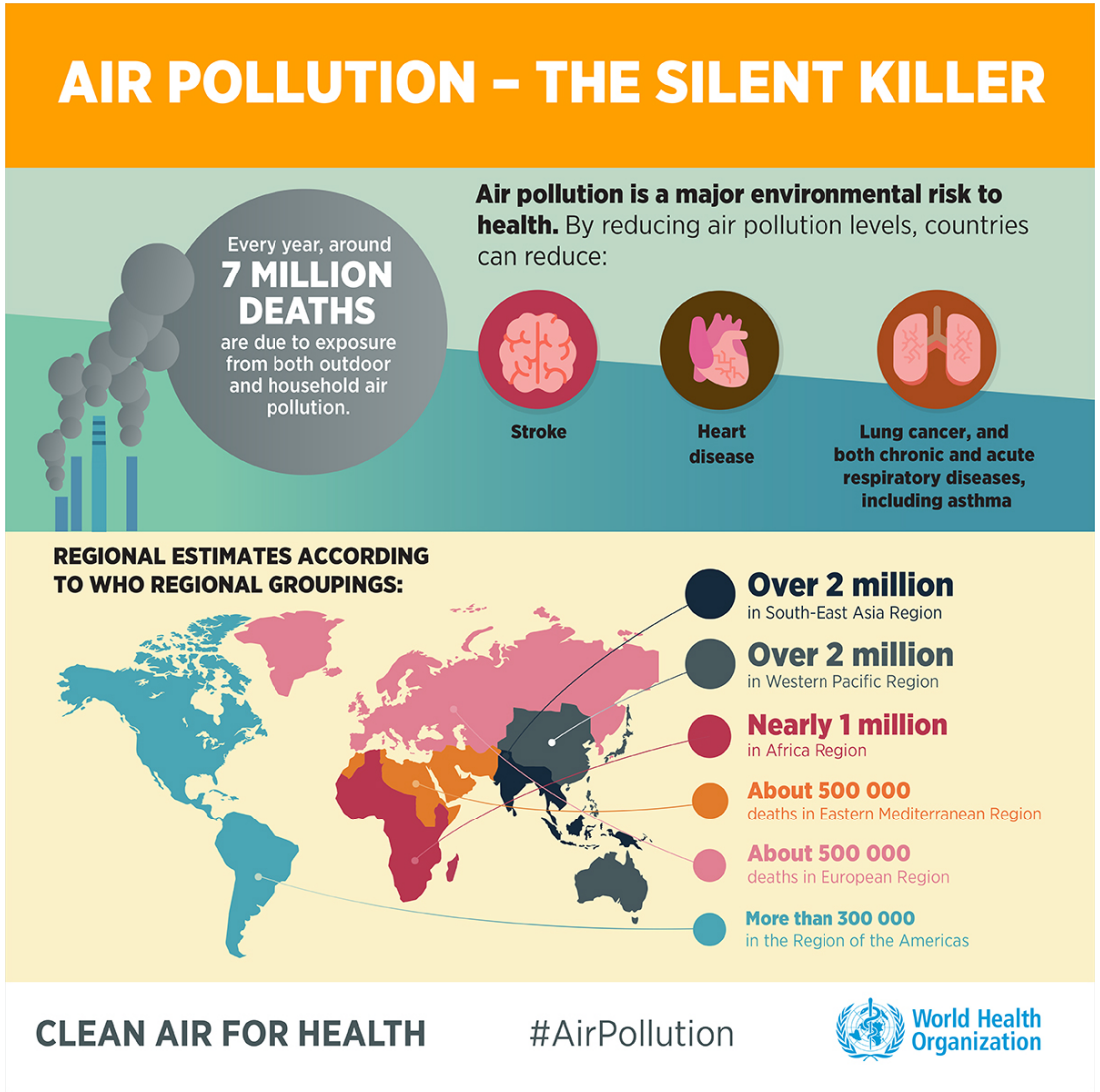
By the end of this presentation, you will be able to:

- Understand what satellites measure
- Explain what plots like these are showing
- Describe the capabilities and limitations of satellite $NO_2$ observations
- Find and download satellite imagery for $NO_2$



# 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

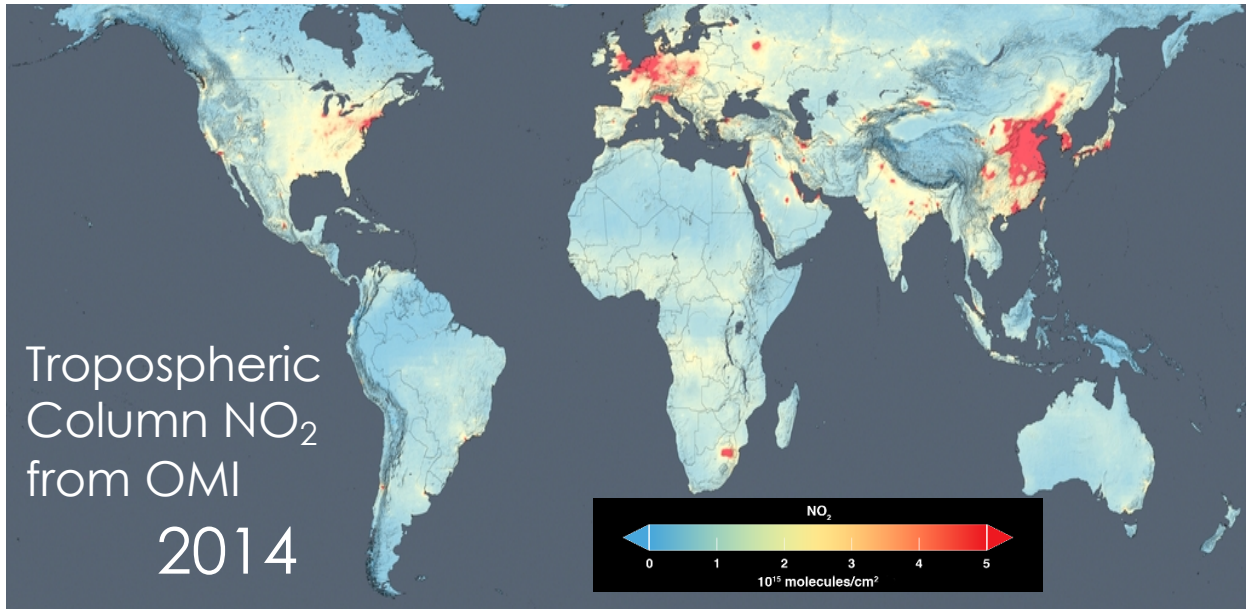
- **Gases**
  - Ozone ($O_3$)
  - Carbon Monoxide (CO)
  - Nitrogen Dioxide ($NO_2$)
  - Sulfur Dioxide ($SO_2$)
  - Greenhouse Gases ($CO_2$, Methane)

Today's presentation focuses on **$NO_2$**

- **Particles/Aerosols**
  - True Color Imagery
  - Aerosol Optical Depth
- **Fire Detection**

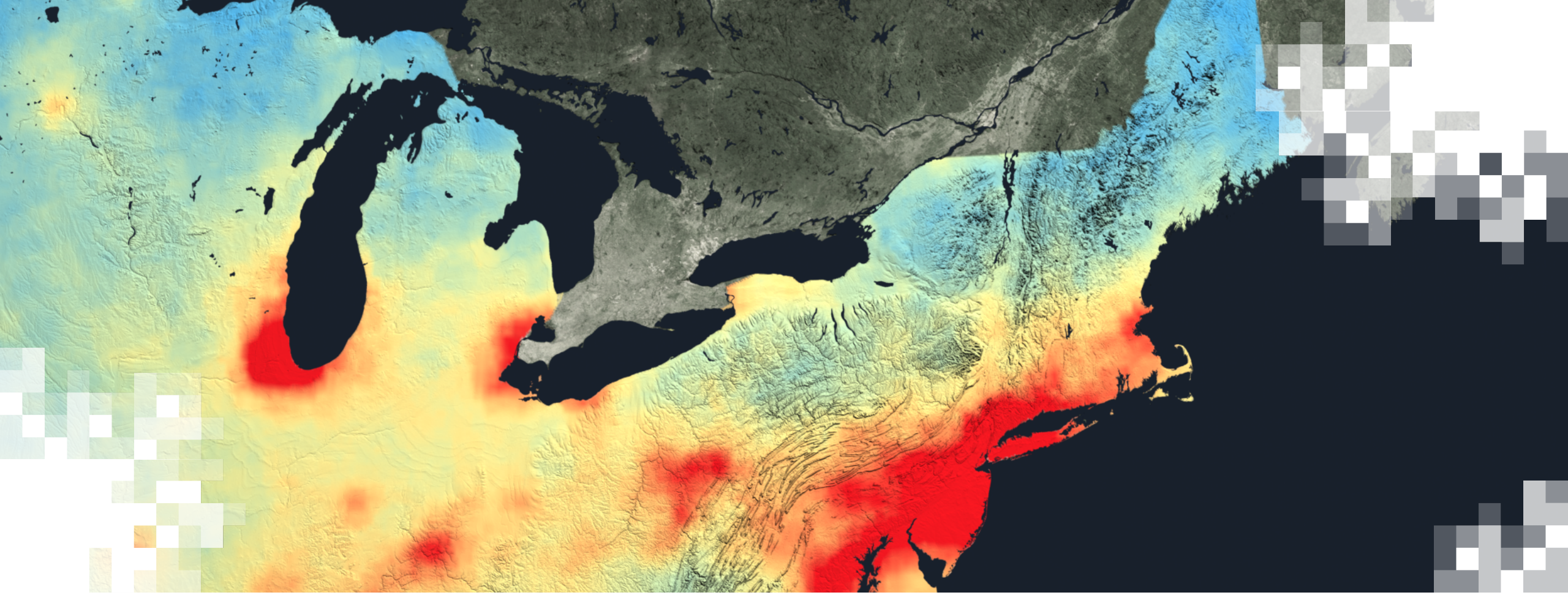
# Why does NASA measure $NO_2$?

- $NO_2$ 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 $NO_2$:
  - Lightning, fires, soils, combustion of fossil fuels (e.g., cars, power plants, manufacturing)




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

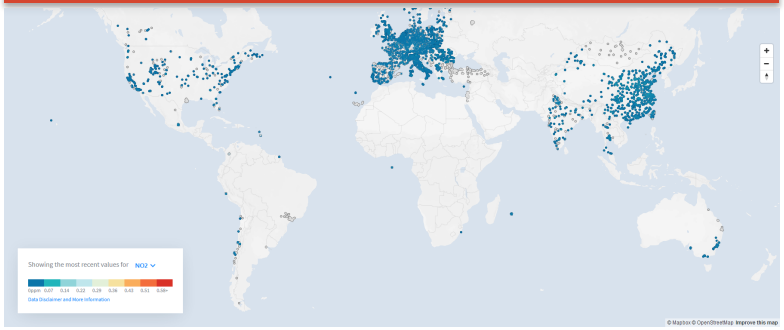
Most of the $NO_2$ pollution is at ground level, where ecosystems and people live and breathe.



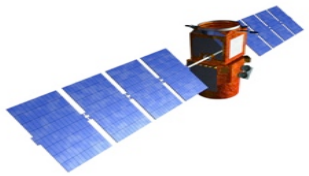
# Remote Sensing Basics

# Air Pollution Monitoring

Ground Measurements



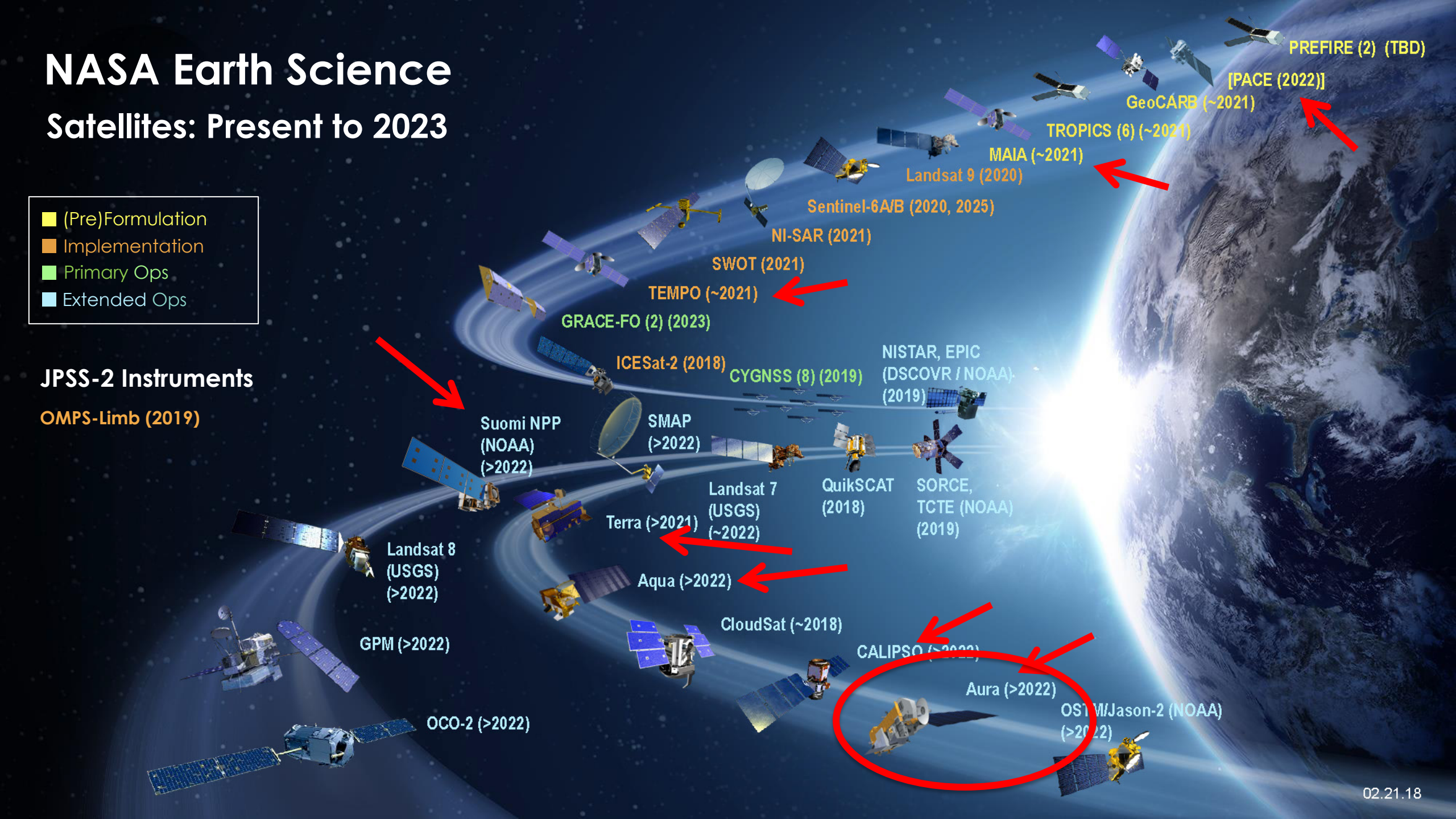
Air & Space Observations



Models

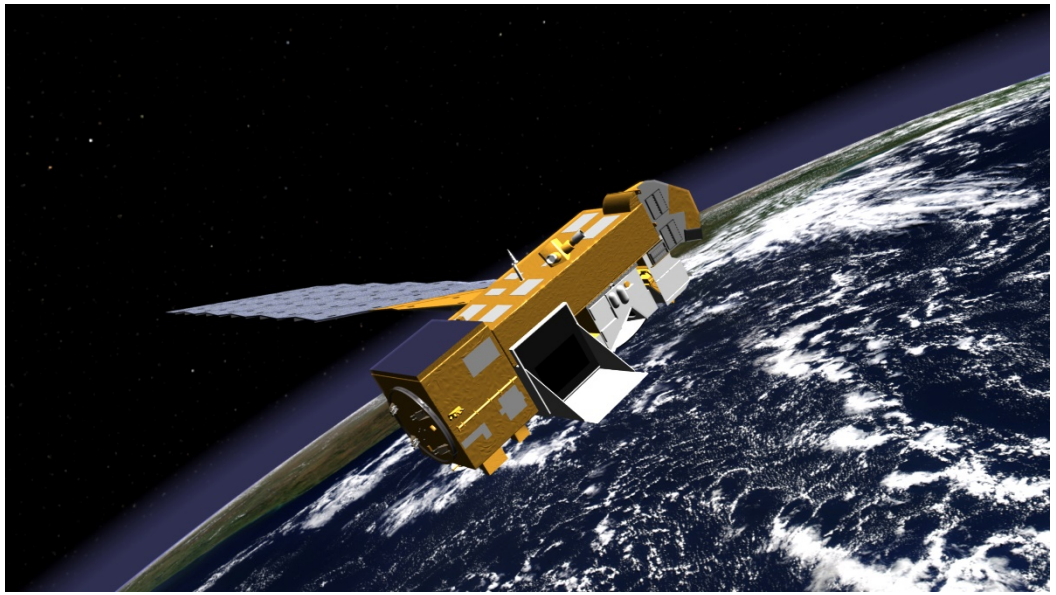
# NASA Earth Science

## Satellites: Present to 2023

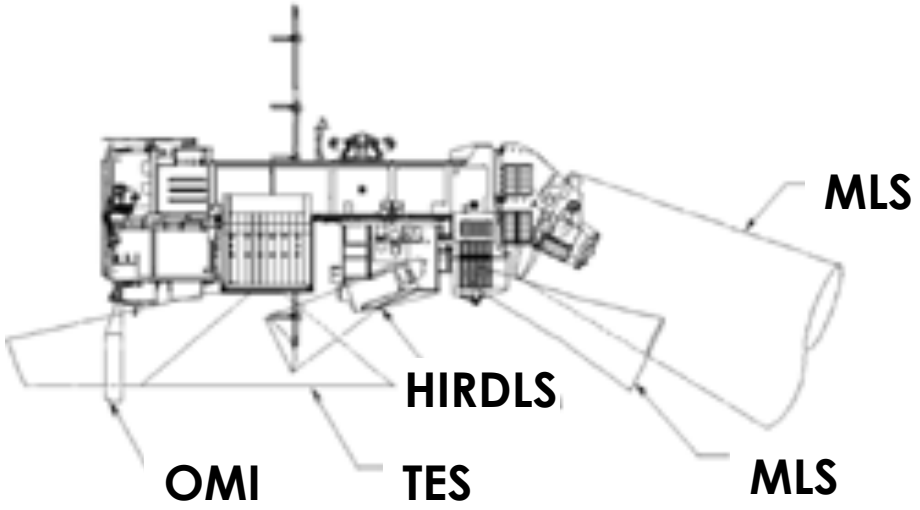


# Satellites vs. Instruments

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 $NO_2$! More on that later.

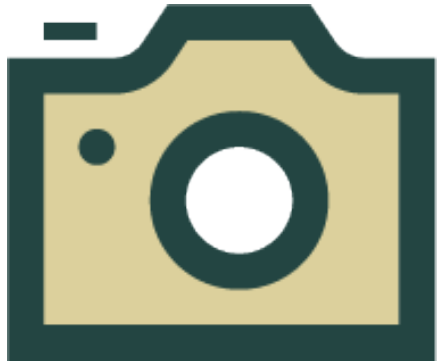


**Aura Satellite**



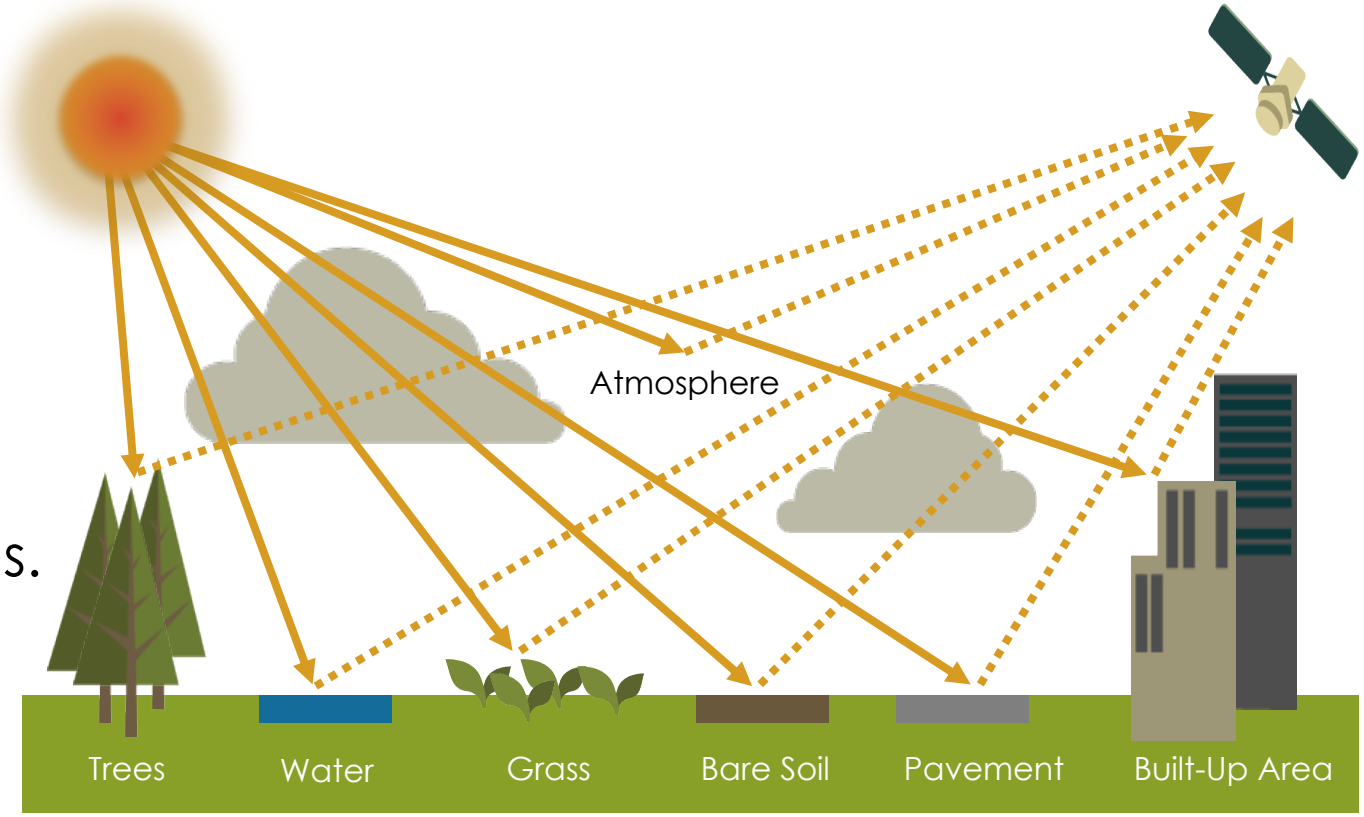
# What is remote sensing?

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

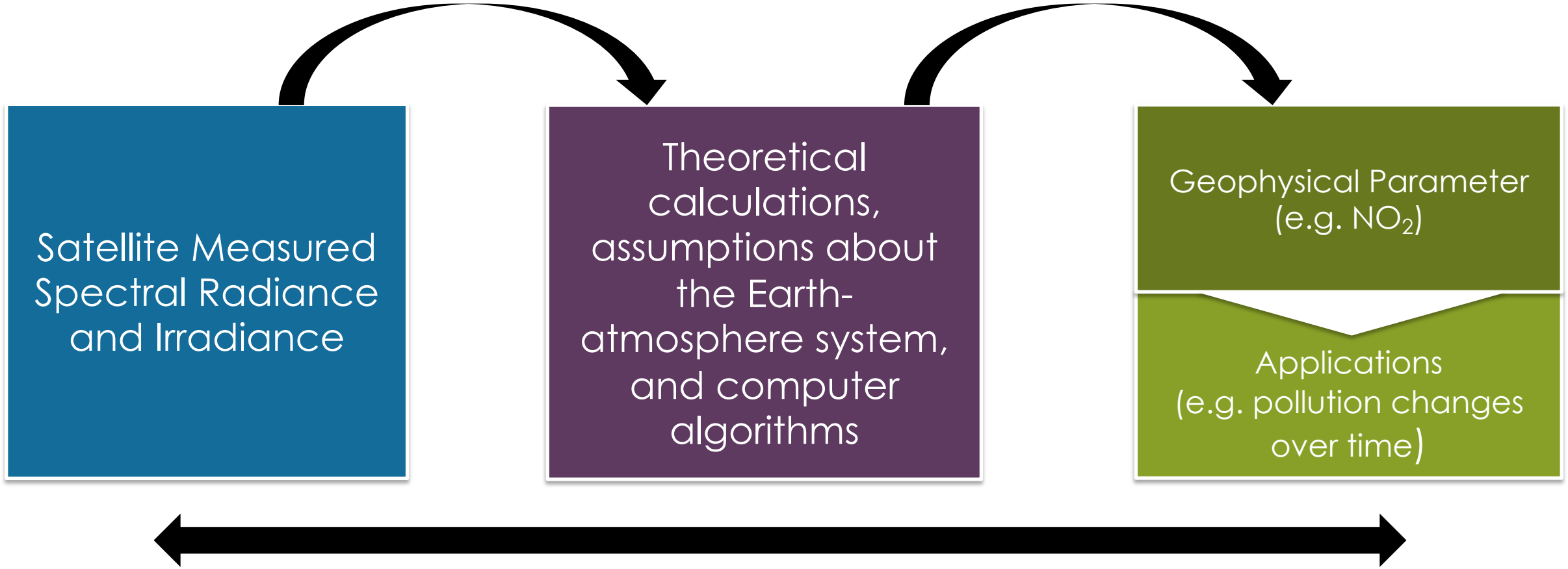


# What do satellite instruments measure?

- 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.

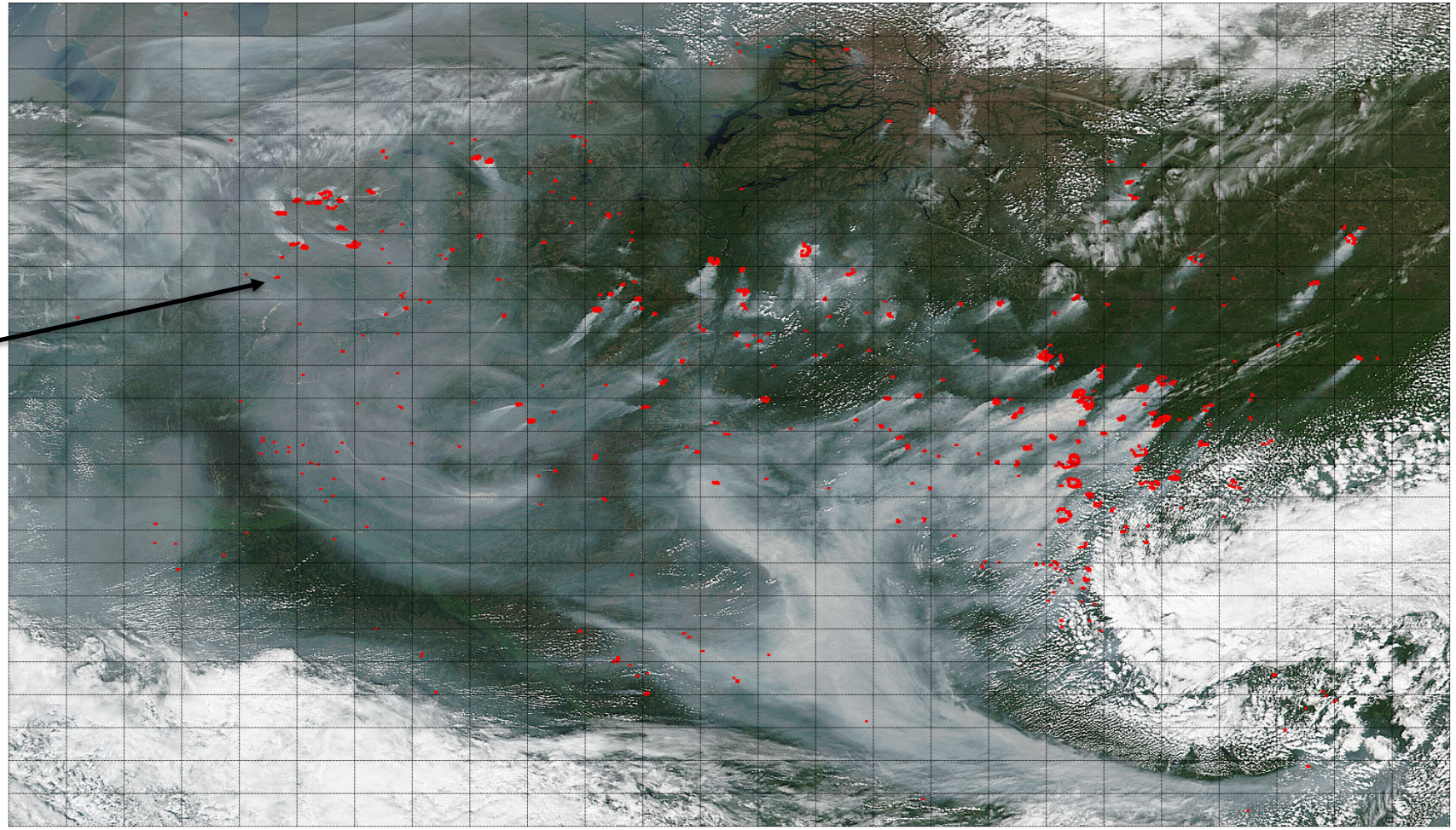


# How do we get from satellite measurements to images, and then to observed changes in air pollution over time?



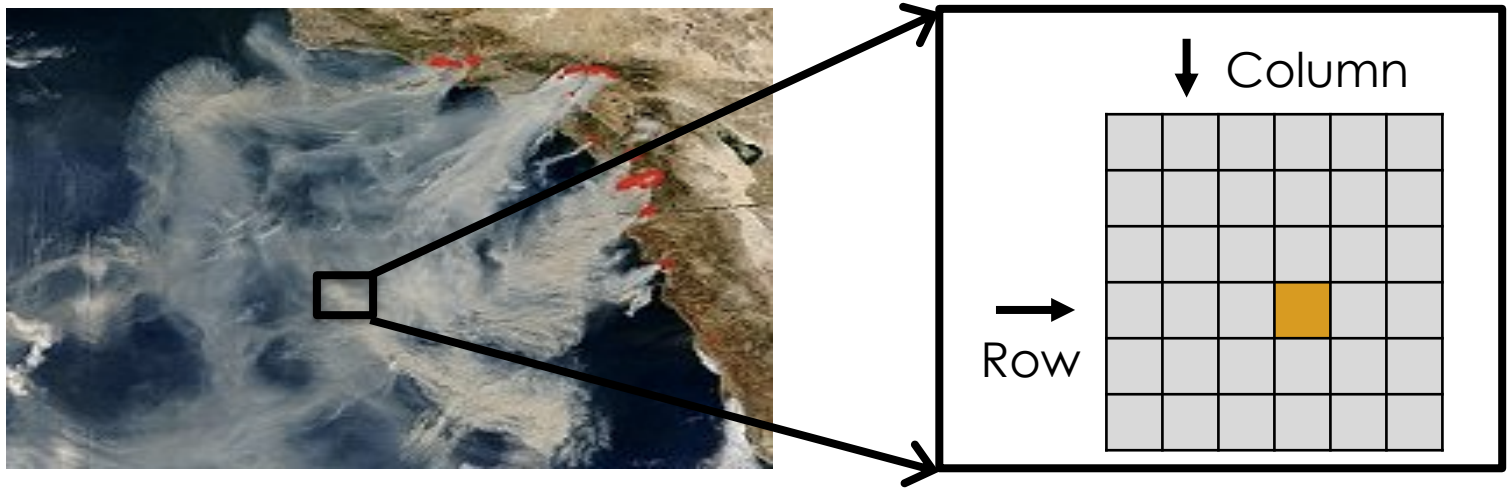
# “A Picture is Worth a Thousand Words”

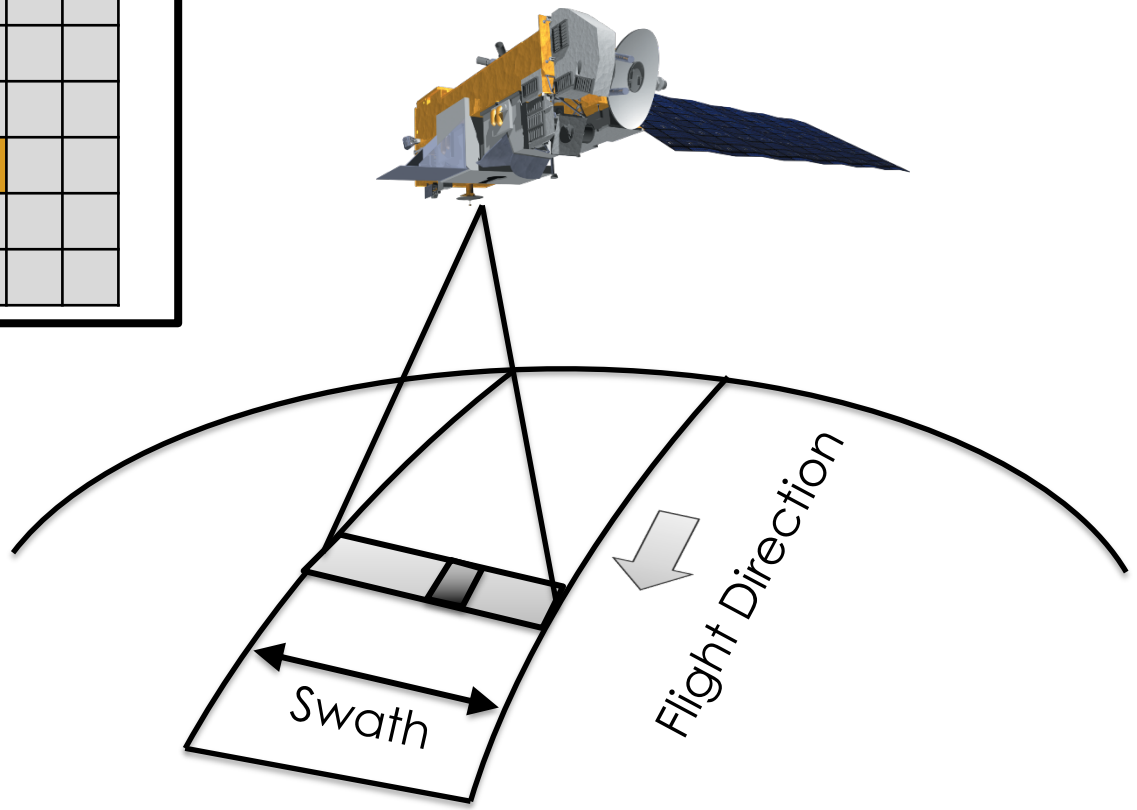
A satellite picture is worth ~~a~~ **millions of data points**.



A geo-physical number

# Pixel – The Smallest Unit of an Image

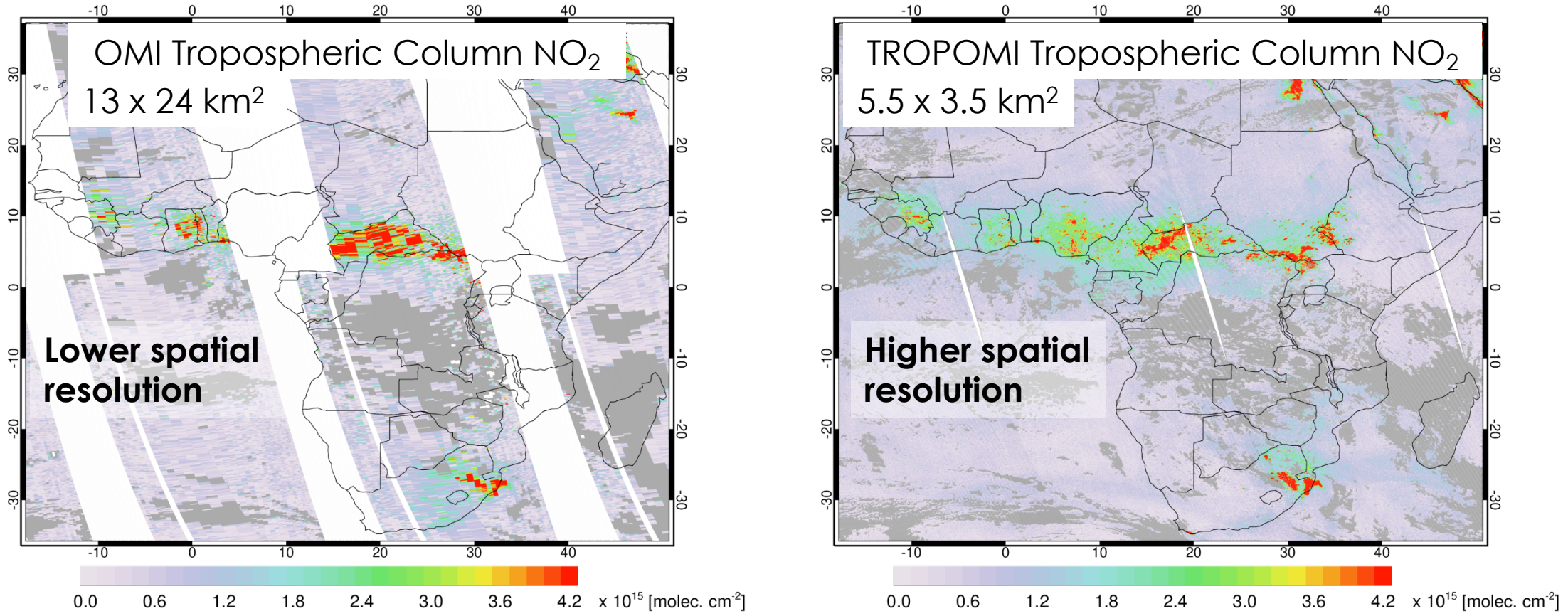



- An image is made up individual picture elements – called *pixels* – arranged in columns in rows.
- Each pixel represents an area on the Earth's surface and has a unique value.
- **Spatial resolution** is defined by the size of a pixel.

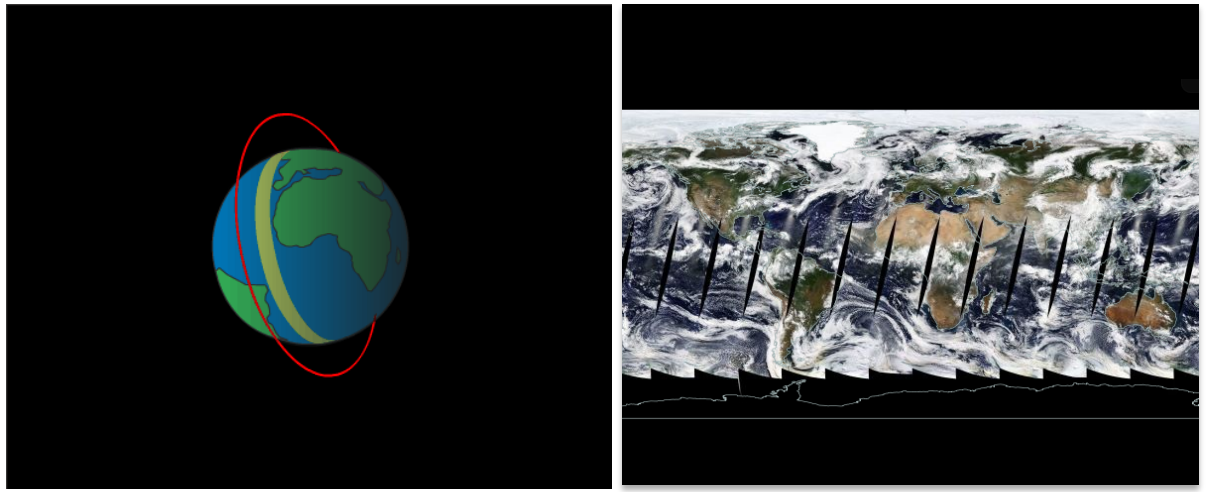
# Why is spatial resolution important?

Higher resolution means that we can identify more features.




Jan 01, 2019

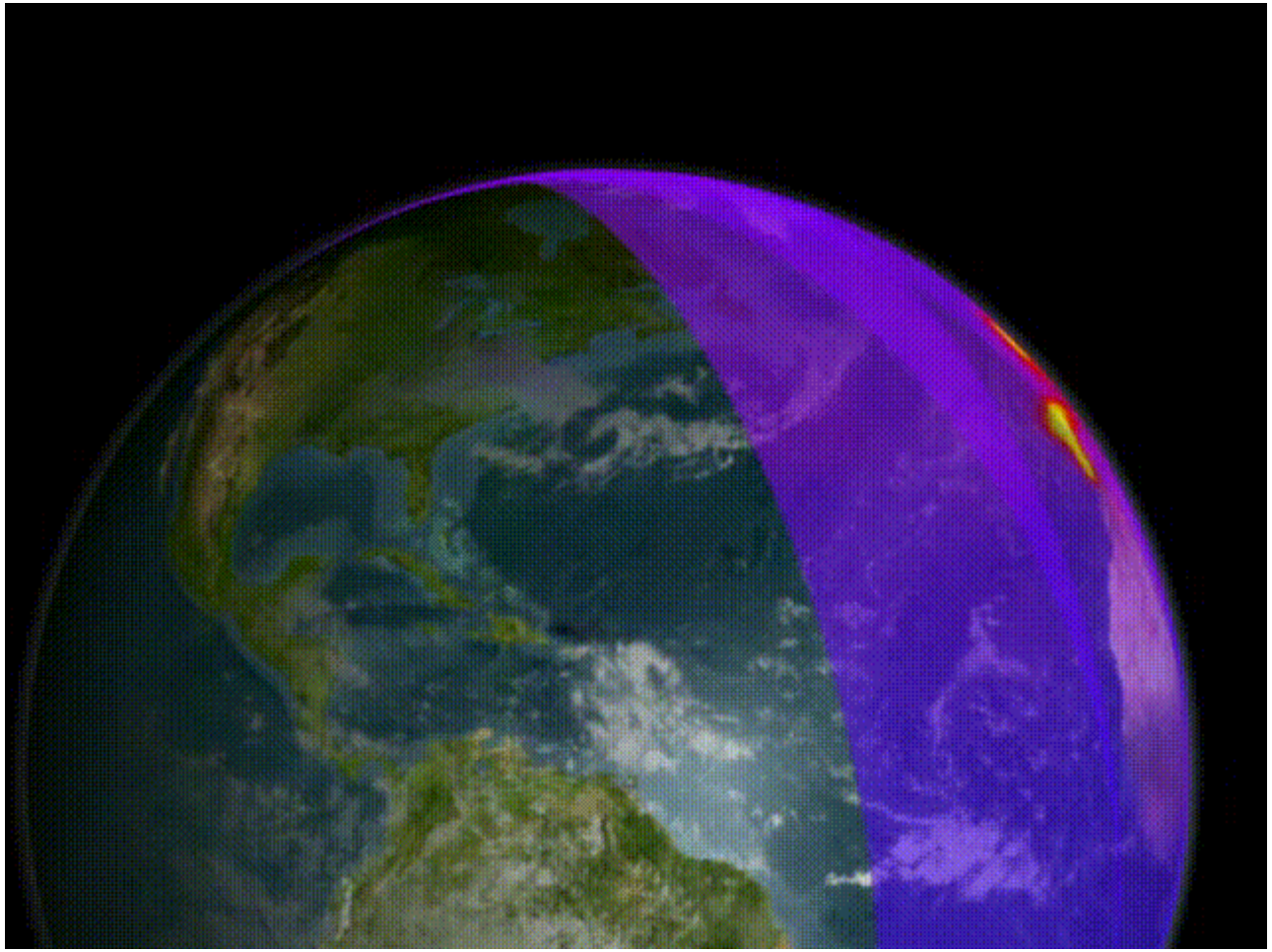
# Where do satellites make measurements?



**Polar Orbit**

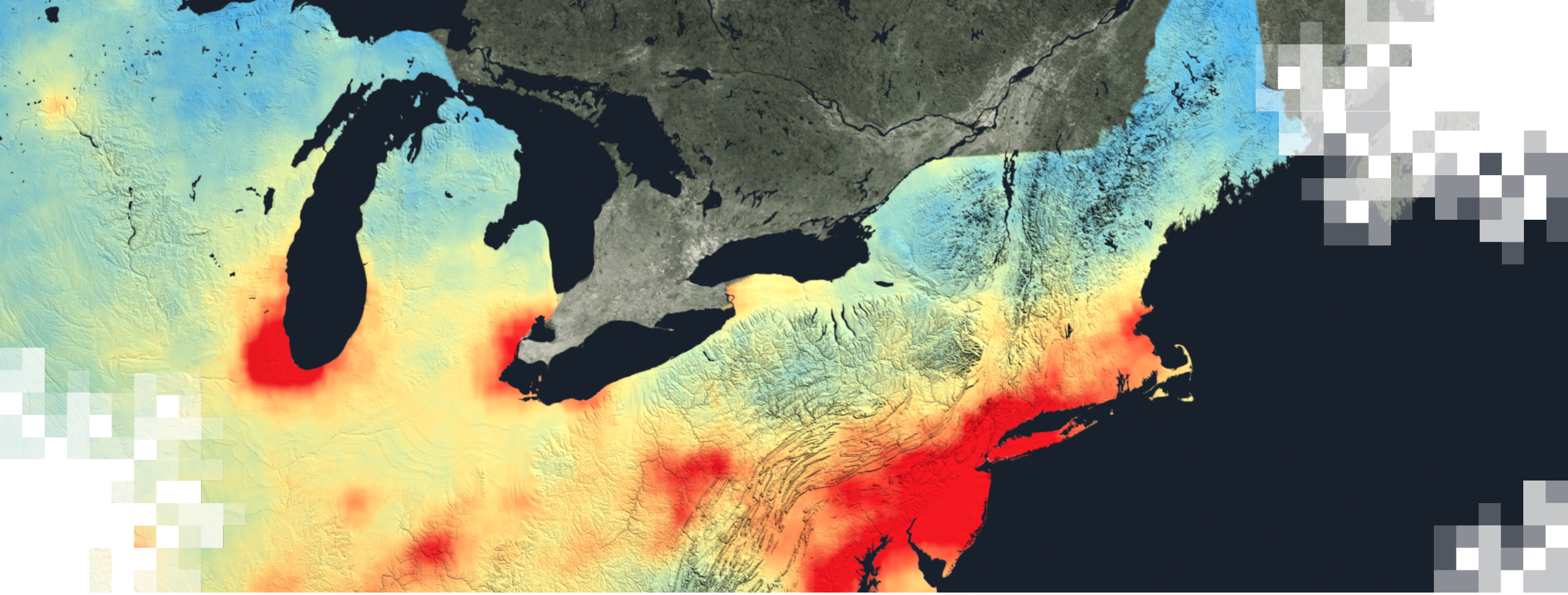
- Fixed, circular orbit above Earth
- ~600-1,000 km above Earth
- Passes overhead at about the **same local solar time** each day
- ***Can provide global coverage***

# 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 $km^2$ (but larger near the edges of the swath)
- Temporal resolution: Global coverage in 1-2 days

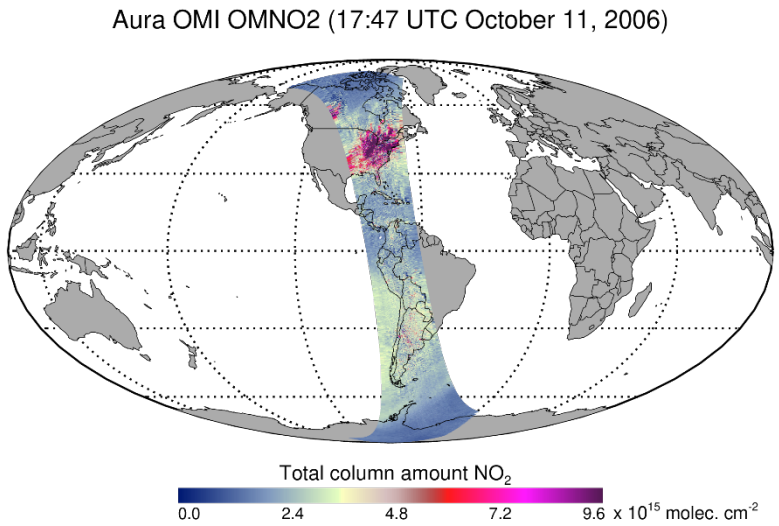
- Types of Measurements
  - Total Column $O_3$
  - Tropospheric Column $O_3$
  - Aerosol optical depth (in UV)
  - Column Formaldehyde
  - Column $NO_2$
  - **Tropospheric column $NO_2$**
  - Column $SO_2$


OMI data are freely available.

# OMI Nitrogen Dioxide ($NO_2$) Data: Native Resolution

- OMI $NO_2$ 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 $NO_2$ 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
- Level 2 data and images can typically be accessed within a day or two.

OMNO2 Level 2
*Native Resolution*

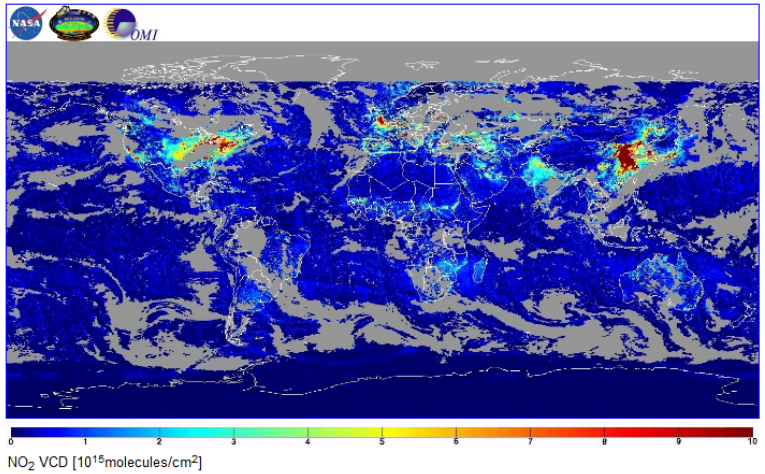



https://disc.gsfc.nasa.gov/

# OMI Data: Gridded Products

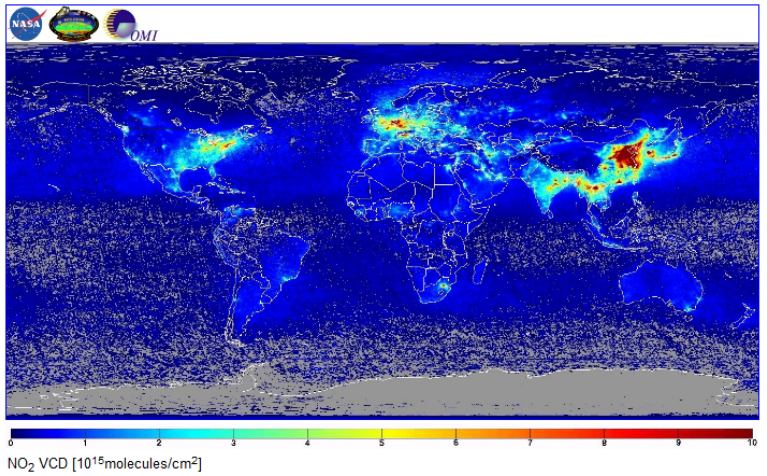
- NASA also provides OMI data on *uniform grids* (also known as Level 3).
- These can take a little longer to be available (few days).

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*

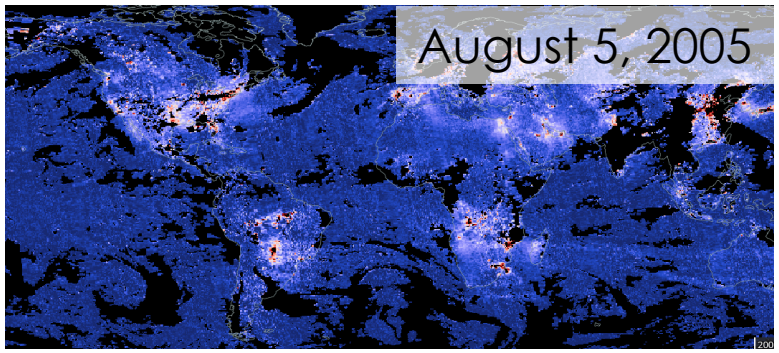


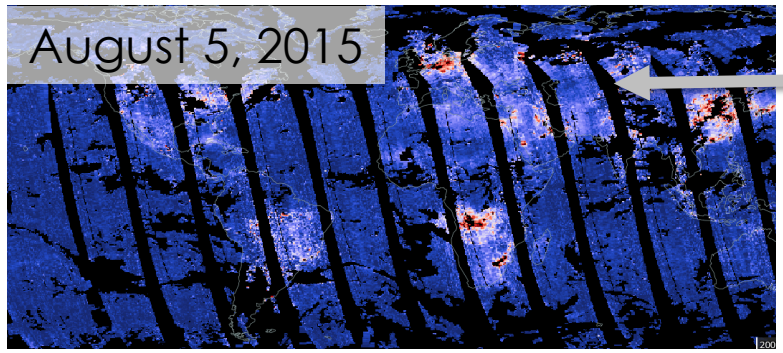

https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L3/OMNO2d_HR/
Daily: hdf5
Monthly: txt, netcdf

# Important Considerations When Using OMI $NO_2$ 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 $NO_2$

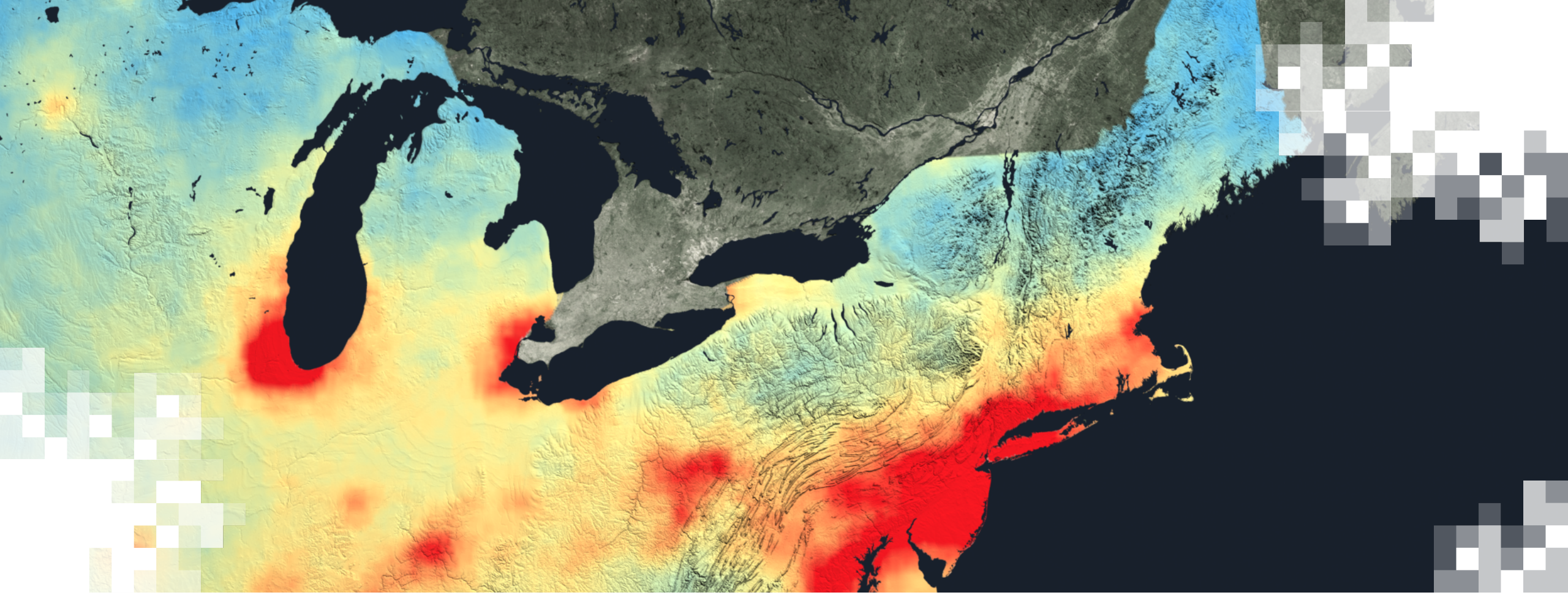



Loss of data due to row anomaly

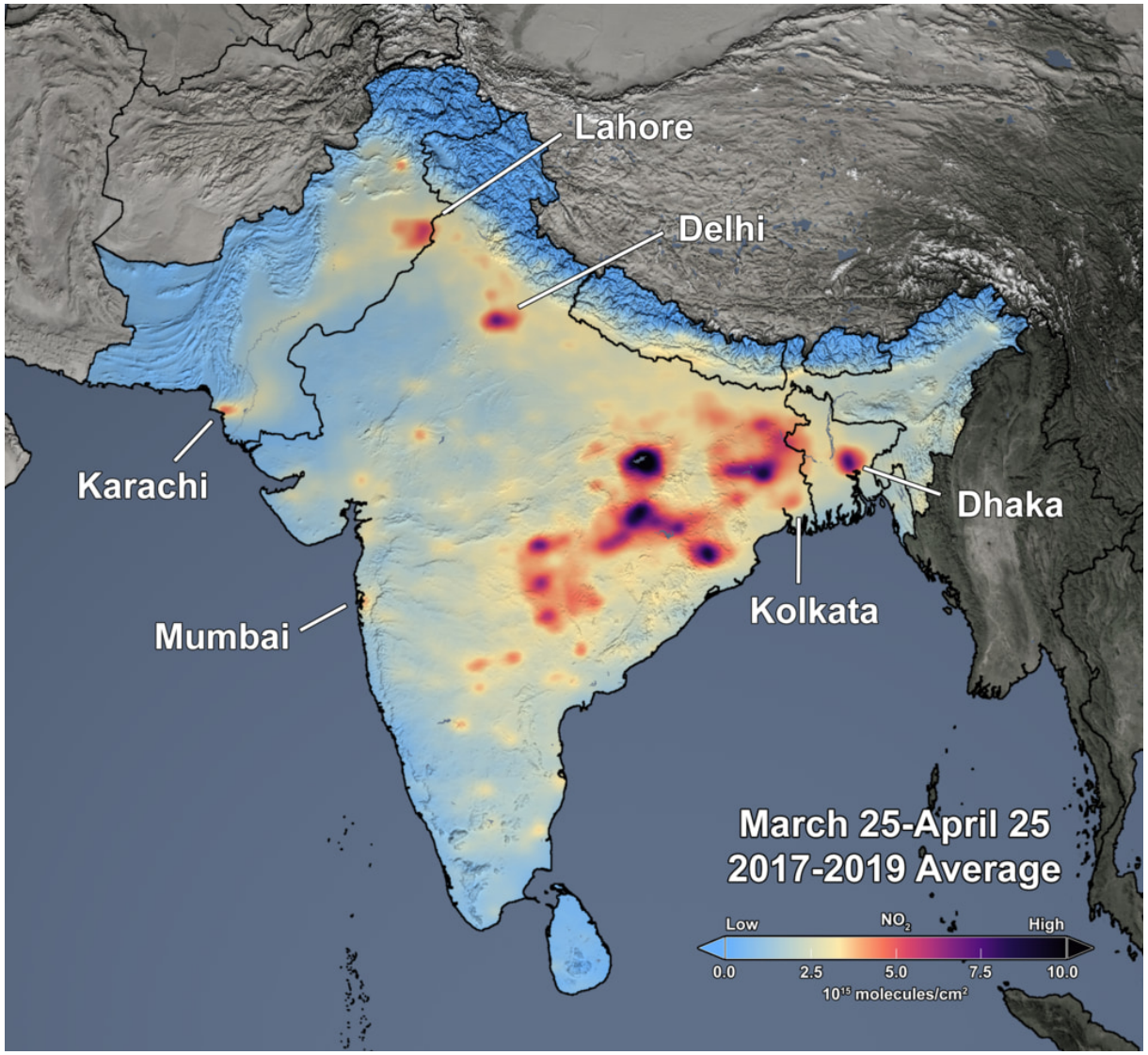
# What other satellite instruments measure $NO_2$? TROPOMI

- Since March 2020, there have been numerous media reports showing global changes in $NO_2$ 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

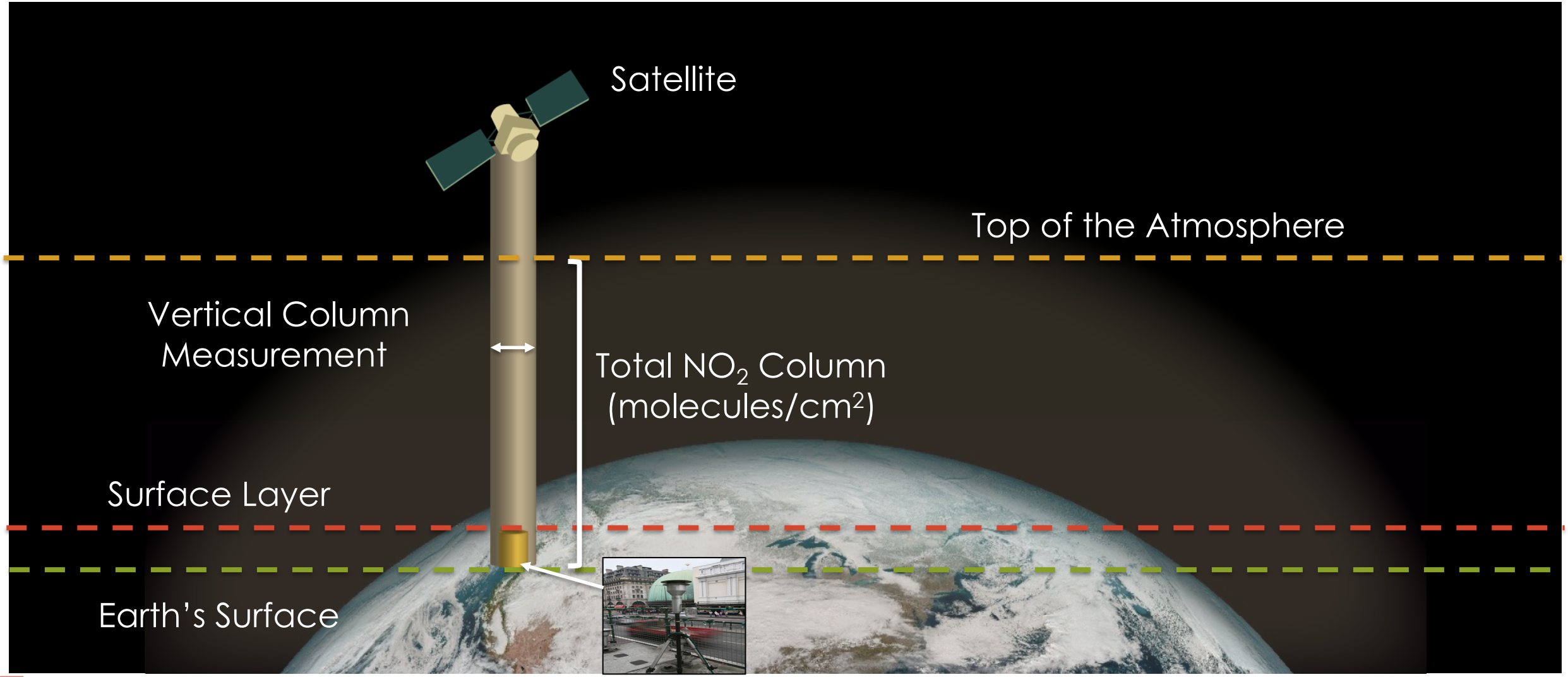


# Basics of $NO_2$ Image Interpretation

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

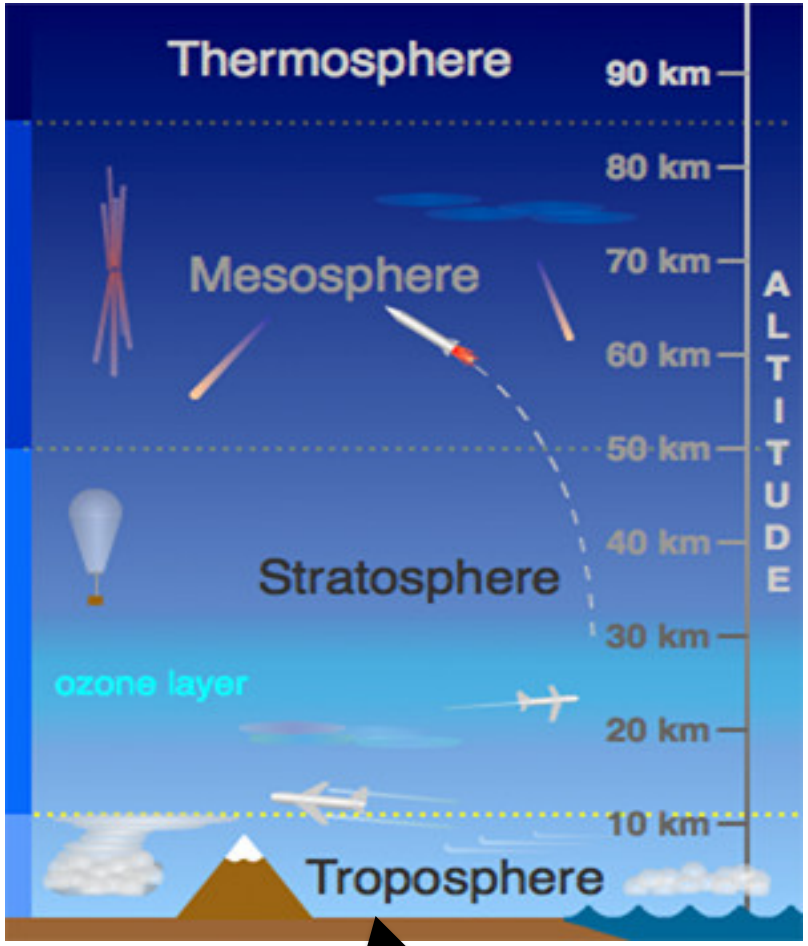


# Satellite vs. Ground-Based Instruments



# 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




Total Column (molecules/cm$^2$)

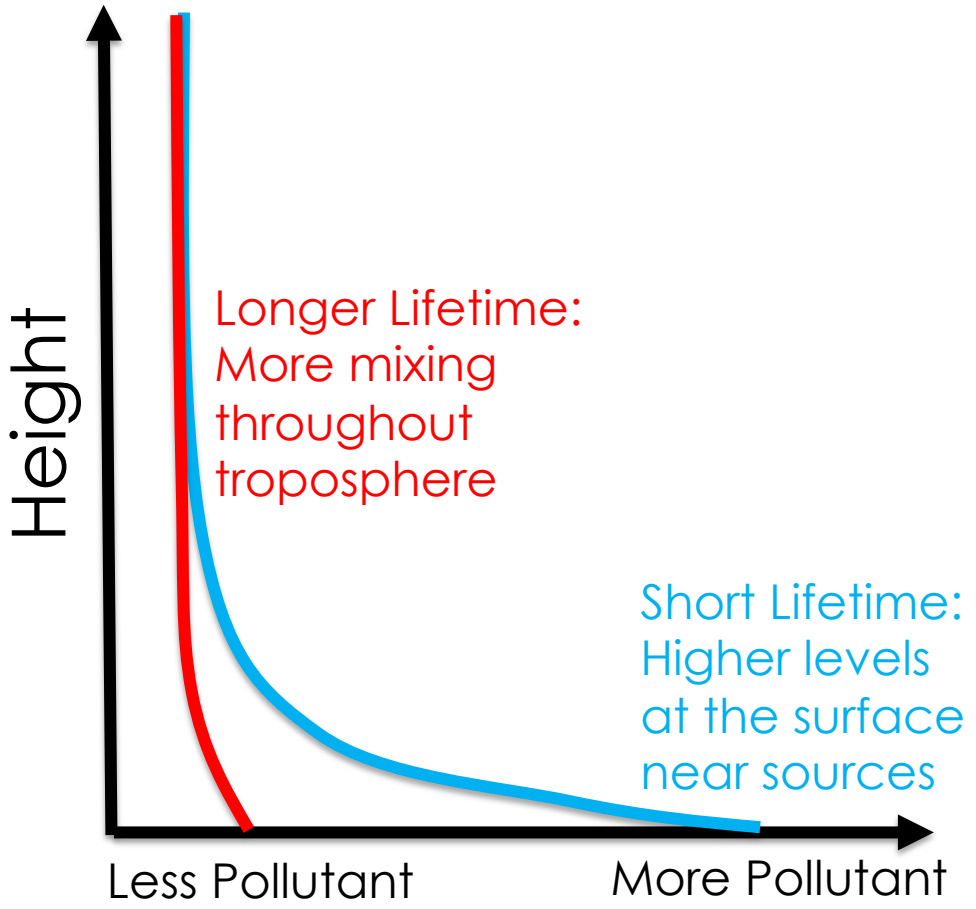
Tropospheric Column (molecules/cm$^2$)

You are Here (Surface, ppm or µg/m$^3$)

Image: https://scied.ucar.edu/atmosphere-layers

# 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 $NO_2$ is emitted at the surface (e.g. vehicles, electrical generation).
- How long does it stay in the atmosphere?
  - Near the surface, $NO_2$ is relatively short lived (a few hours), so pollution levels are much higher around a source.



# Changes in the $NO_2$ Column Can Give Us Information about Changes at the Surface

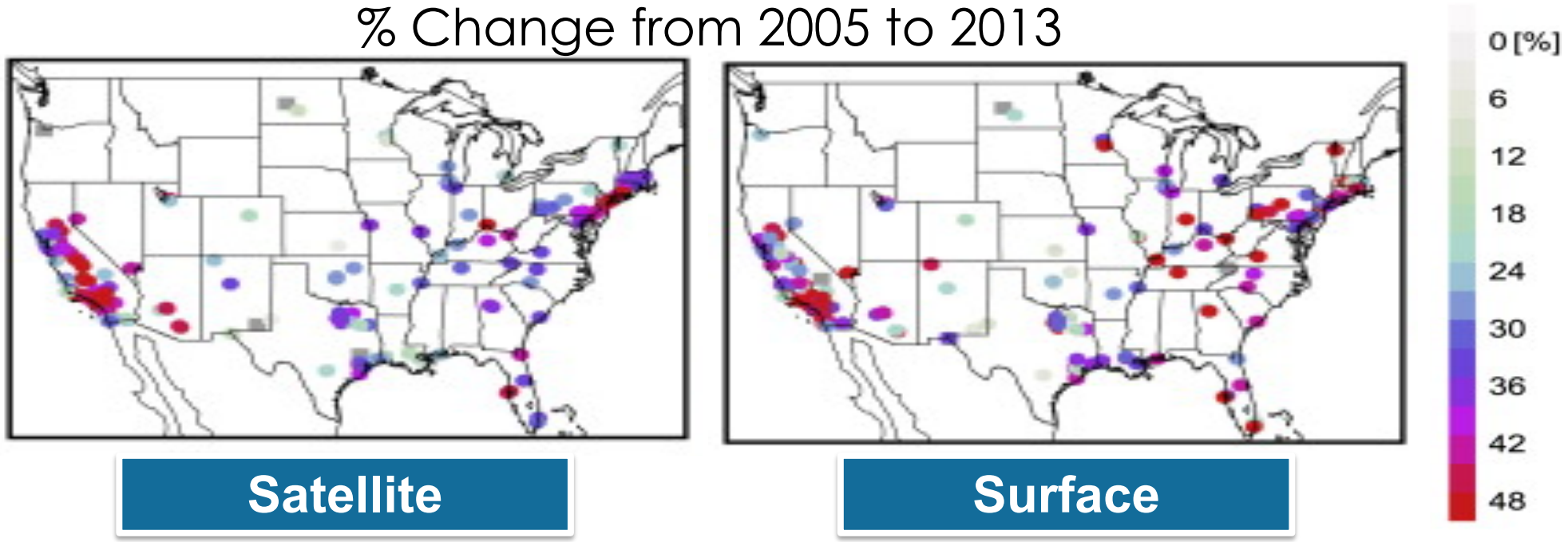
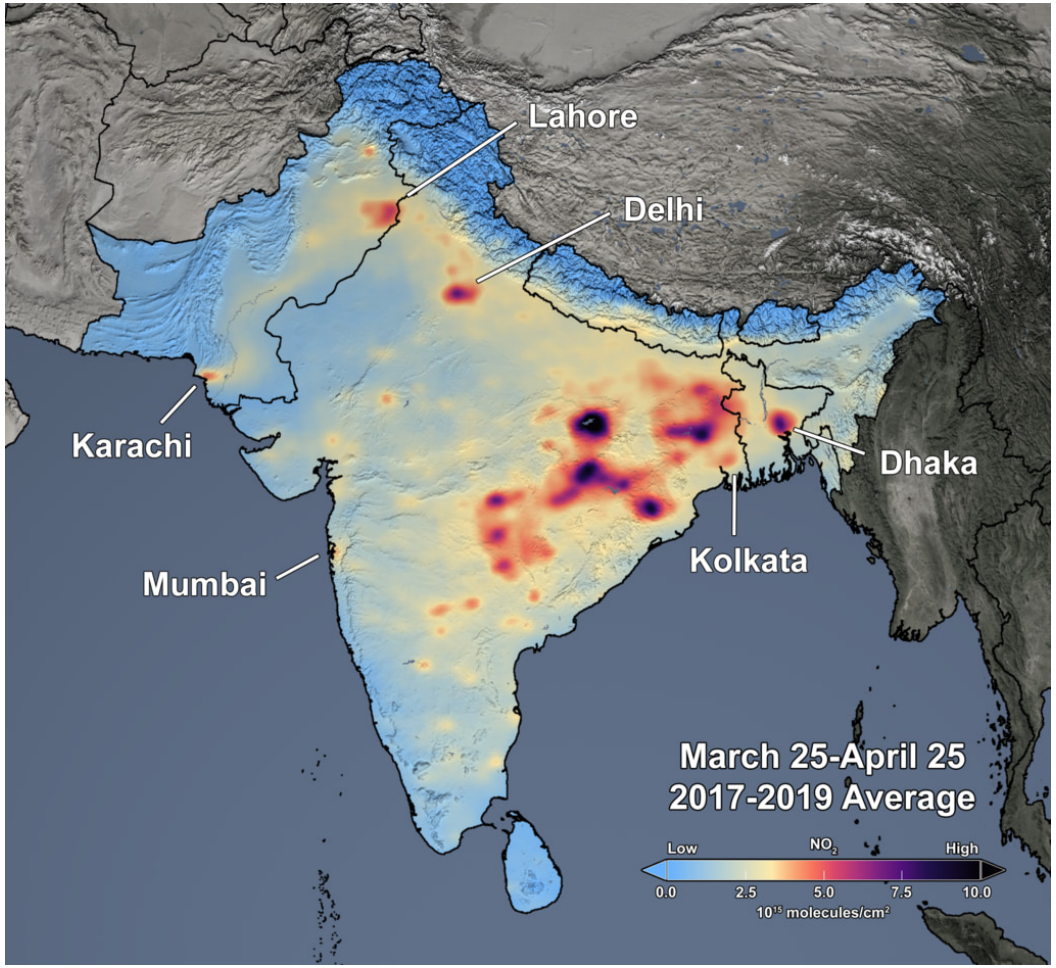



Image Credit: Lamsal et al. (2015)

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

- The color bar indicates the amount of $NO_2$ from the surface to the top of the tropopause (molecules/cm2).
- If processed and interpreted carefully, $NO_2$ levels observed from OMI serve as an effective proxy for $NO_2$ levels at the surface.
- This image has been produced by averaging daily data over a 30-day period over three years (2017-2019).
- OMI $NO_2$ imagery captures features at local to regional scales.
  - Fine enough to resolve individual power plants and large cities



# What determines the amount of $NO_2$ at ground level?

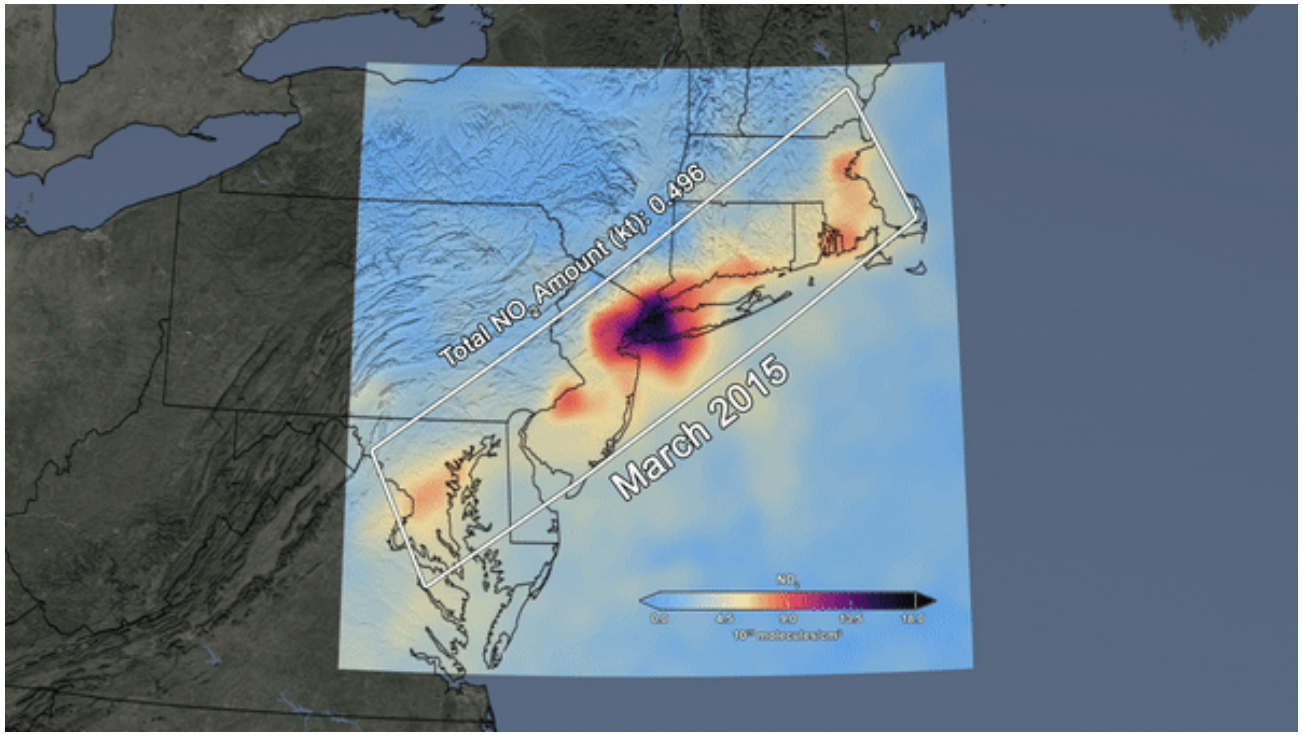
Emissions

+

Chemistry

+

Weather



# What determines the amount of $NO_2$ 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?

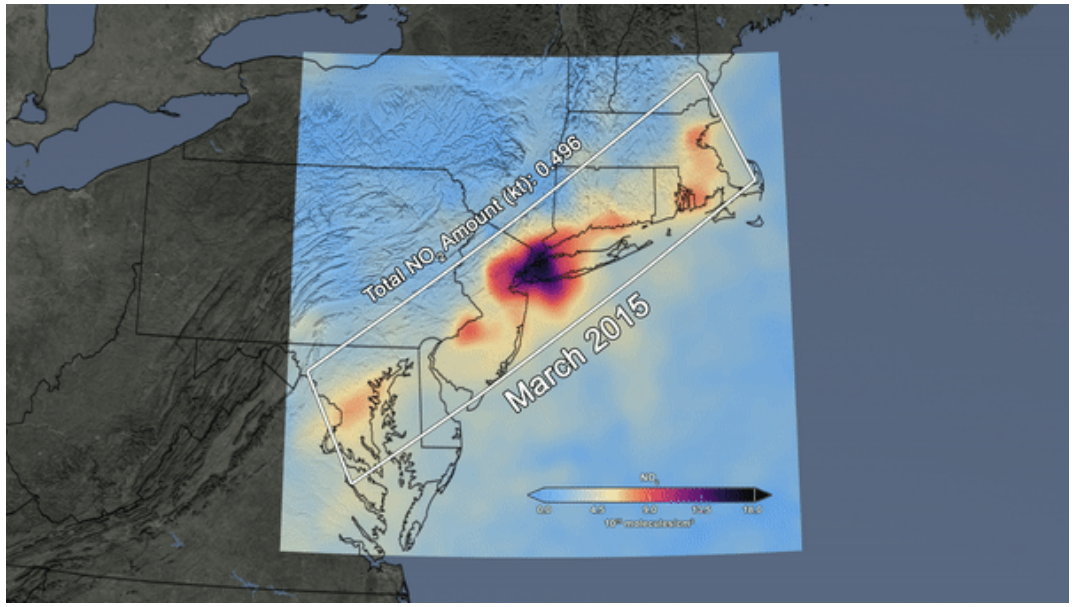
- Increased use of renewable energy
- Air quality or climate-change policy or regulation
- Unexpected changes
  - Economic recession
  - Natural disasters
  - Lockdown due to COVID-19
  - Sudden policy interventions (e.g. Beijing Olympics)

# What determines the amount of $NO_2$ at ground level?

**Chemistry**

There are always emissions of $NO_2$ 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.



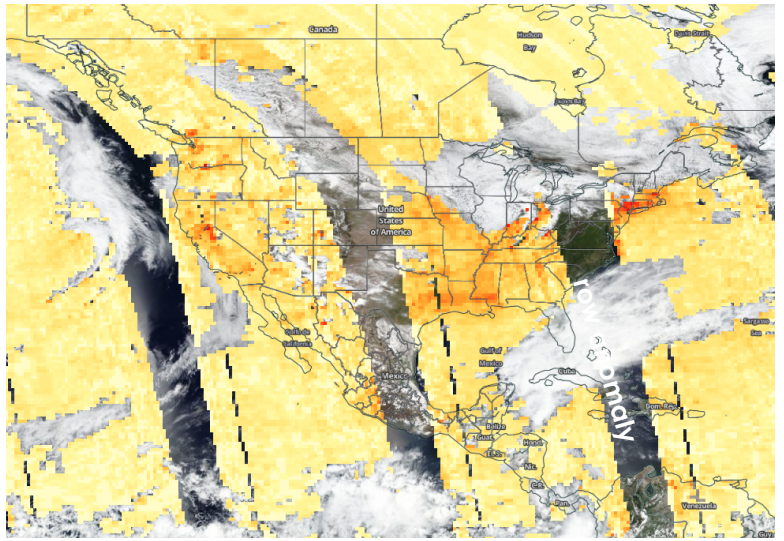
# What determines the amount of $NO_2$ at ground level?

**Weather**

Weather varies from year to year and can impact the amount of $NO_2$ at the surface.

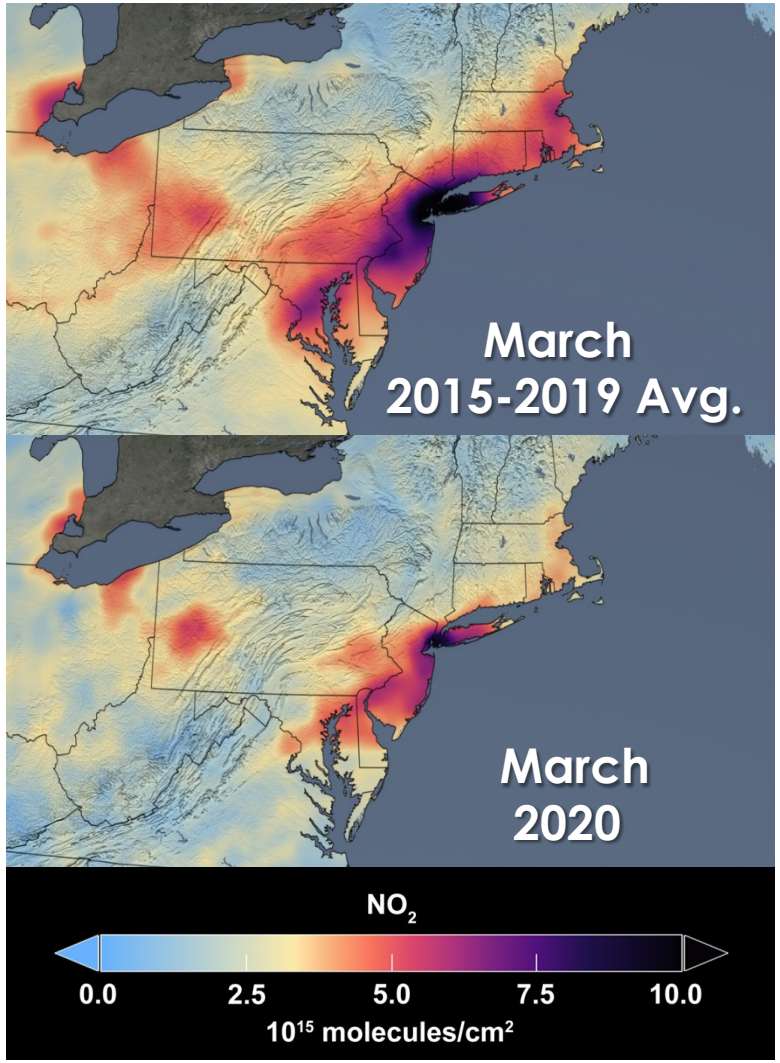
- *Winds:* Winds can disperse emissions, changing $NO_2$ levels depending on wind direction and speed
- *Temperature, Clouds:* Higher temperatures and/or more sunlight can speed up $NO_2$ chemistry in the air.
- Clouds can also interfere with an instrument's ability to "see" all the way to the surface.
- *Rain:* Rain can wash away pollutants, cleaning the air and lowering pollutant levels.

OMI Tropospheric Column $NO_2$
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?

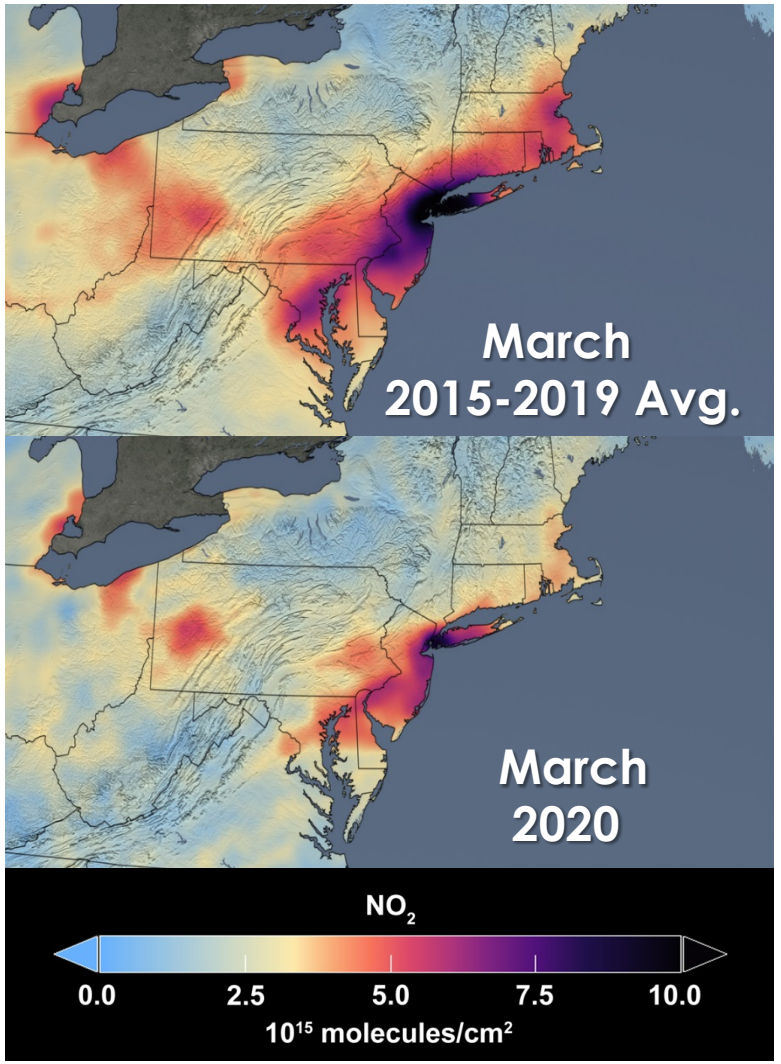
*Tropospheric Column $NO_2$*

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 $NO_2$ at the surface, where people breathe?

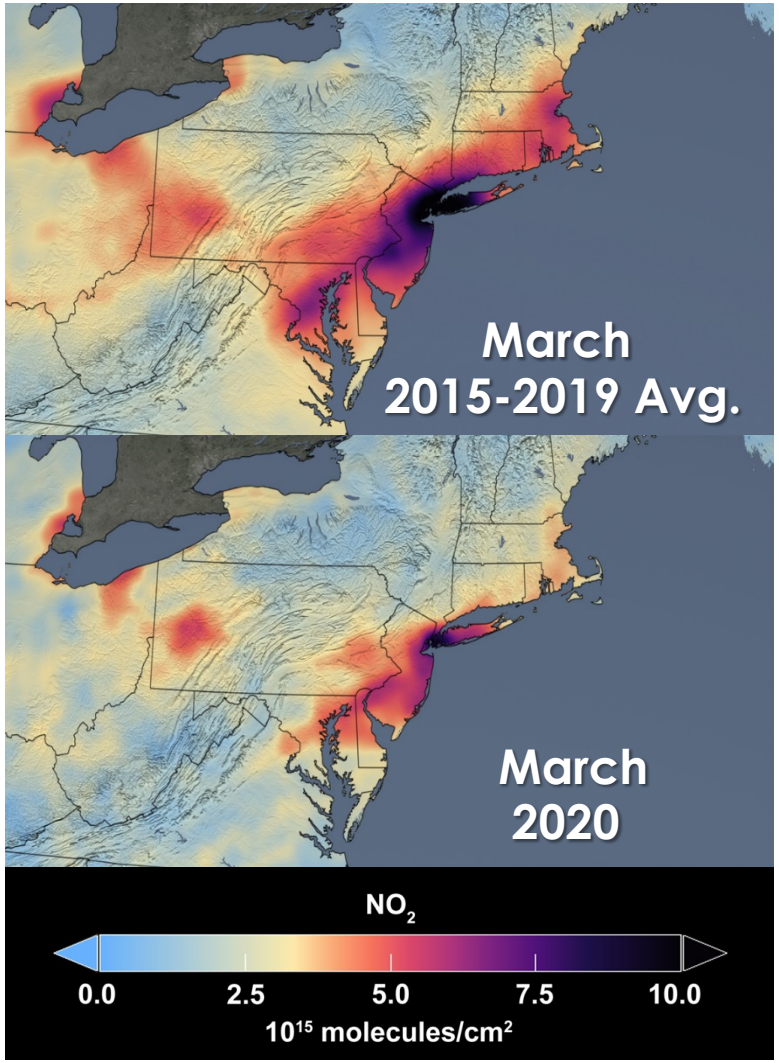
*No, this is a map of tropospheric column $NO_2$, which is the total amount of $NO_2$ from the surface to the top of the troposphere.*

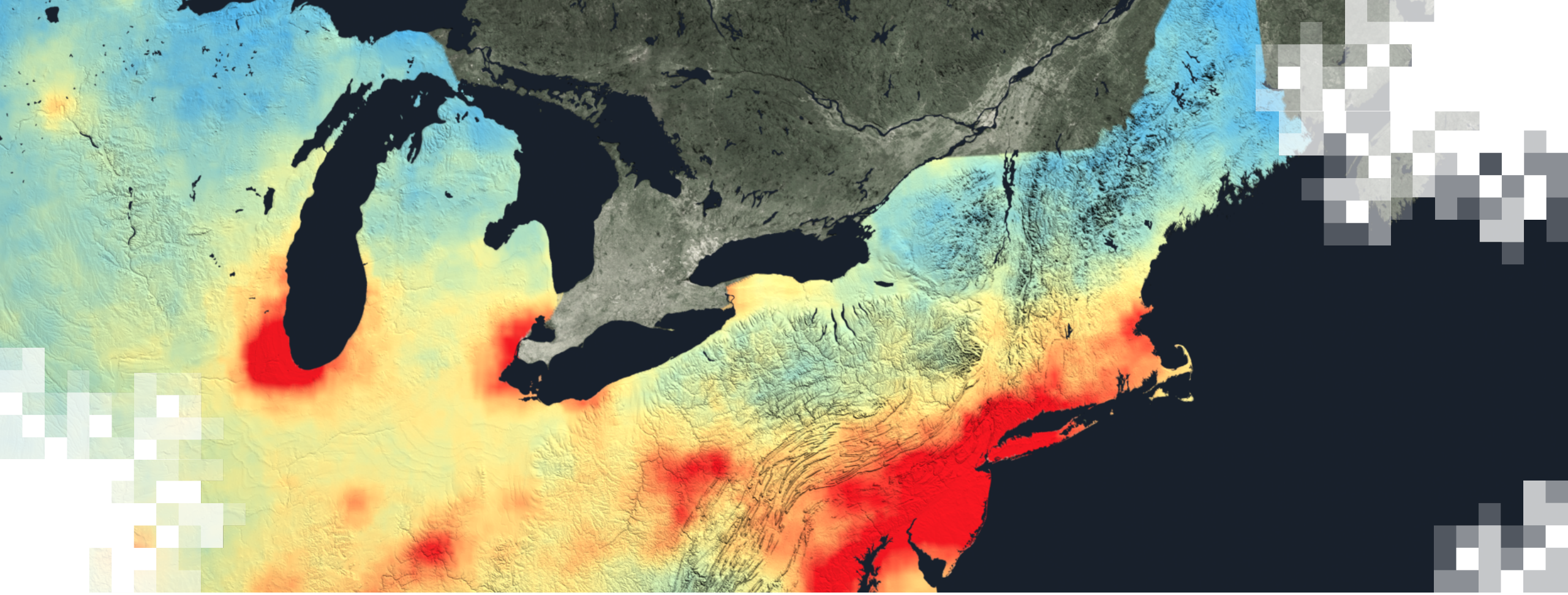
Can changes in the tropospheric column tell me information about changes at the surface?

*Yes, sources of $NO_2$ 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 $NO_2$ depends on:*
*emissions + chemistry + weather*
*Calculating the change in $NO_2$ from the lockdown requires careful and rigorous scientific analysis.*





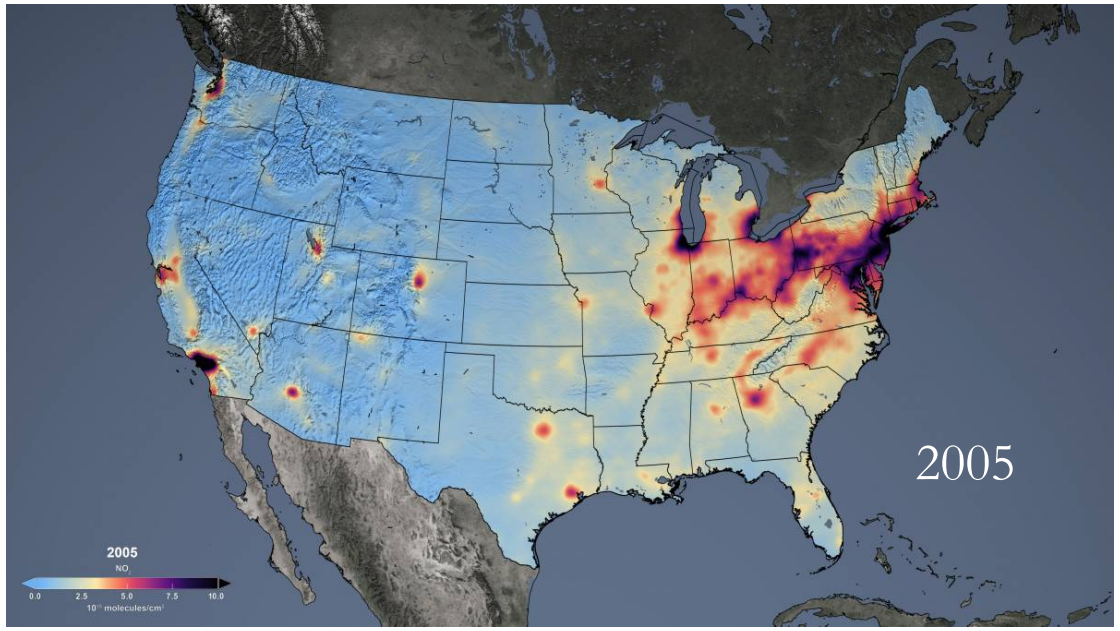
# Practical Uses of $NO_2$ Satellite Images and Data

# Practical Uses of $NO_2$ 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 ($CO_2$)

# OMI Detects $NO_2$ Changes in Pollution Over Time

## Between 2005 and 2018, air quality regulation led to large decreases in $NO_2$.



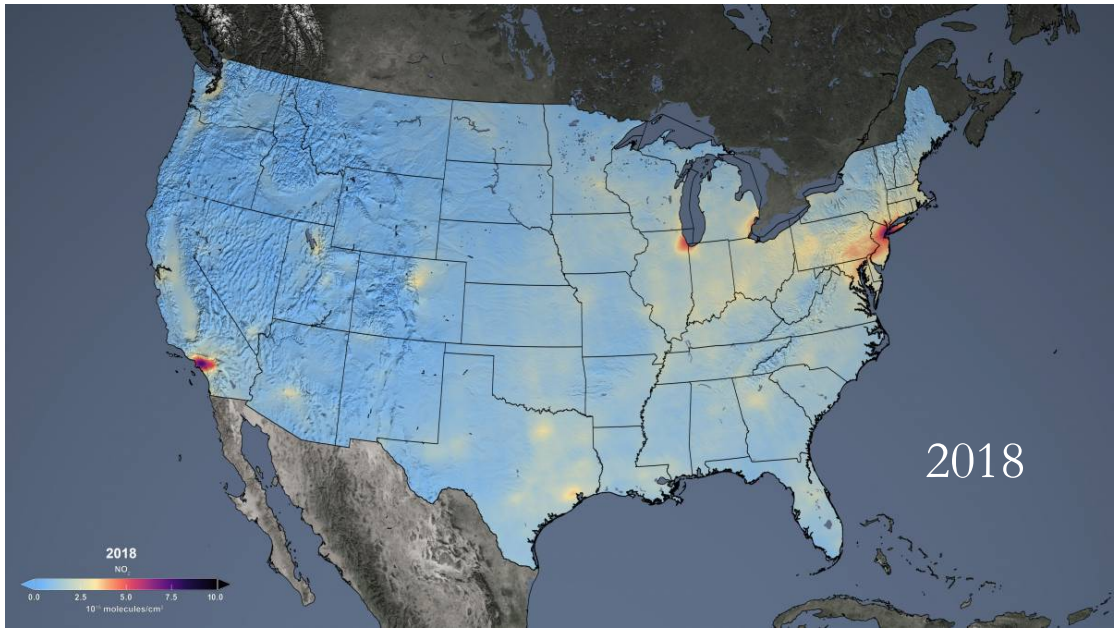
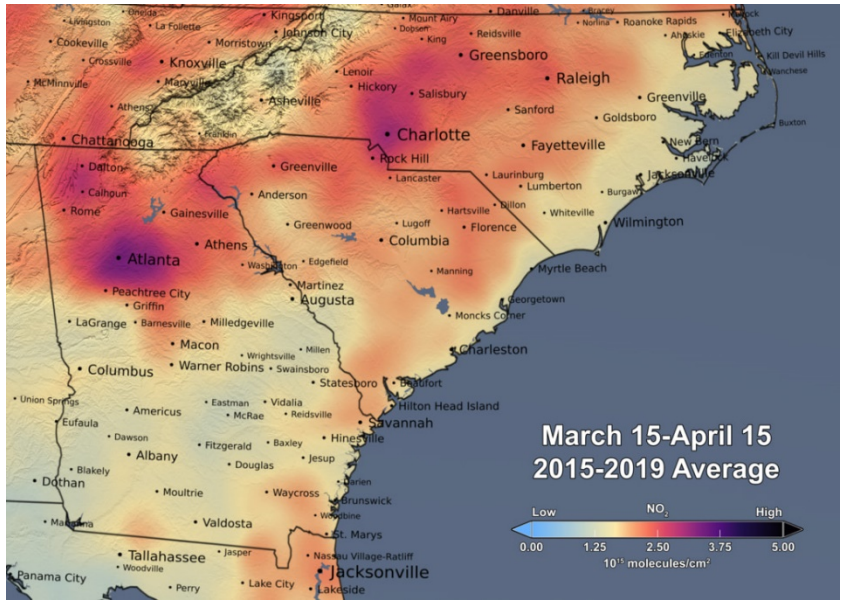
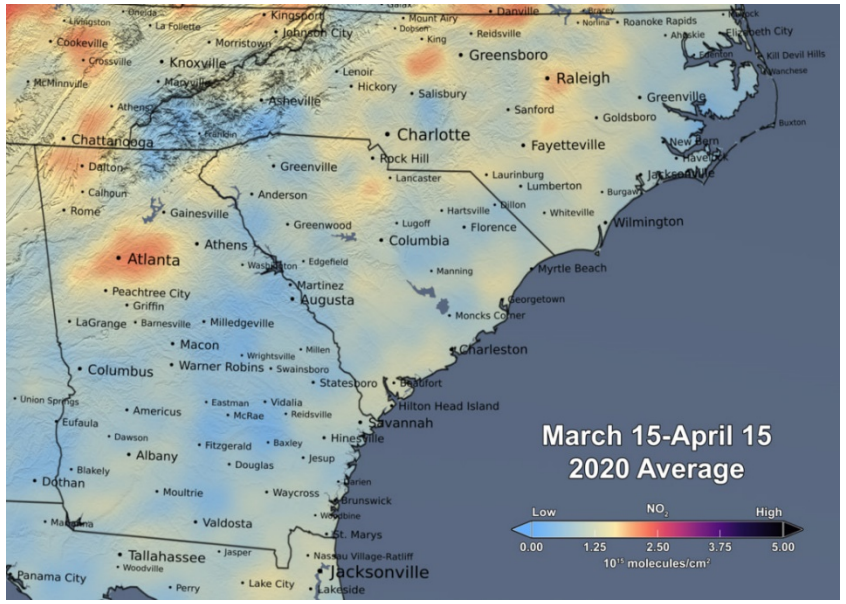
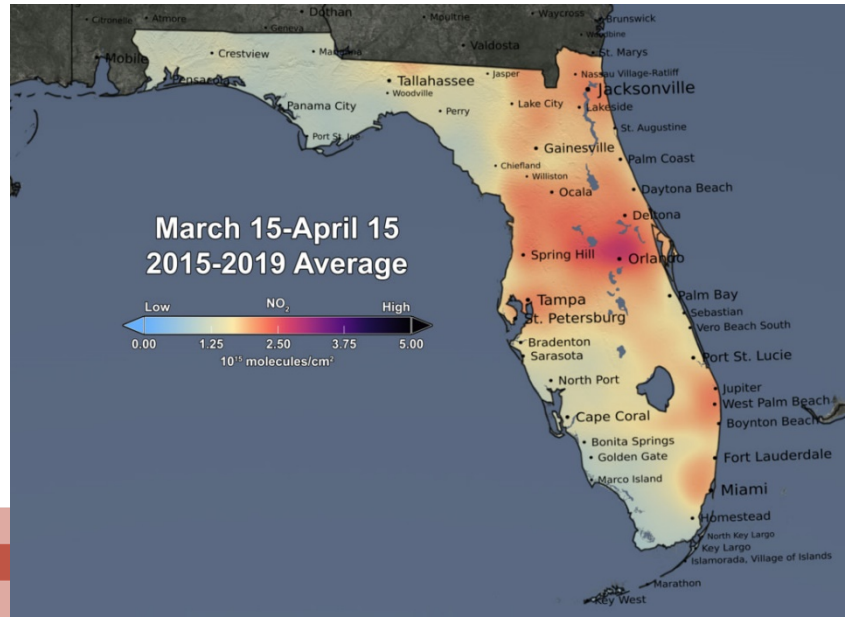



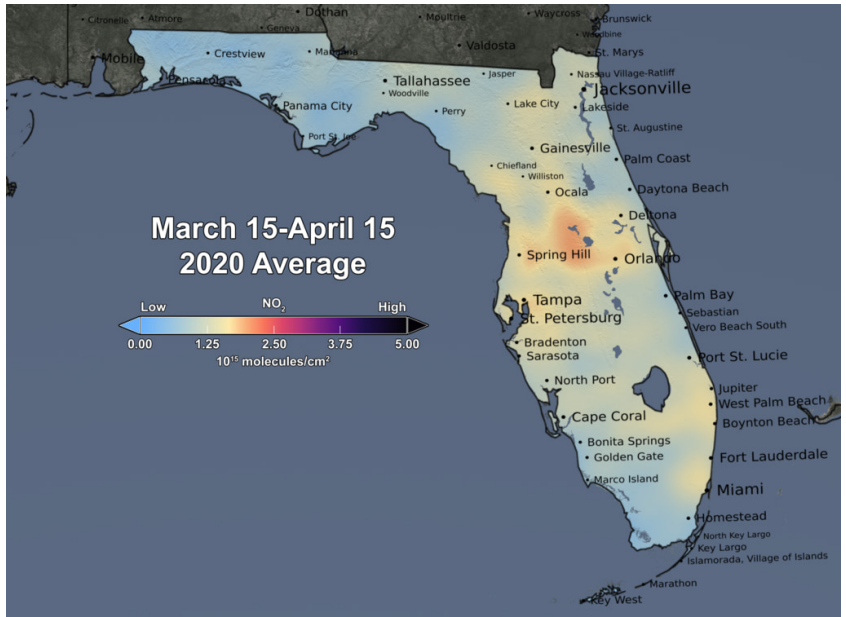

Image Credit: B. Duncan

# Recent decreases in $NO_2$ are lower than an average of the previous four years.



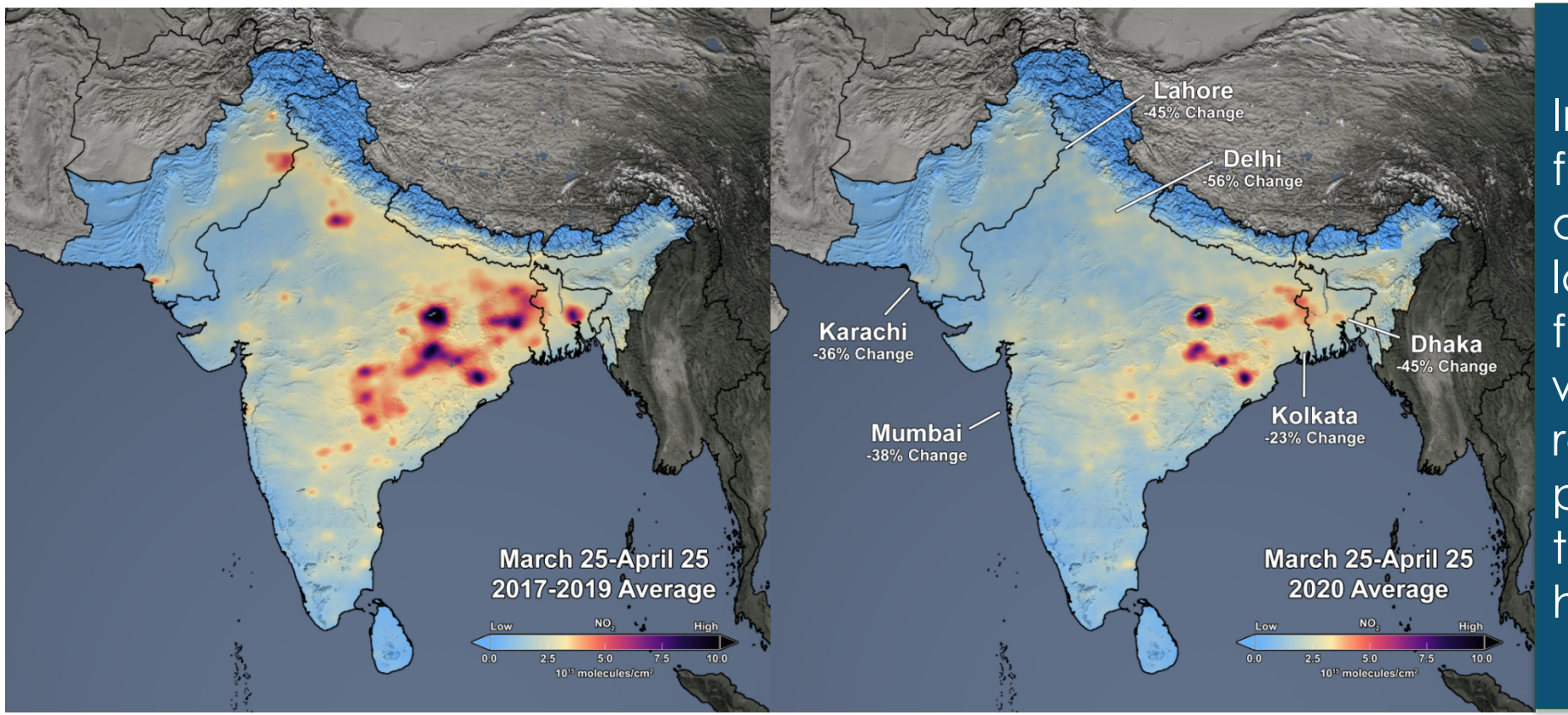




$NO_2$ levels from March 15 – April 15 of 2020 were 30-40% lower than the average from 2015-2019

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 $NO_2$ are lower than an average of the previous four years.

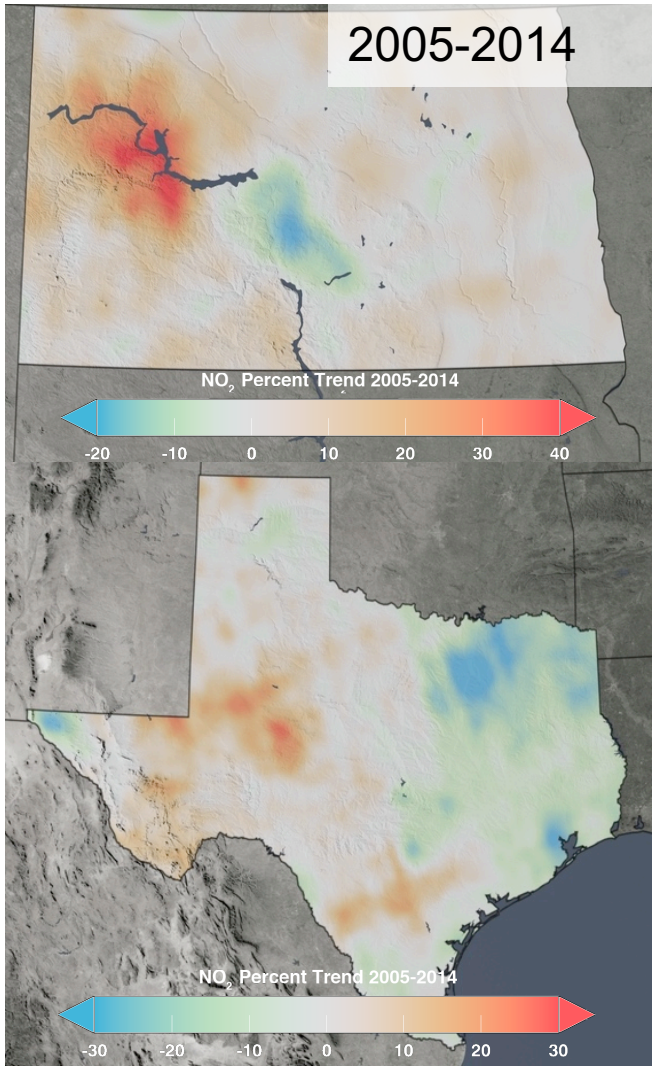






In South Asia, $NO_2$ levels from March 25 – April 25 of 2020 were 30-60% lower than the average from 2017-2019, with some of the highest reductions in densely populated areas with the strictest stay-at-home orders.

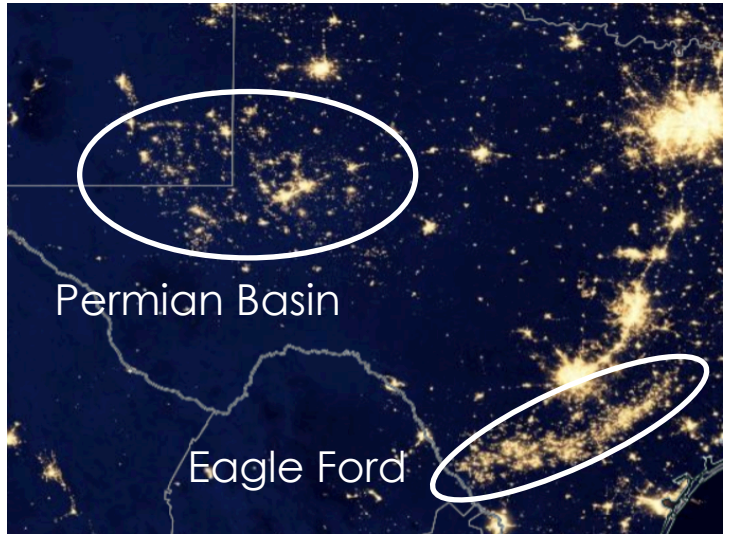
# OMI Detects $NO_2$ Increases from Oil and Natural Gas Activities




North Dakota


**Suomi NPP VIIRS Lights at Night**

Texas



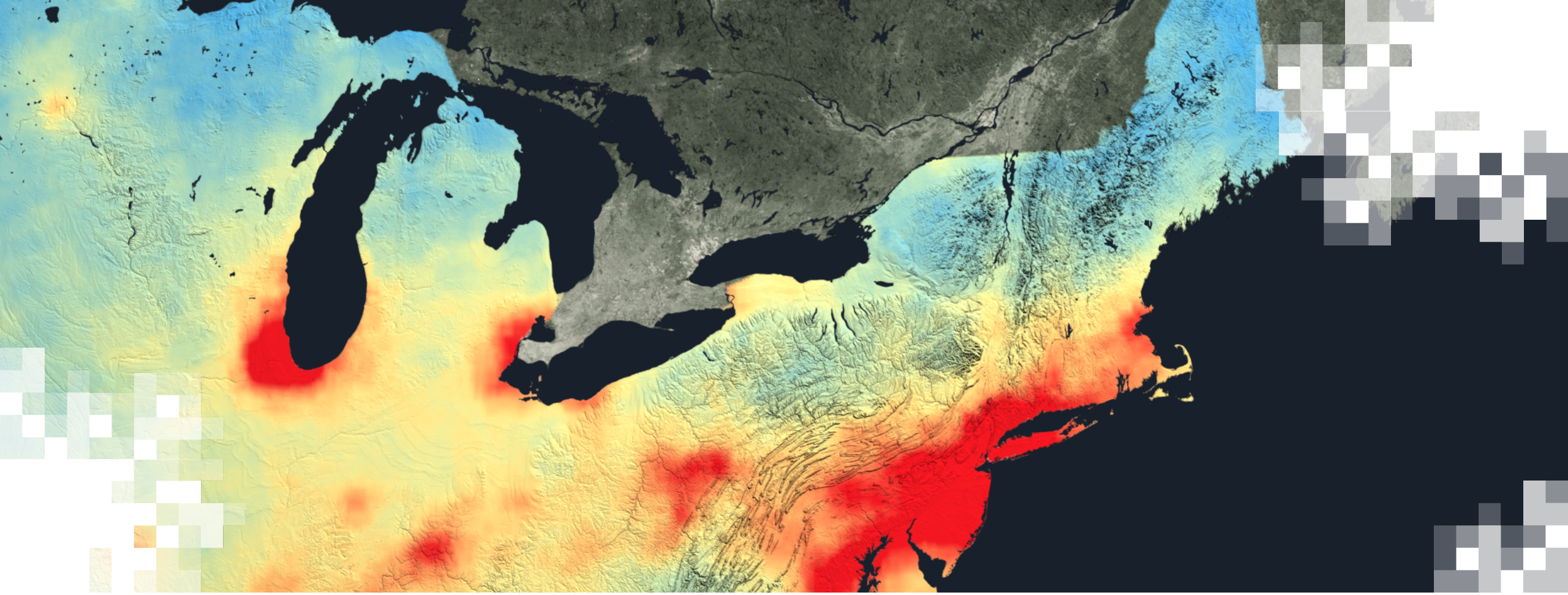



Courtesy of Bryan Duncan

# Data from OMI has been used to estimate surface level $NO_2$

- Using information from an atmospheric chemistry model, tropospheric column $NO_2$ from OMI has been used to estimate surface level $NO_2$.
- 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 | https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L4/OMI_Surface_NO2/Monthly/ |

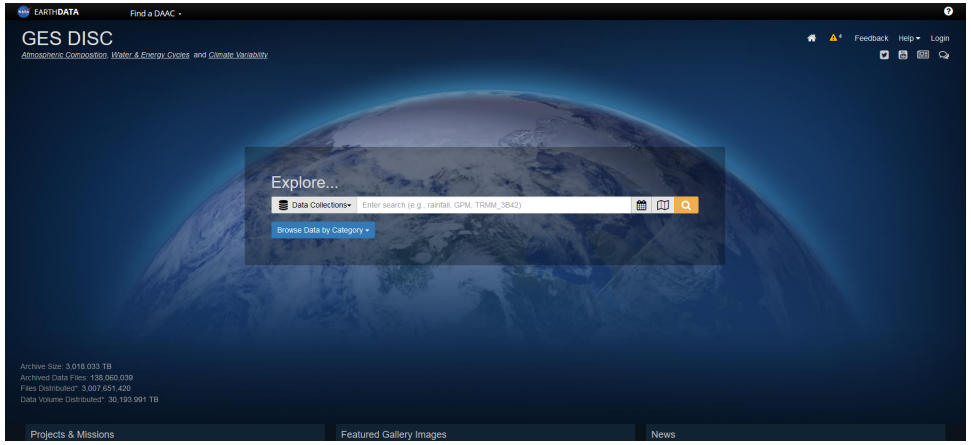


How do I access $NO_2$ data and images?

# OMI Data

## Gridded and Native Resolution Data

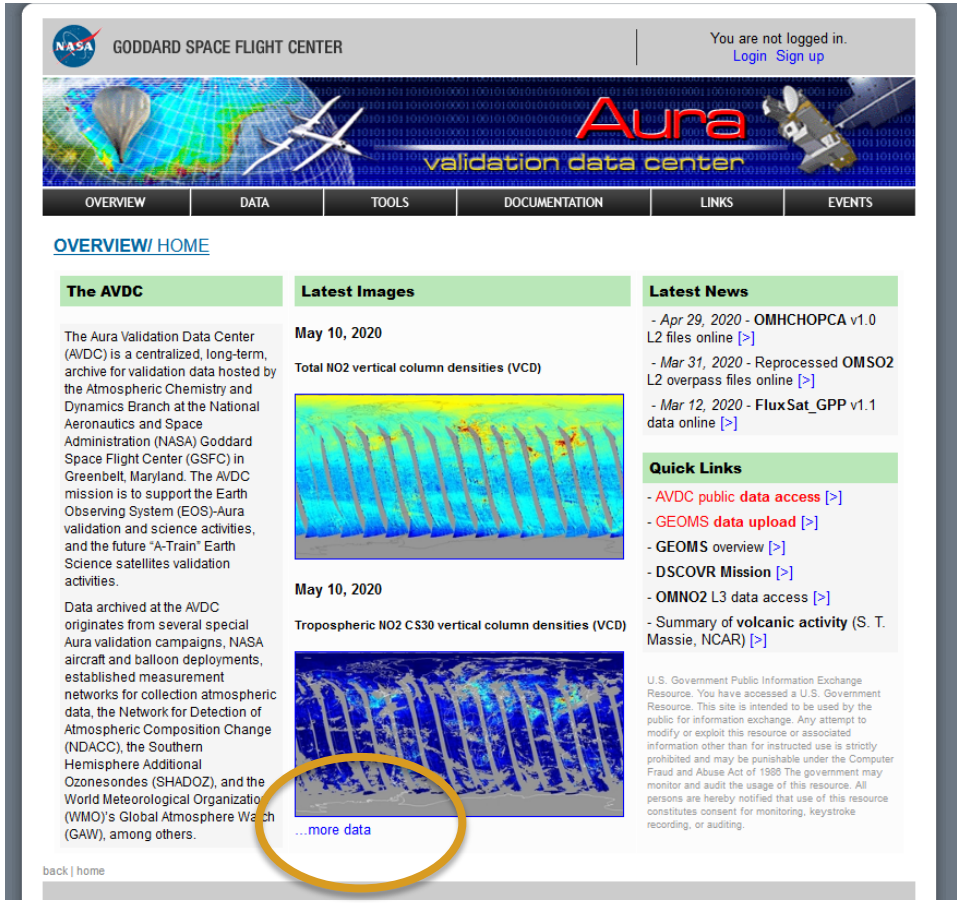
https://disc.gsfc.nasa.gov/




Sign up for an Earthdata account to download data

## Gridded Data and Images

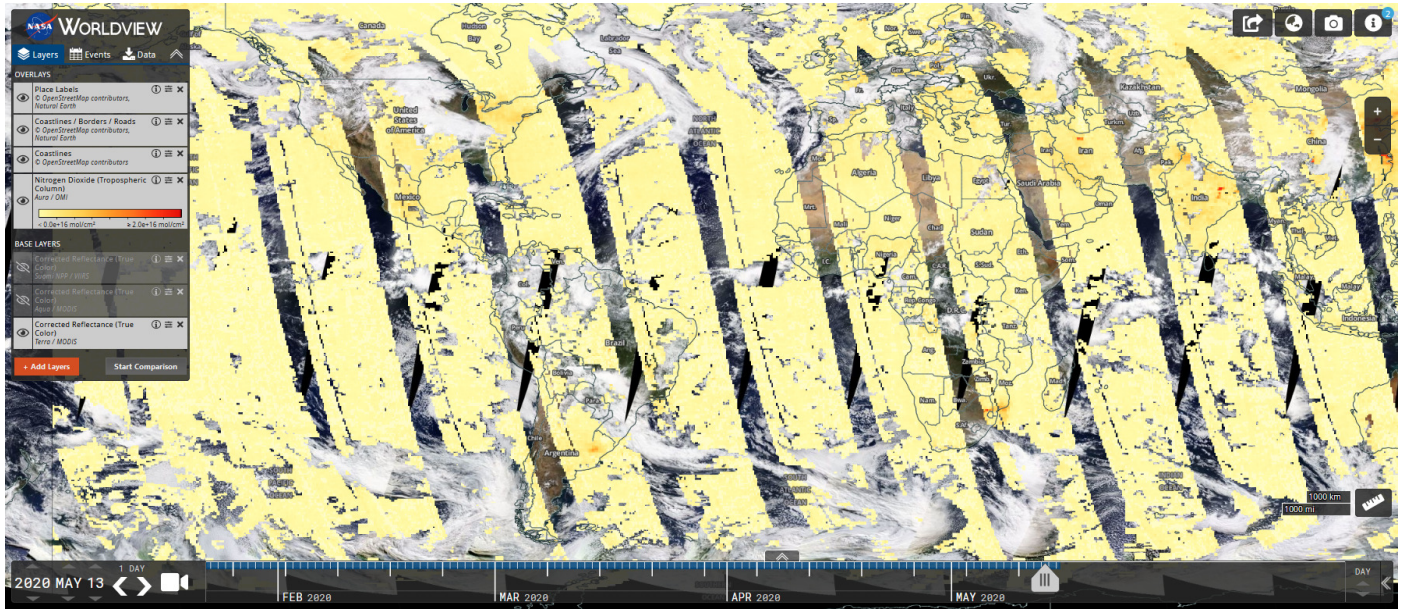
https://avdc.gsfc.nasa.gov/



# 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

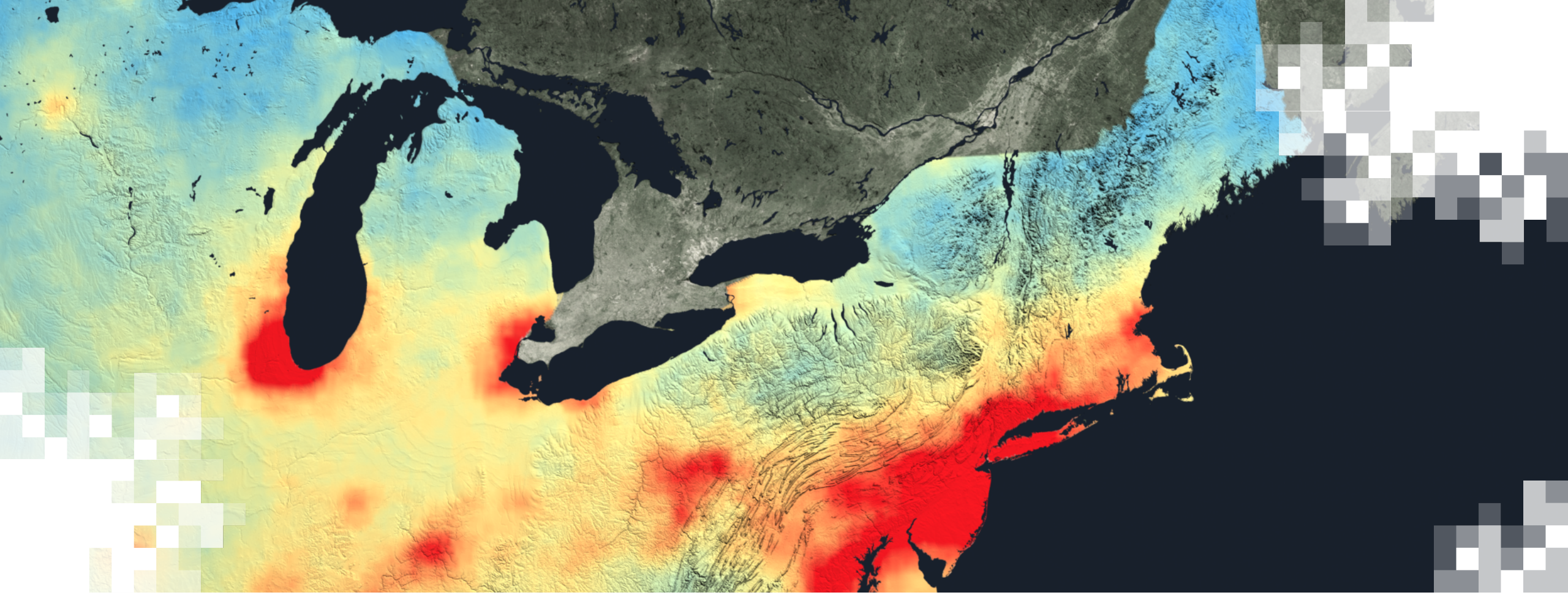
https://airquality.gsfc.nasa.gov/

*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

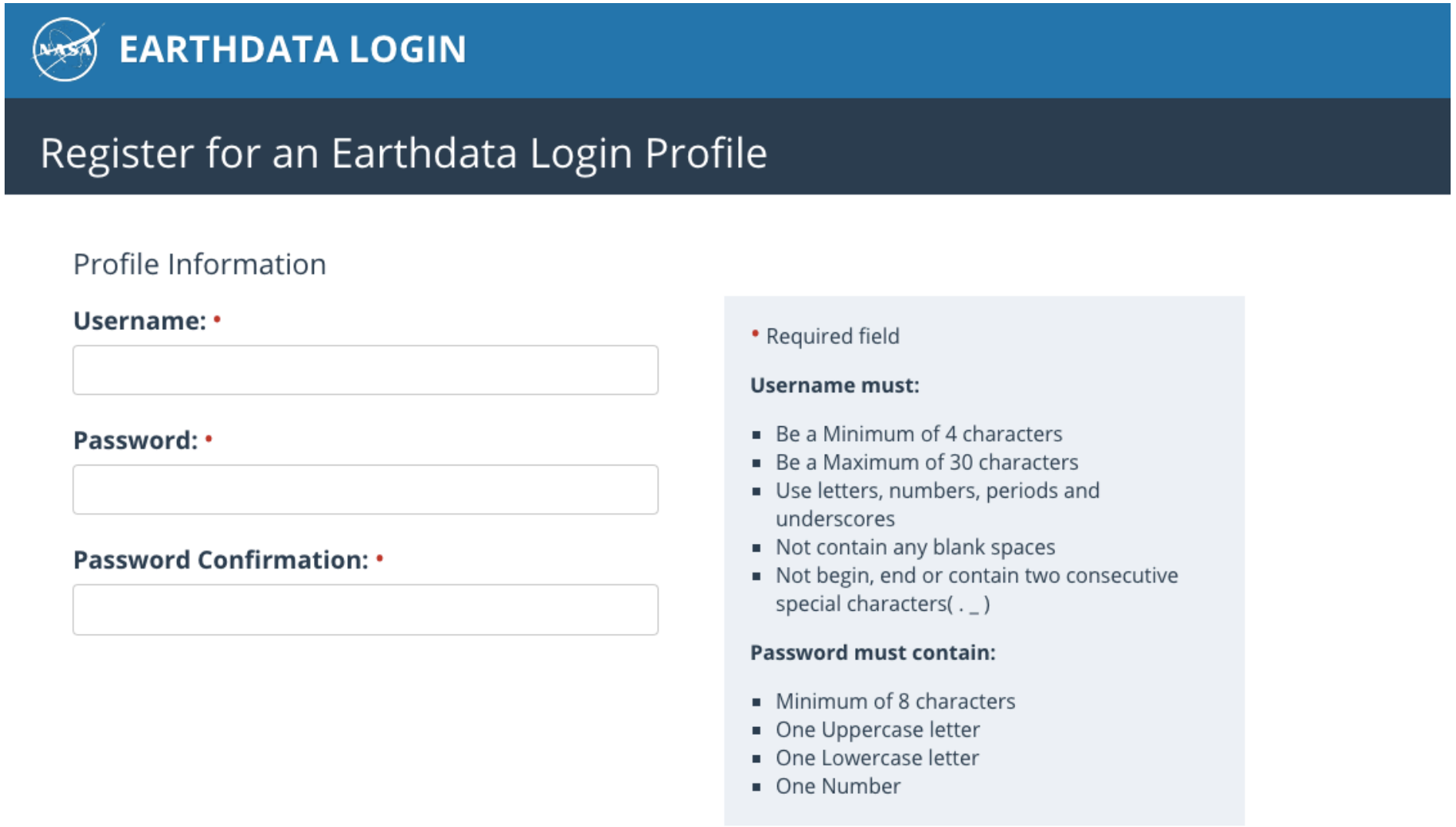
# NASA Giovanni

- *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/

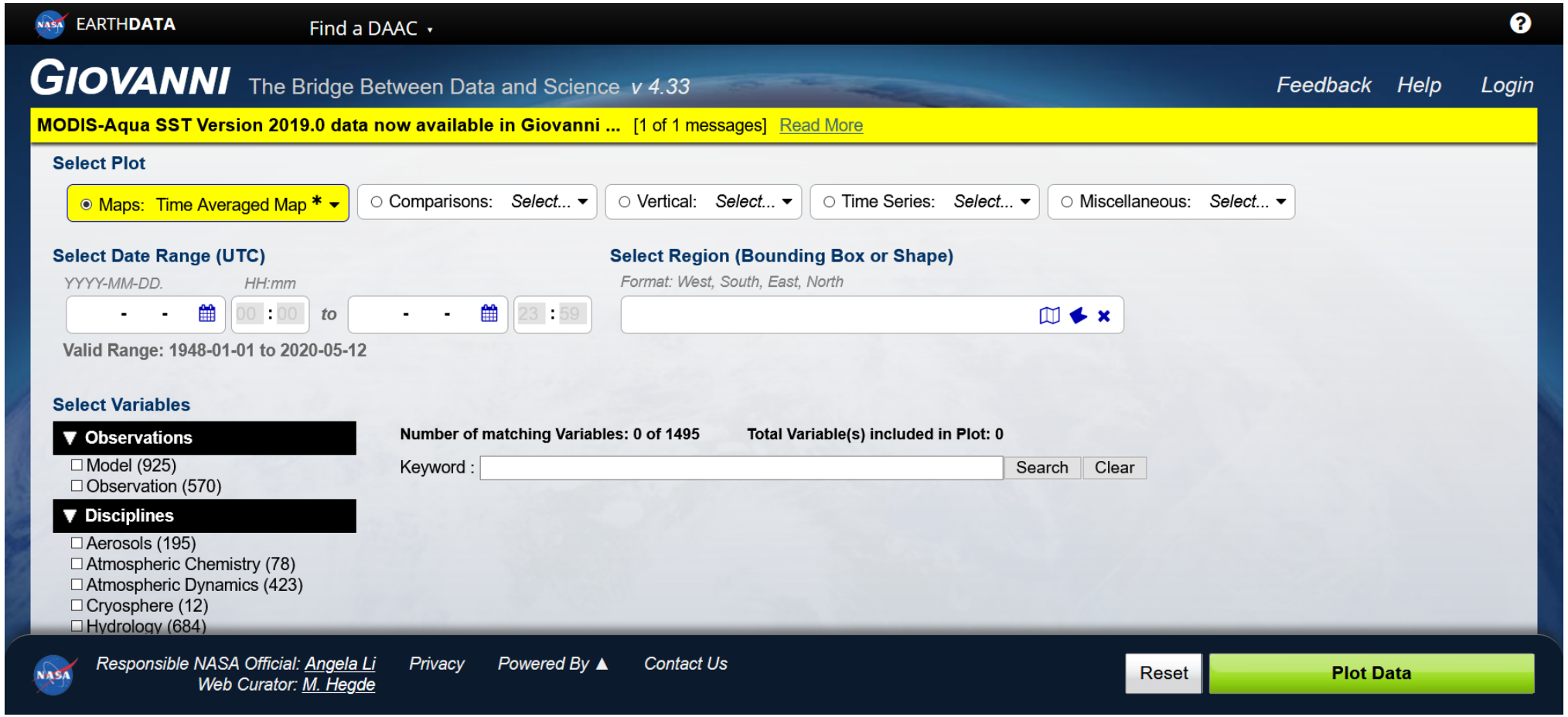
- If you have a question, we can address it during the Q&A, or feel free to email me after the webinar

# Visit https://urs.earthdata.nasa.gov/users/new



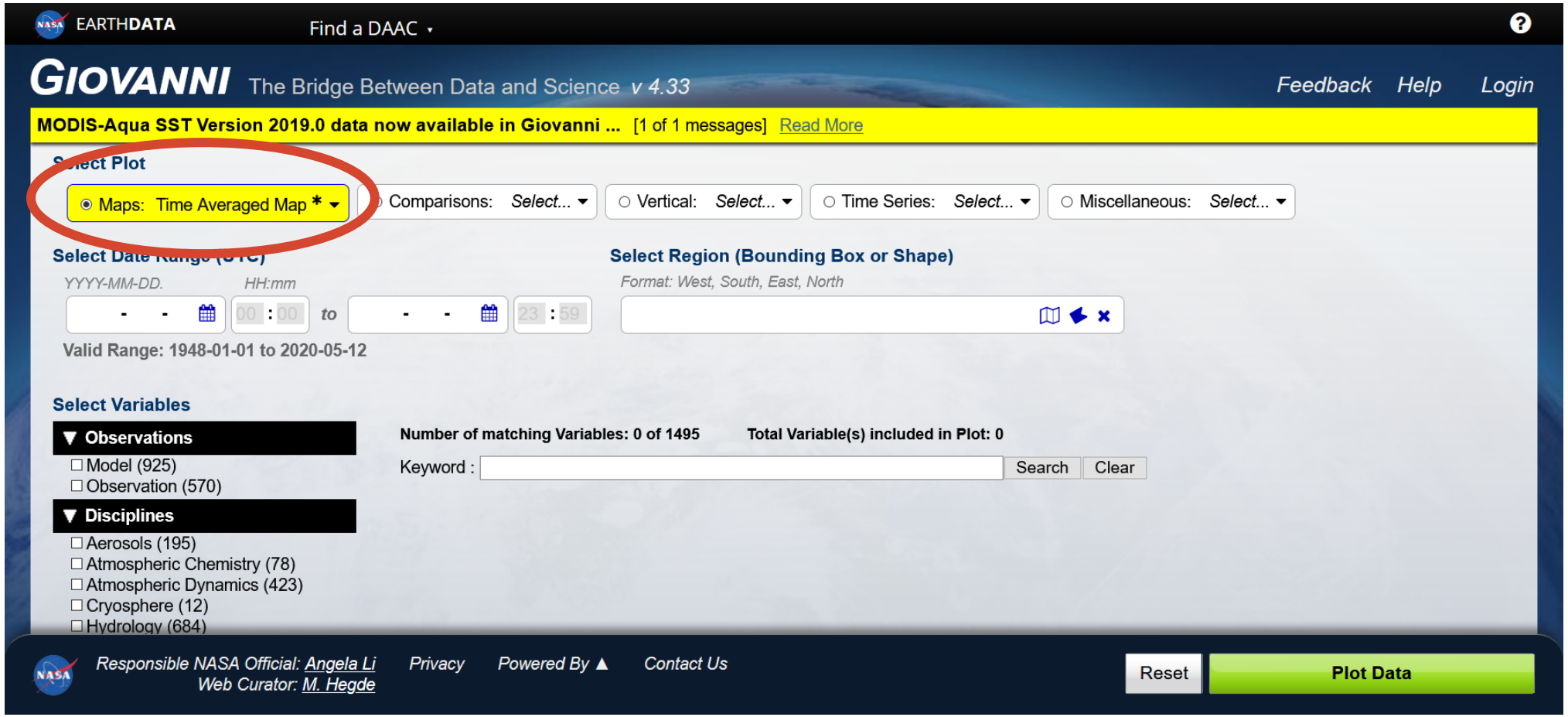
# Time Averaged Maps: Step 1

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



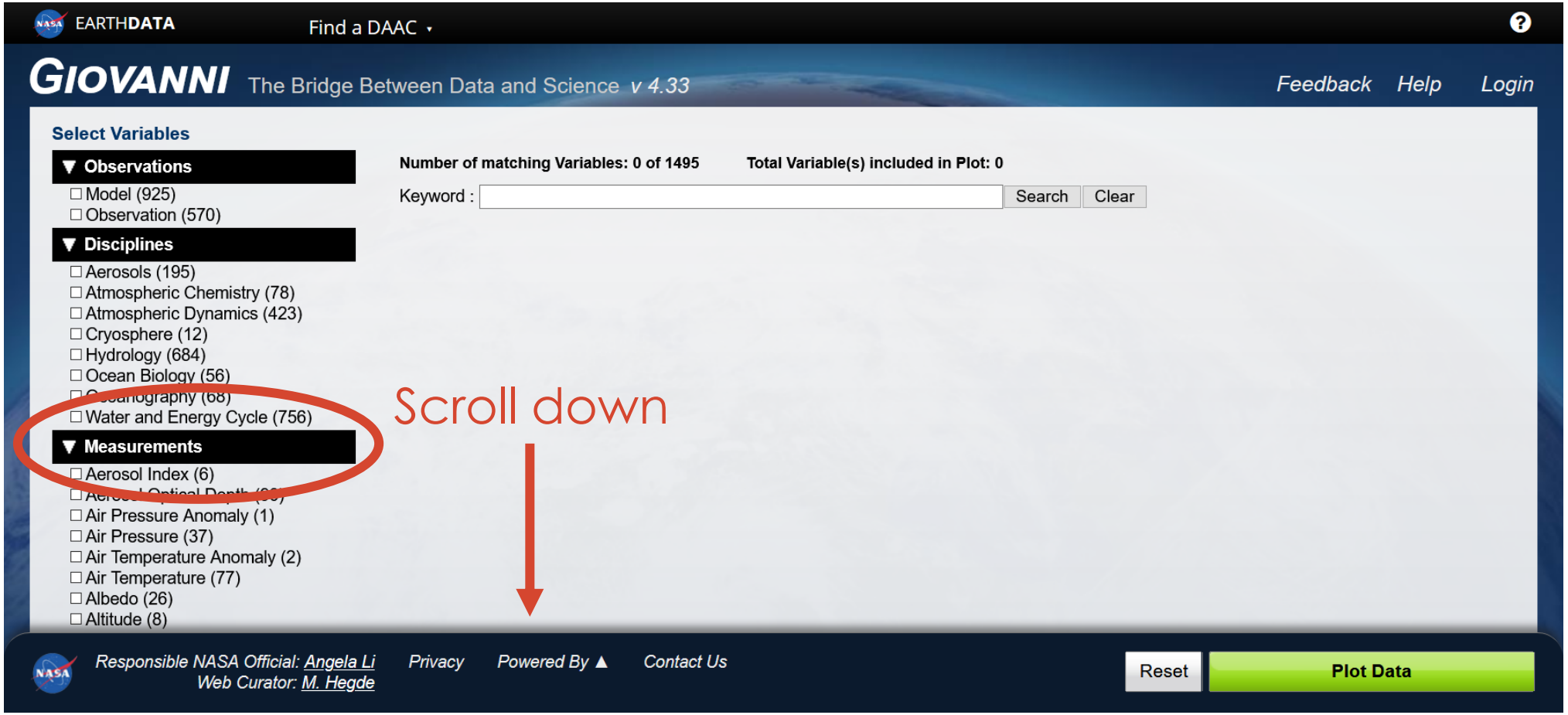
# Time Averaged Maps: Step 2

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



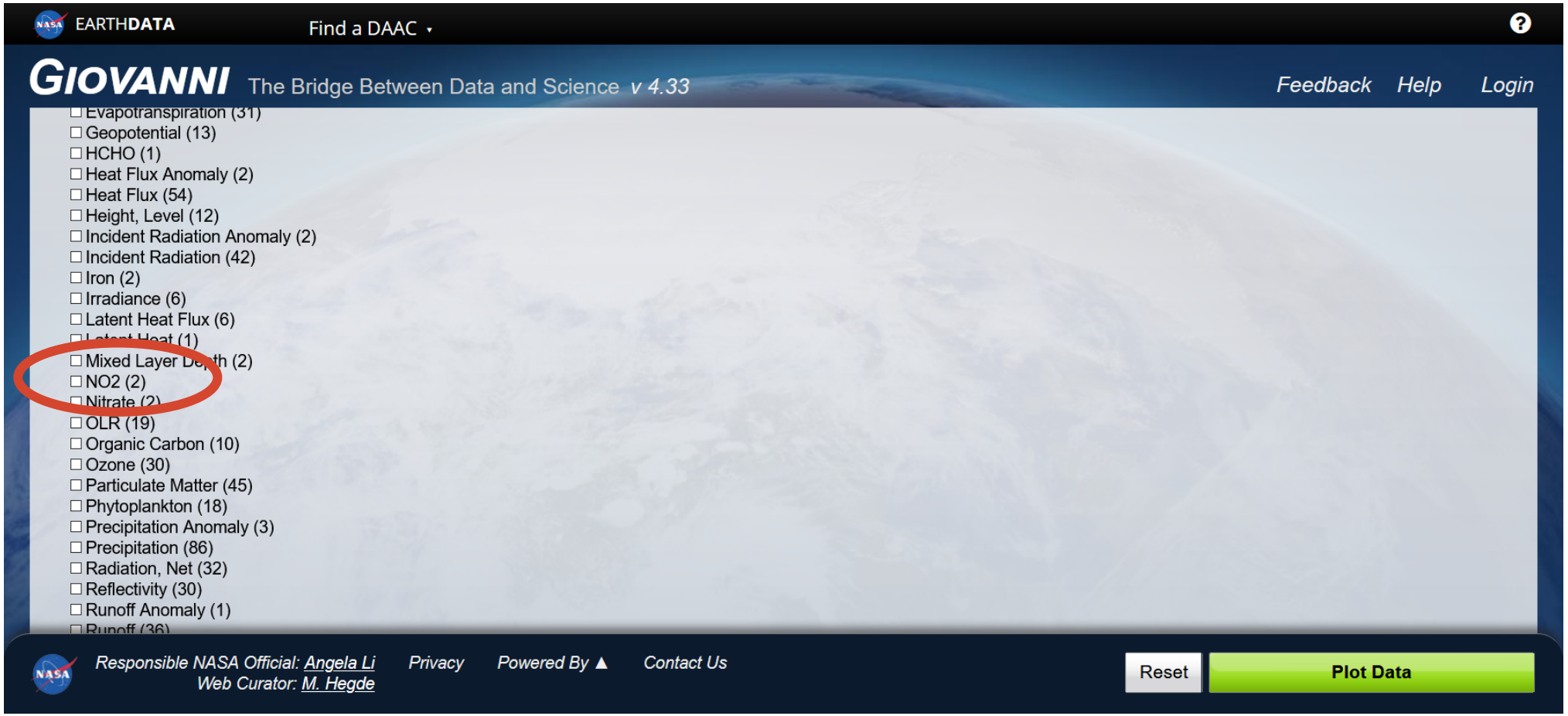
# Time Averaged Maps: Step 2

- Under **Measurement**, select **$NO_2$**



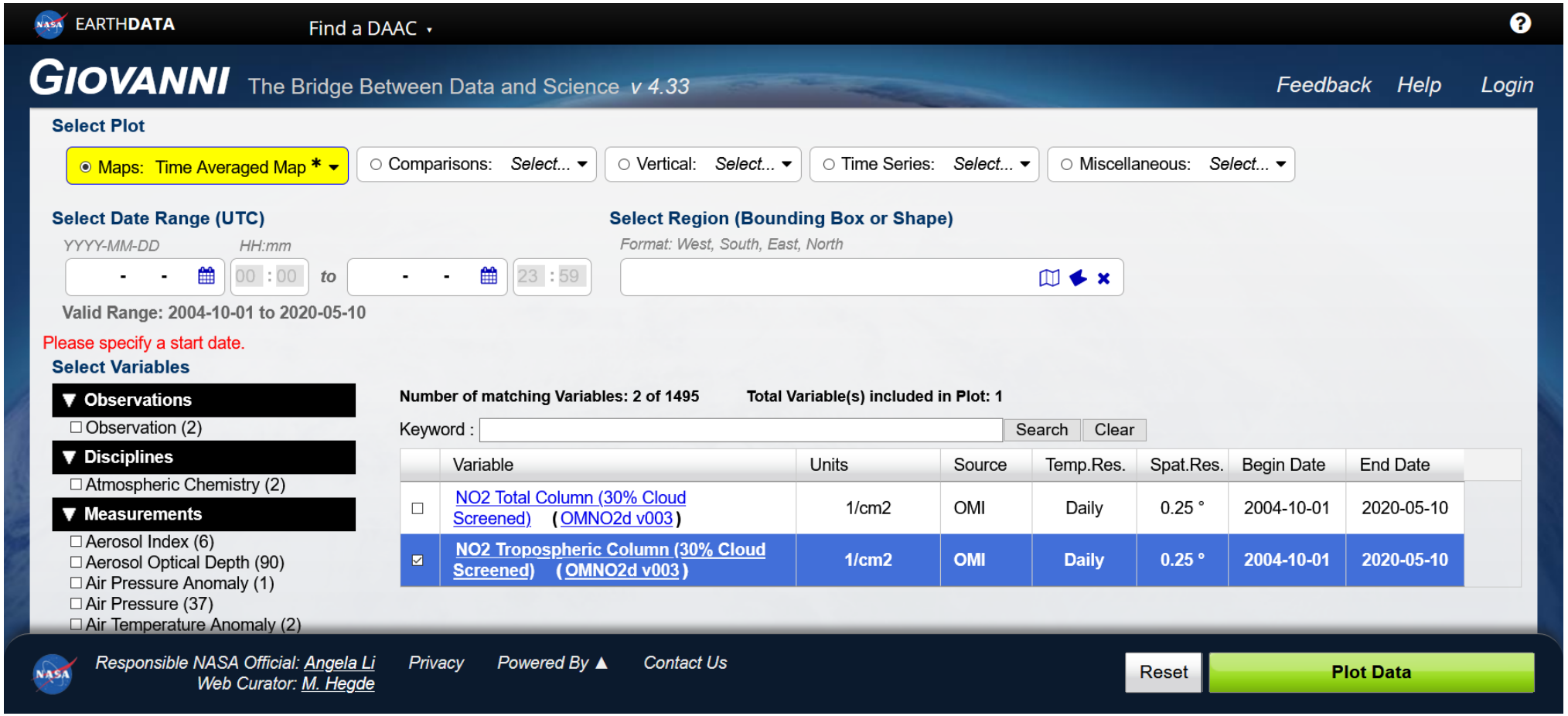
# Time Averaged Maps: Step 2

- Under **Measurement**, select **$NO_2$**



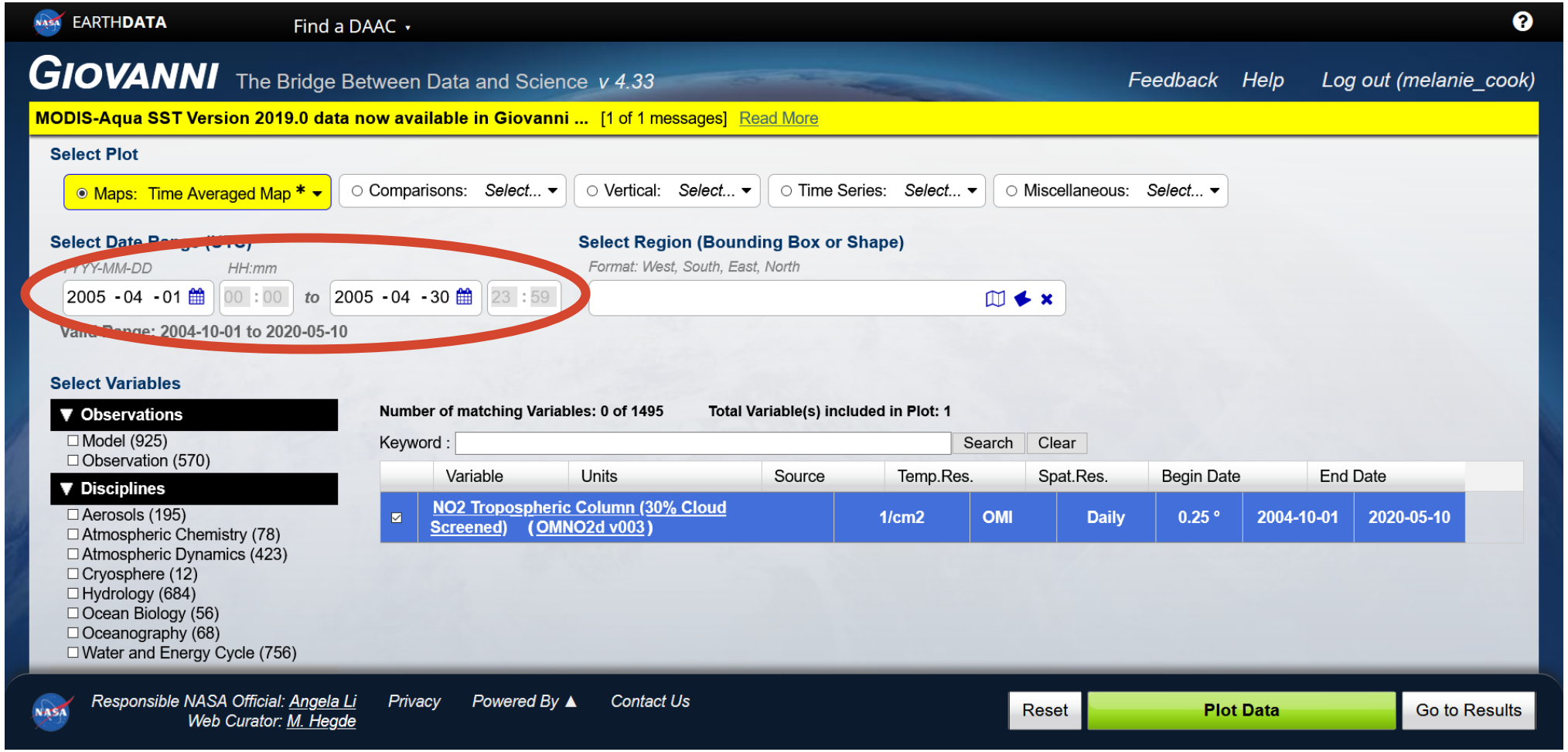
# Time Averaged Maps: Step 3

- Select $NO_2$ Tropospheric Column (30% Cloud Screened) (OMNO2d_v003)



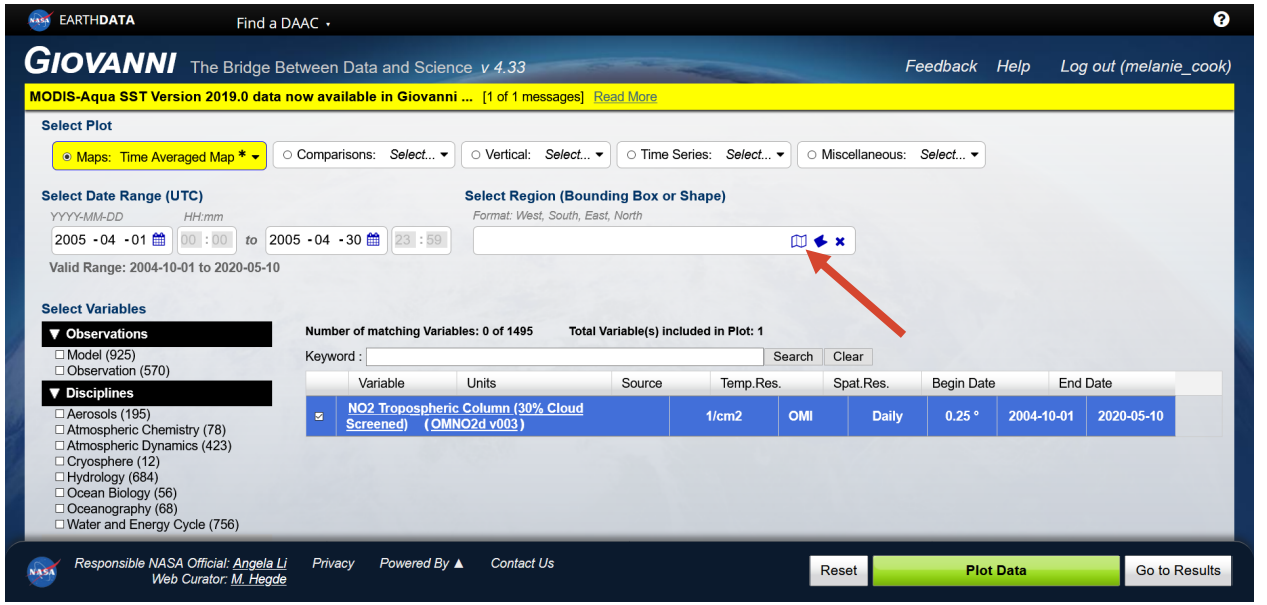
# Time Averaged Maps: Step 4

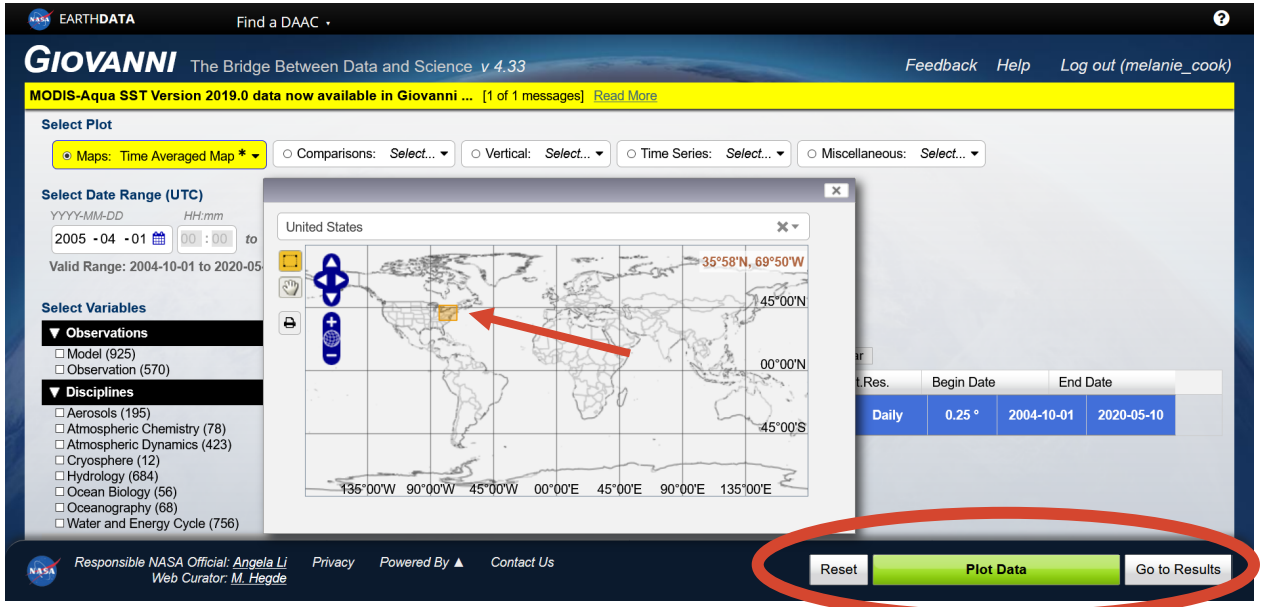
- Set the date range as **April 1, 2005** to **April 30, 2005**



# 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.

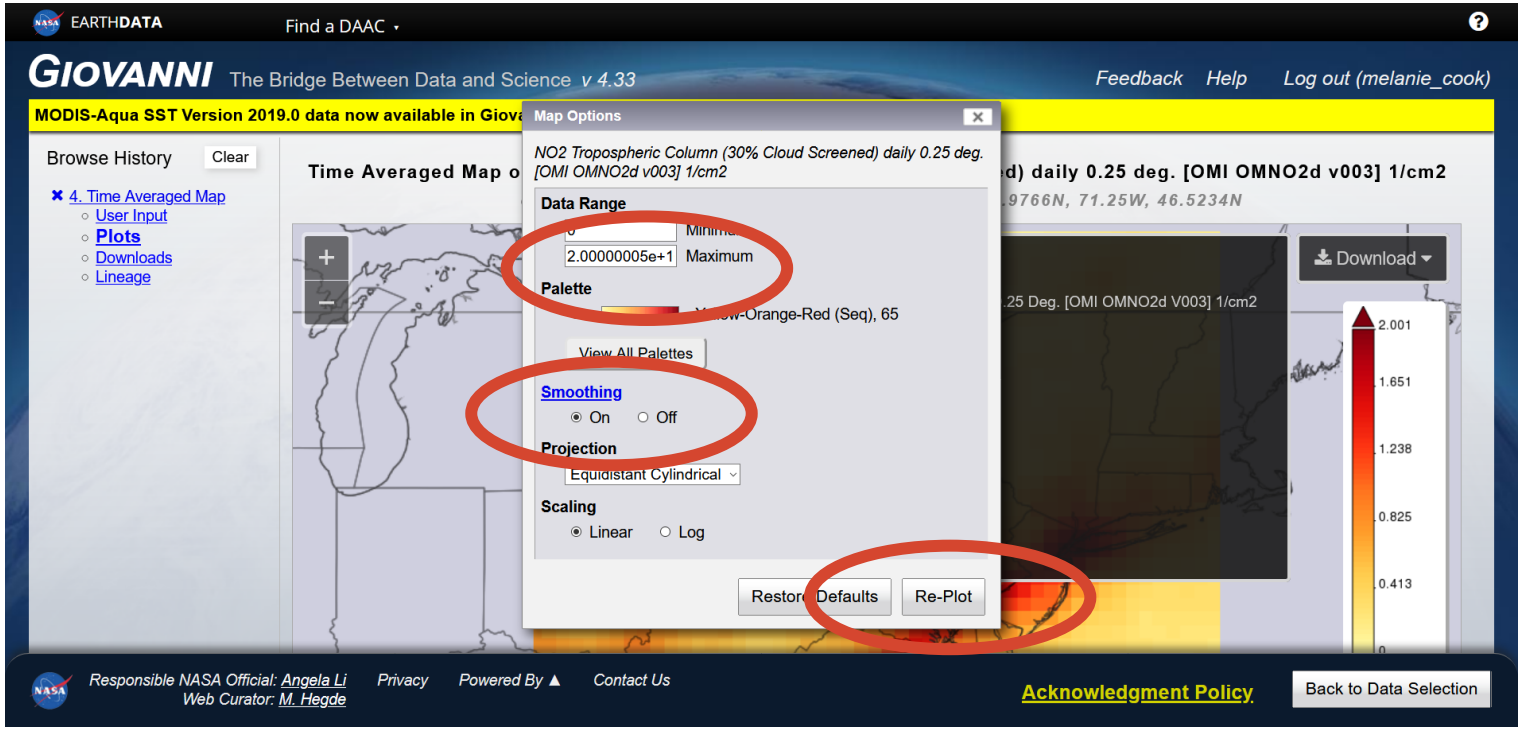


# Time Averaged Maps: Step 6

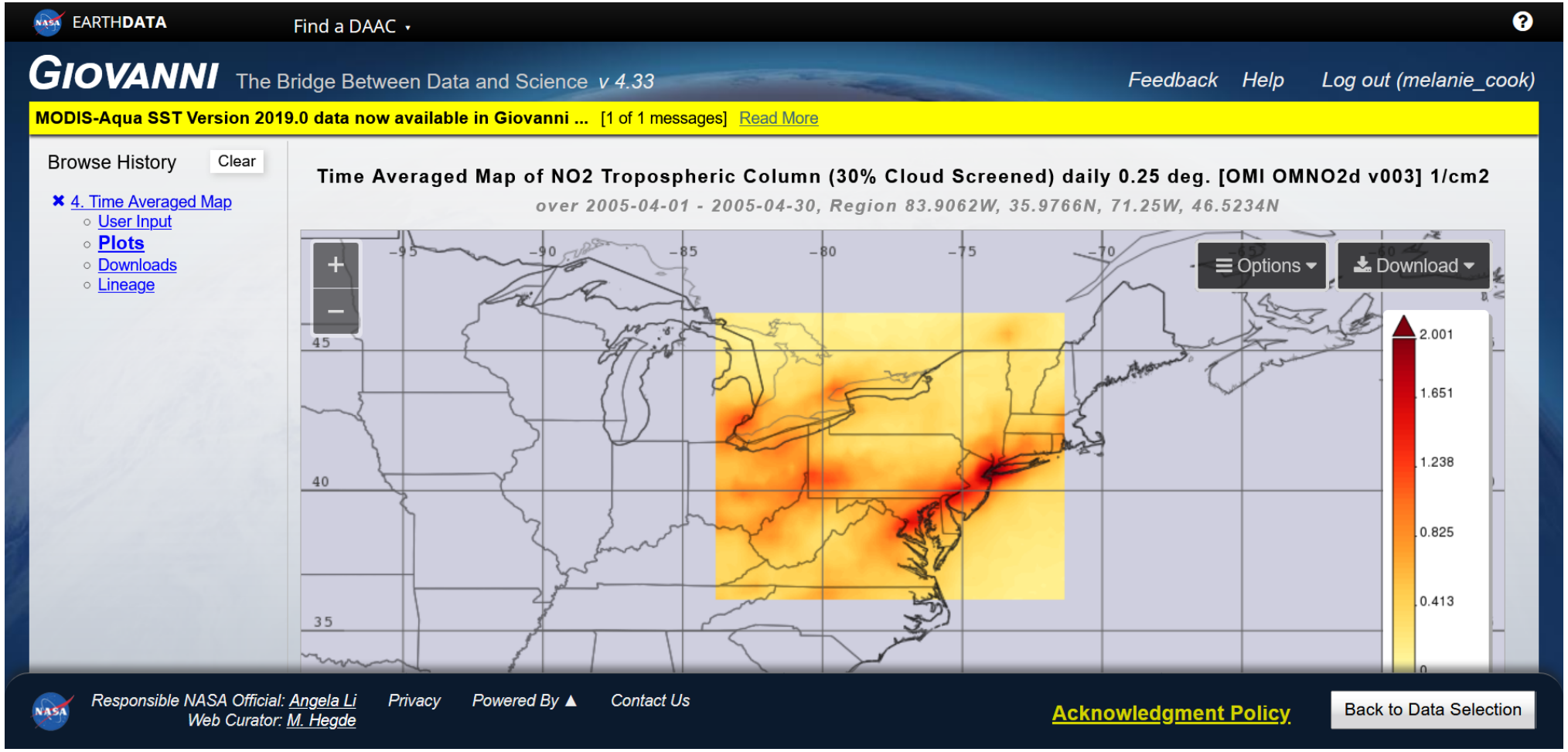
You can:

- 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.



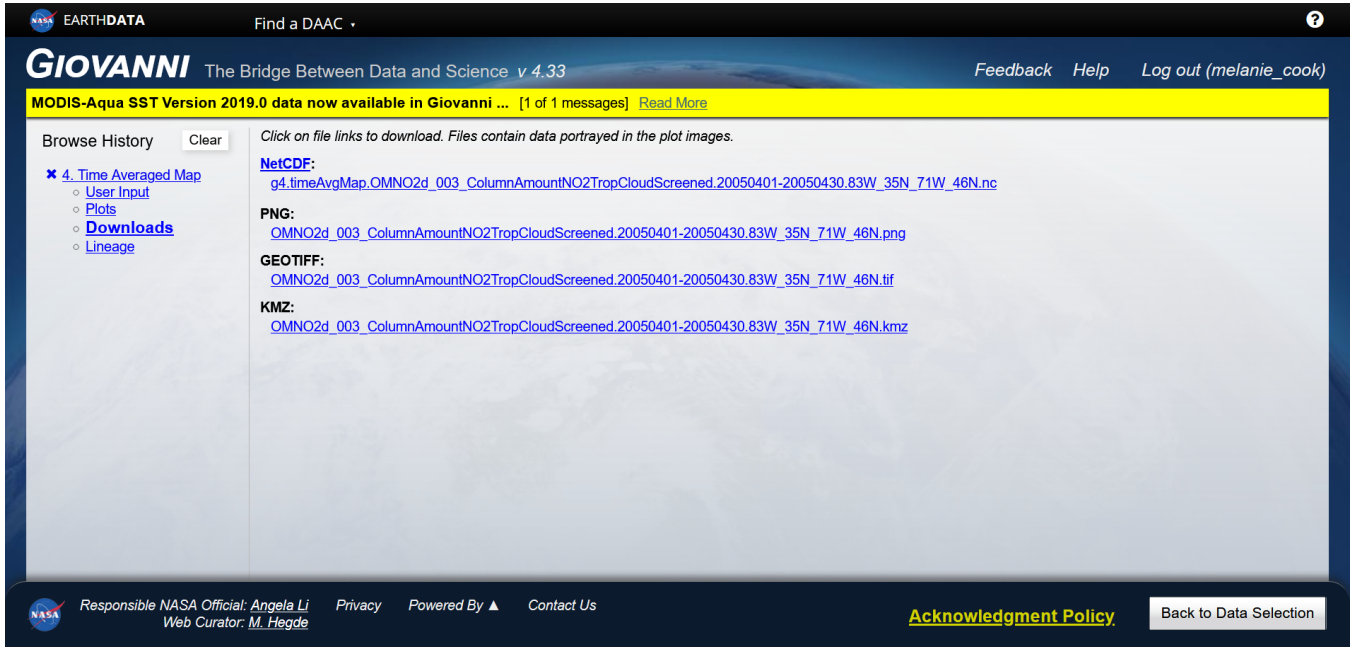

- Change the maximum to 1.00 e+16
- Turn 'Smoothing' to On
- Click 'Re-Plot'

# 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.



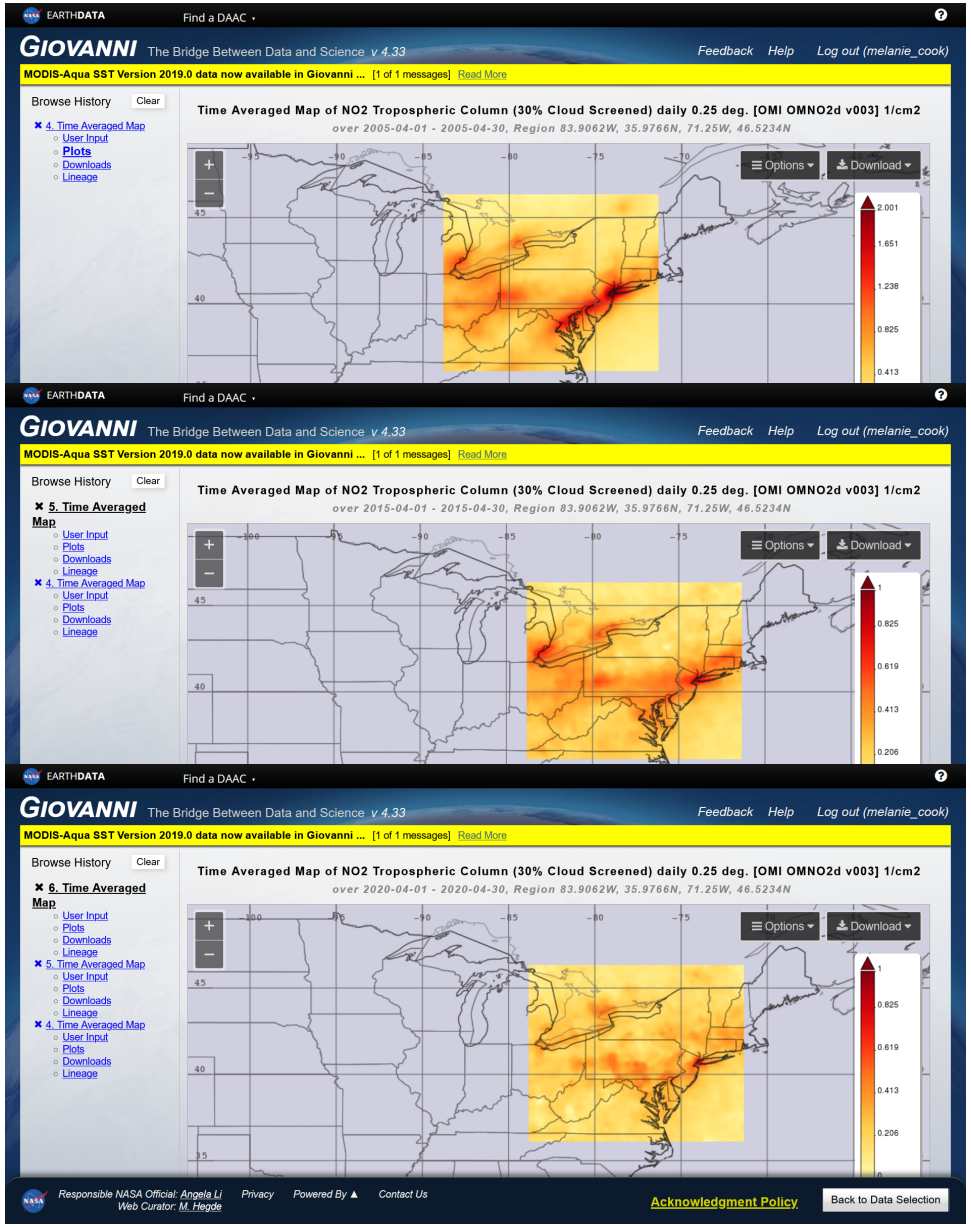
# Time Averaged Maps: Step 8

- 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.

2005

2015

2020




You can quickly access previous plots from the left menu.

# Want to Learn More?

- ARSET offers more advanced air quality trainings. You can learn:
  - How to use Python to read $NO_2$ 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 $NO_2$ 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