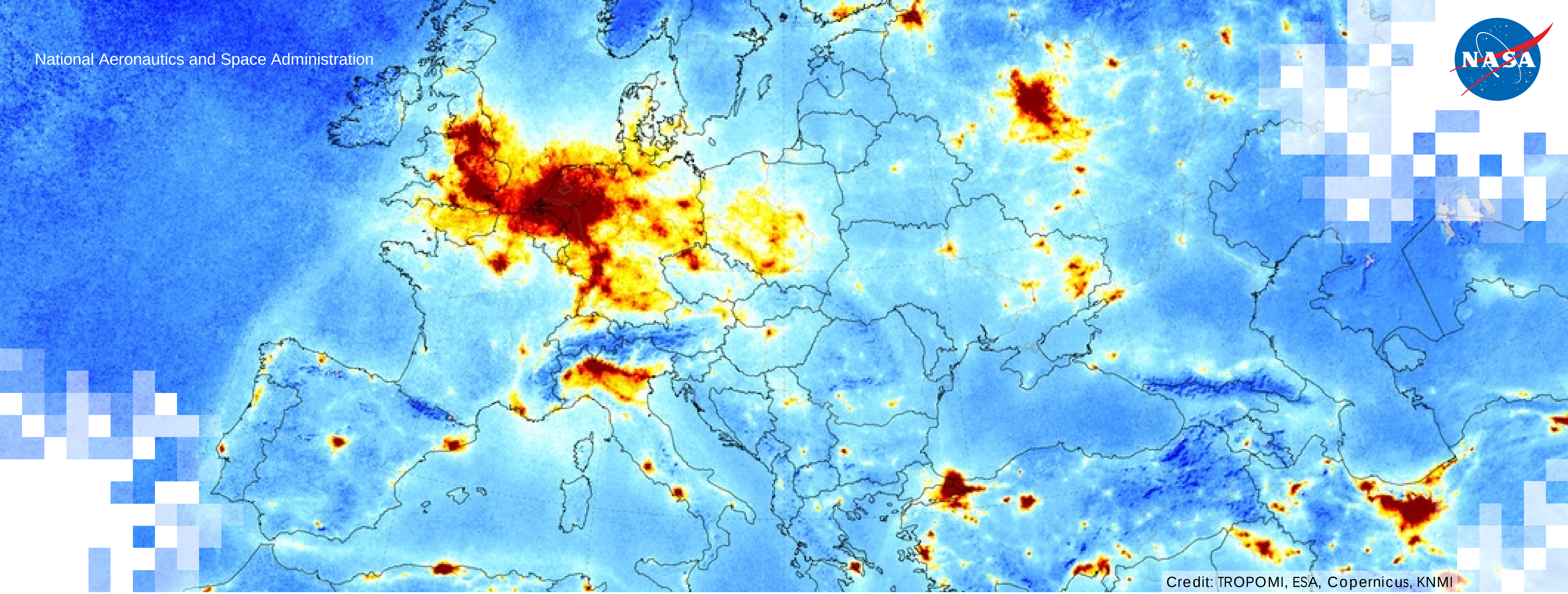
National Aeronautics and Space Administration

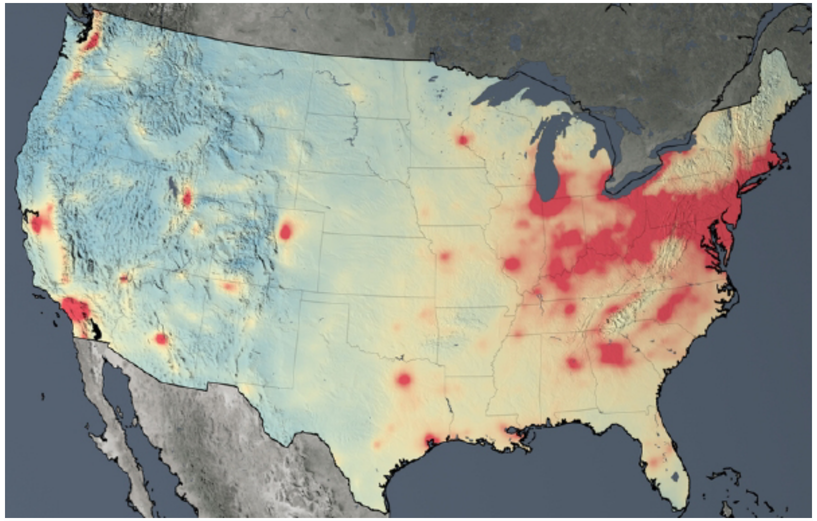


Remote Sensing of NO_2, OMI Data Products, and Tools

Melanie Follette-Cook, Pawan Gupta

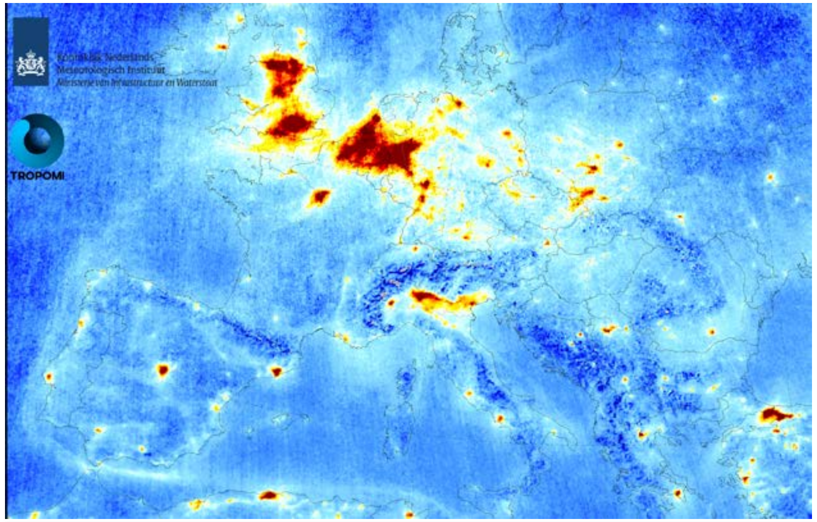
Webinar Agenda

Session 1



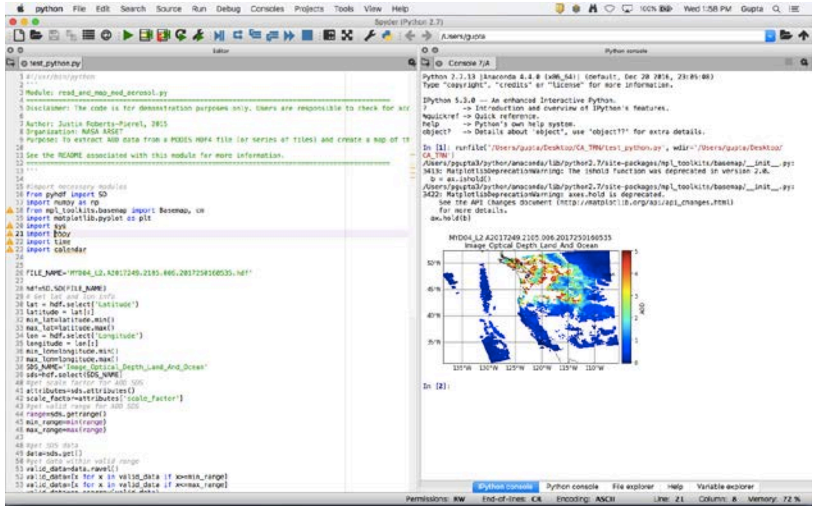
Remote sensing of NO_2, OMI Data Products, and Tools

Session 2



Introducing TROPOMI - High Resolution NO_2 Observations from Space

Session 3



Python Tools - TROPOMI

Session 2 Image Credit: TROPOMI

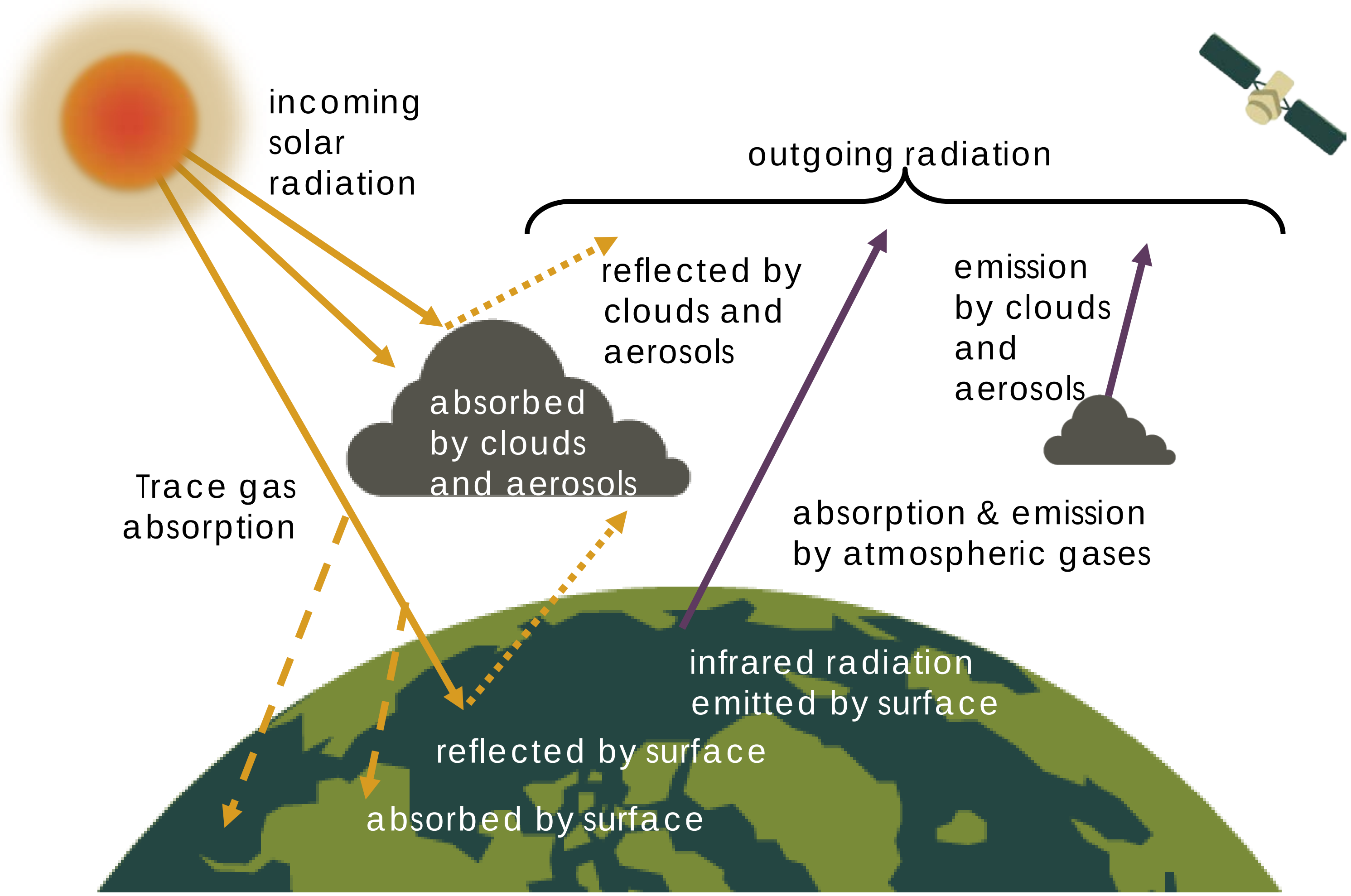
Learning Objectives

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

- Describe existing satellite capabilities for global NO_2 observations
- Describe the current NO_2 data products available from the Ozone Monitoring Instrument (OMI)
- Identify various air quality monitoring applications utilizing OMI NO_2 observations
- Perform a data download of OMI and/or TROPOMI data

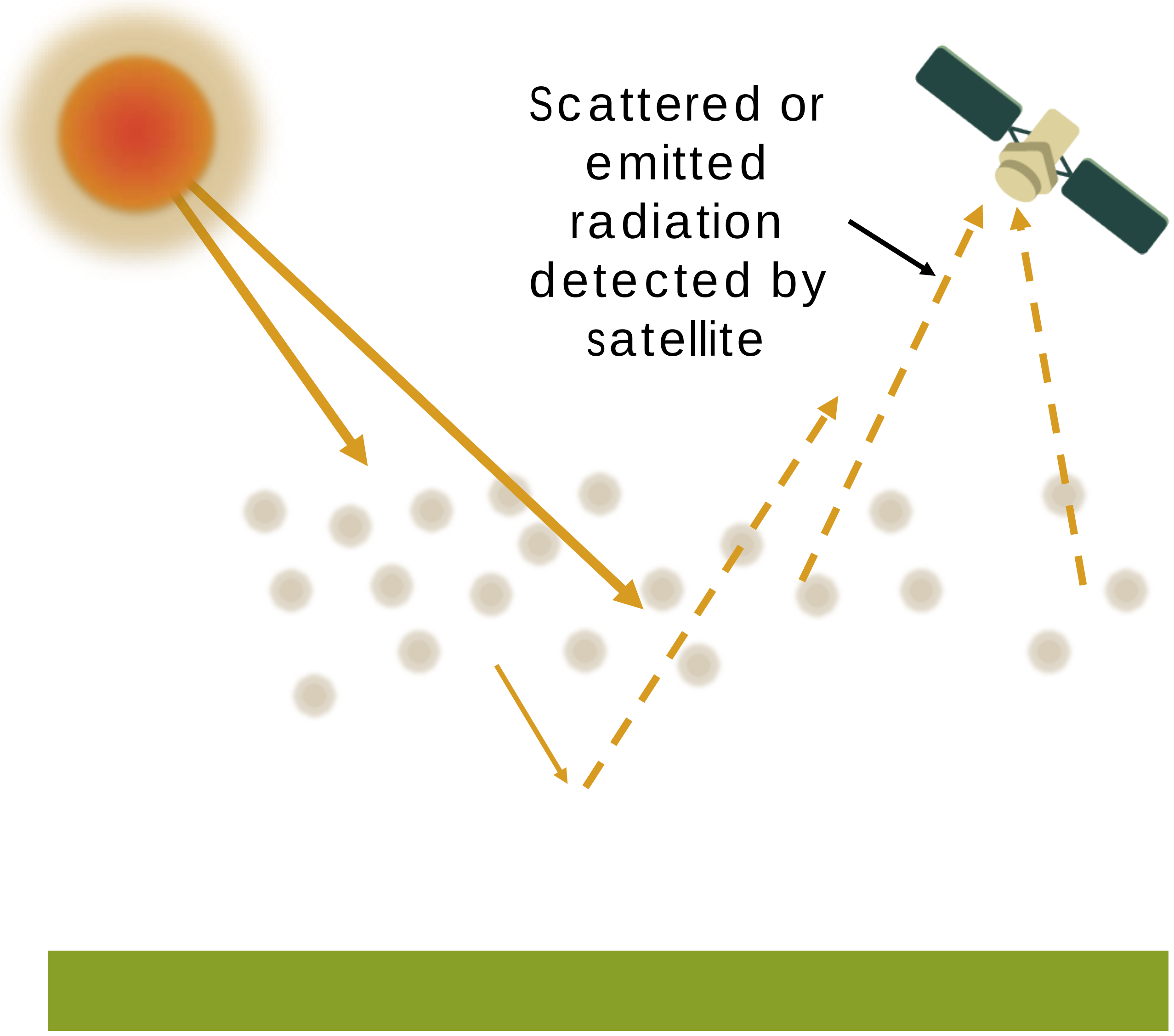
What do Satellites Measure?

- Remote sensing: collecting information about an object without being in direct physical contact with it
- The intensity of reflected and emitted radiation to space is influenced by the surface and atmospheric conditions
- Satellite measurements contain information about the surface and atmospheric conditions



Measuring Trace Gases from Space

- Satellites detect backscattered UV, visible, and/or emitted thermal radiation
- We know the distinct absorption spectra of each trace gas
- We can identify a "spectral fingerprint" for each atmospheric constituent
- Retrieval algorithms (a model) infer physical quantities such as number density, partial pressure, and column amount



A Spectral Signature of a Trace Gas is Unique like a Fingerprint

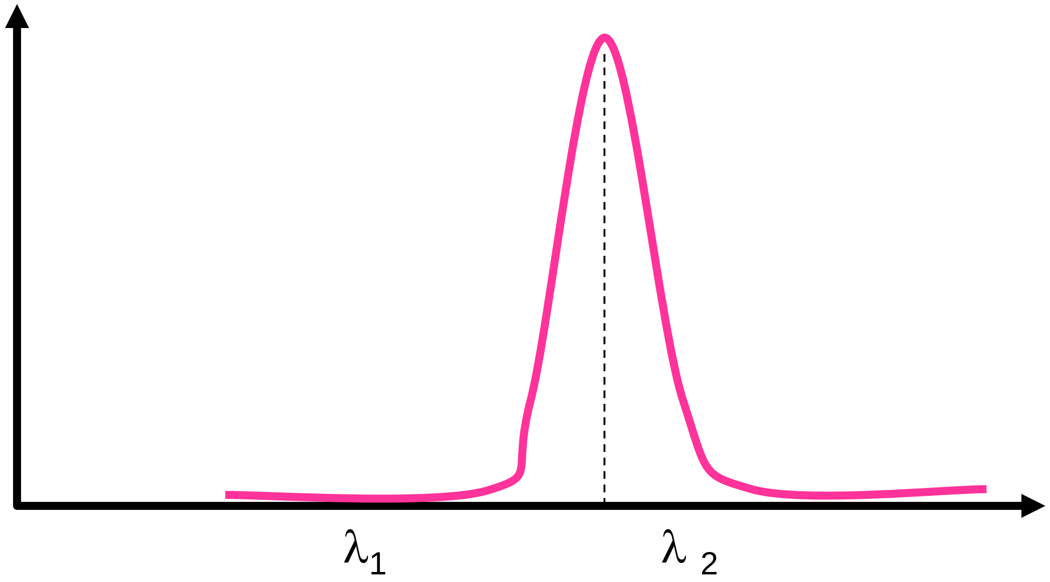
vs

- One fingerprint on a drink can allows the owner to be identified
- If a lot of people touch the drink can, it can be very difficult to identify any one person. This is the case for trace gases as spectral signatures often overlap.

Image Credits (left to right): Walmart Canada; Wikimedia Commons, The Photographer

A Spectral Signature of a Trace Gas is Unique Like a Fingerprint

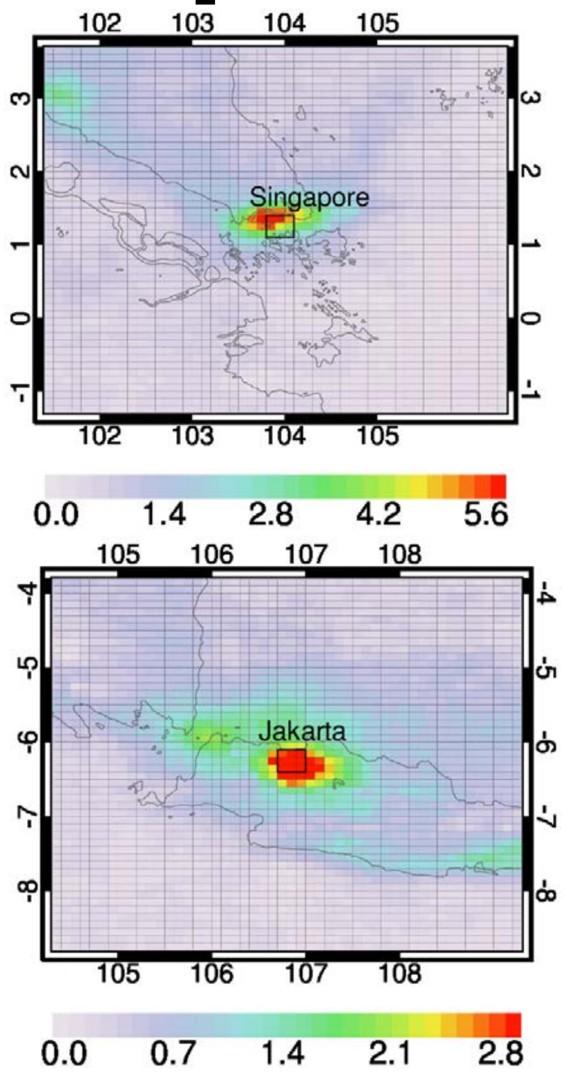
- Two wavelengths (λ) are used in retrievals
  - λ_1 is NOT absorbed by trace gas
  - λ_2 is absorbed by trace gas



Vertical Distribution

- Very little information can be obtained on the vertical distribution of trace gases in the troposphere from a nadir view
- Some information on vertical distribution can be inferred by taking the altitude of the trace gas source and its lifetime into account
- Examples:
  - NO_2 is short-lived and primarily emitted from fossil fuel combustion (e.g., cars, power plants), so most NO_2 is found near the surface

OMI NO_2 ($\times 10^{15}$ molec/cm^2)



Data Formats & Resolutions

Data Level	Description
Level 0	Raw data at full instrument resolution
Level 1A	Raw data that have been time-referenced and supplemented with information such as radiometric and geometric calibration coefficients and geo-referencing parameters. These are computed and appended, but not applied to Level 0 data.
Level 1B	Level 1A data that has been processed to sensor units (not all instruments have Level 1B source data)
Level 2	Derived geophysical variables at the same resolution and location as Level 1 source data
Level 2G & 3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency
Level 4	Model output or results from analyses of lower level data (e.g. variables derived from multiple measurements)

Trace Gases: Using Level 3 vs. Level 2 Data

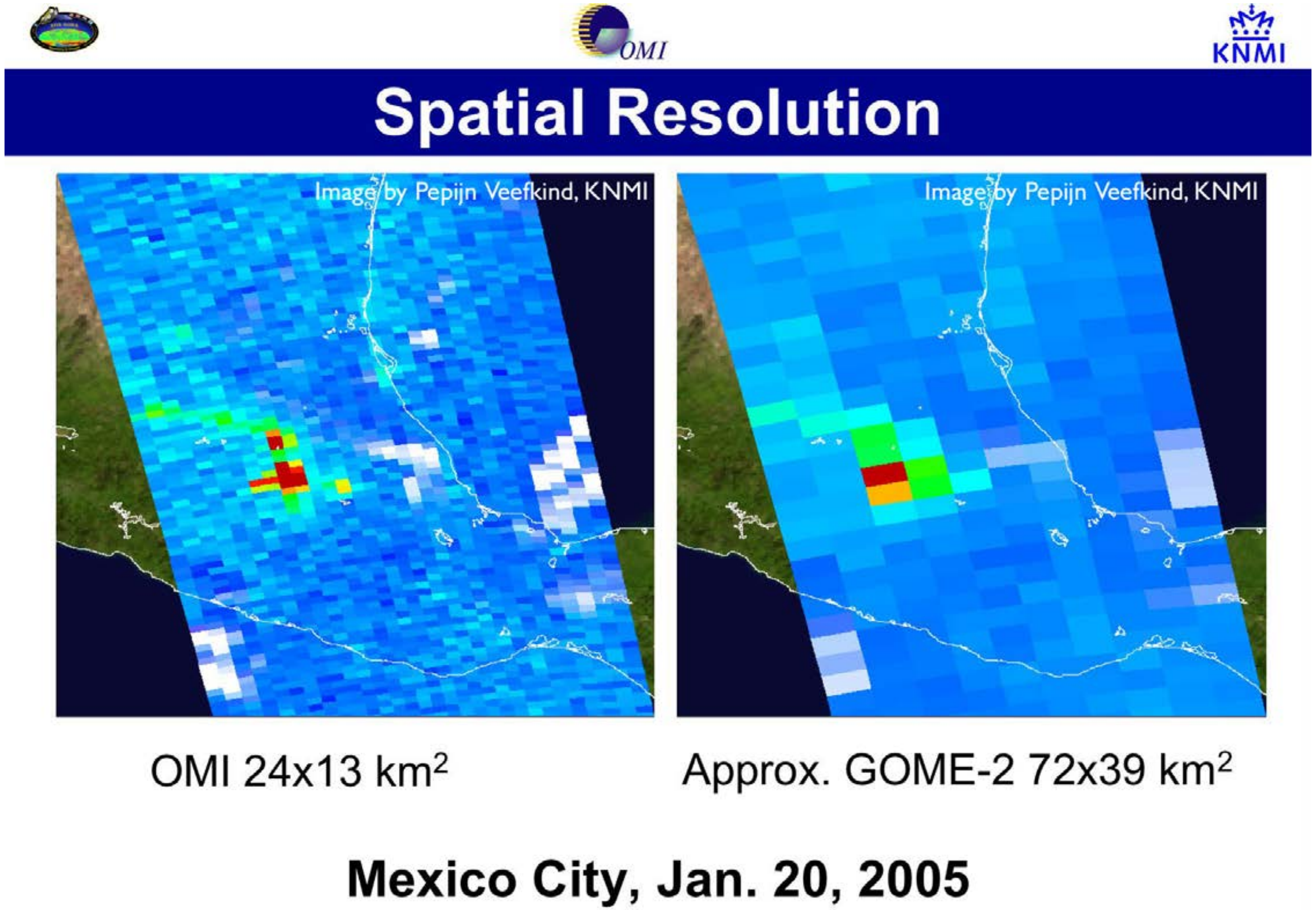
- Advantages
  - Uniform grid
  - One file per day
  - Smaller sized files
  - Quality flags and filtering criteria have been applied
- Limitations
  - Can be coarser resolution than L2
  - L2 observation typically at the same location as the L1 source data

Spatial Resolution: Trace Gases

- Spatial resolution of current satellite instruments (10s to <10 km diameter)
  - good enough to map tropospheric concentration fields on local to regional scales
  - fine enough to resolve individual power plants and large cities
- For species with short atmospheric lifetimes (e.g. NO_2), averaging over larger satellite pixels can lead to significant dilution of signals from point sources, complicating quantitative analysis and separation of emission sources
- For quantitative analysis: Level 2 and high resolution gridded Level 3 data are optimal

Source: Richter, 2010

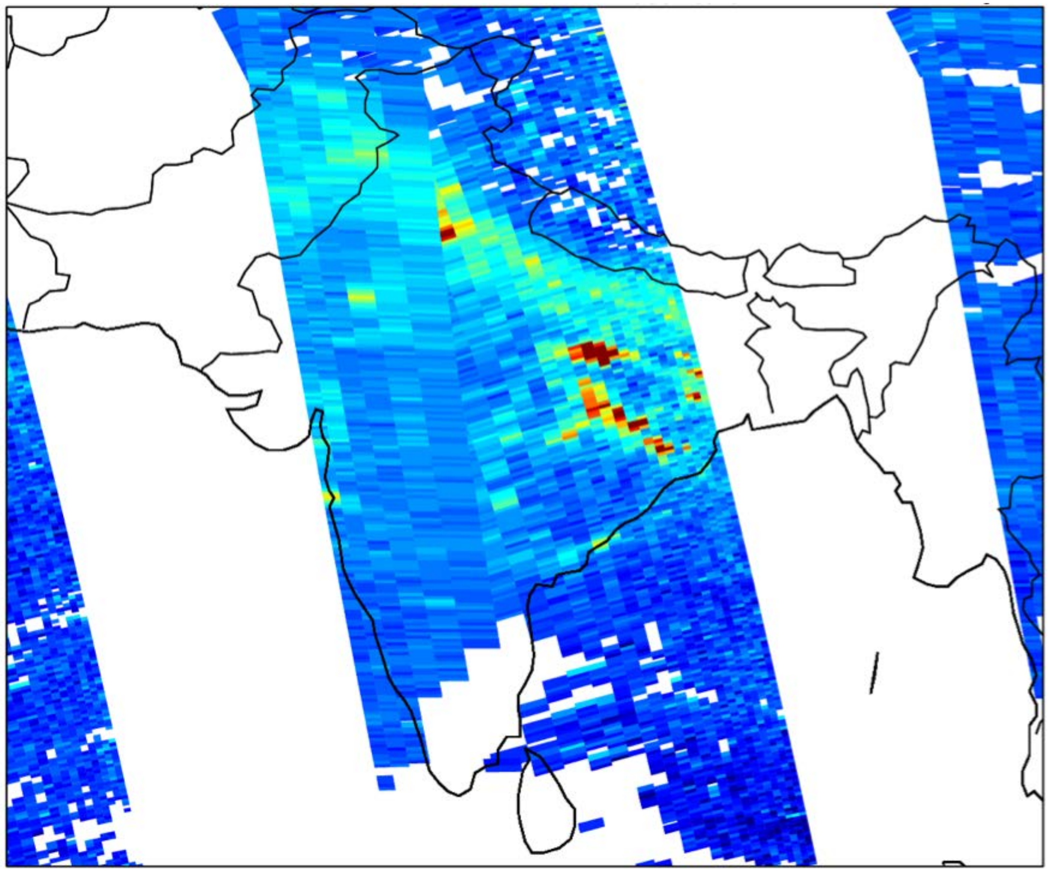
Perspective…



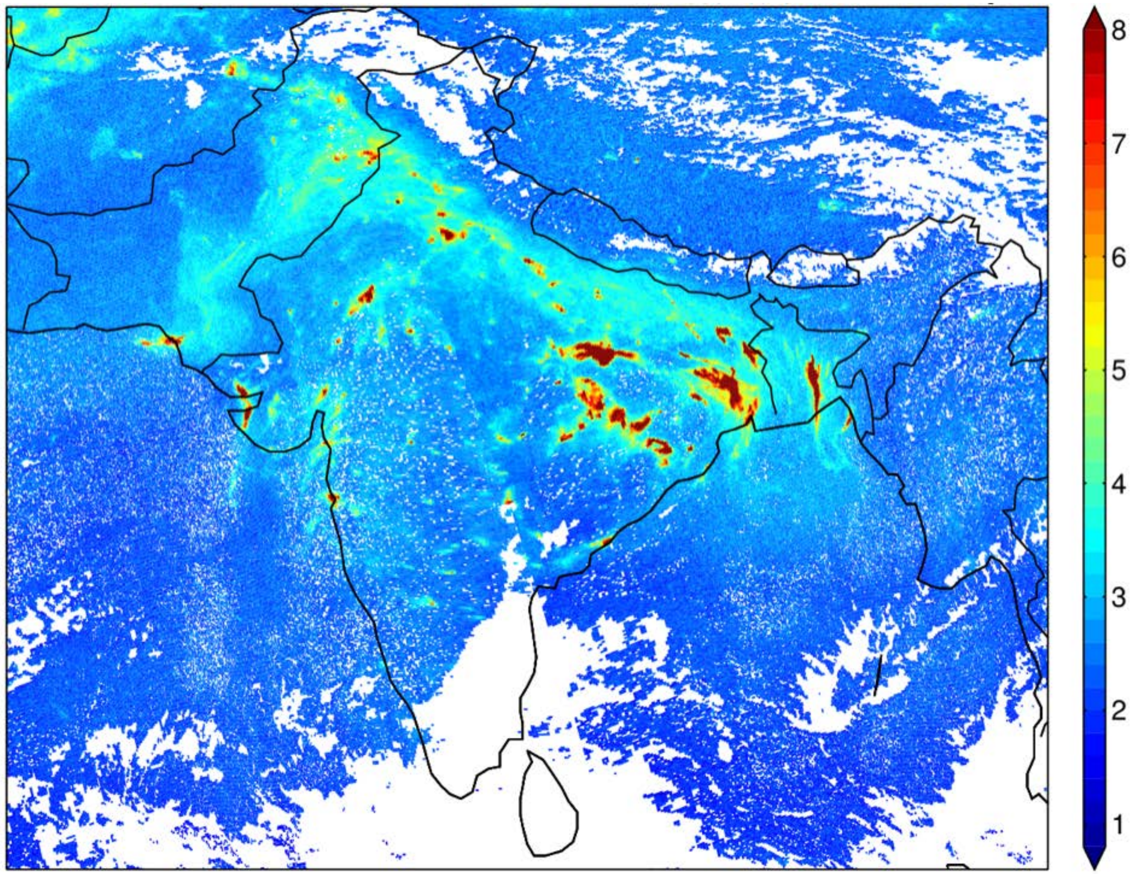
TROPOMI: Impact of Resolution

November 28, 2017

OMI NO_2



TROPOMI NO_2



Spatial Resolution = 3.5 x 7.0 km^2

TROPOMI data courtesy of ESA

Global Pollution Monitoring Constellation (2020-2022)

Policy-relevant science and environmental services enabled by common observations

- Improved emissions over industrialized Northern Hemisphere
- Improved air quality forecasts and assimilation systems
- Improved assessment, e.g., observations to support the United Nations Convention on Long Range Transboundary Air Pollution

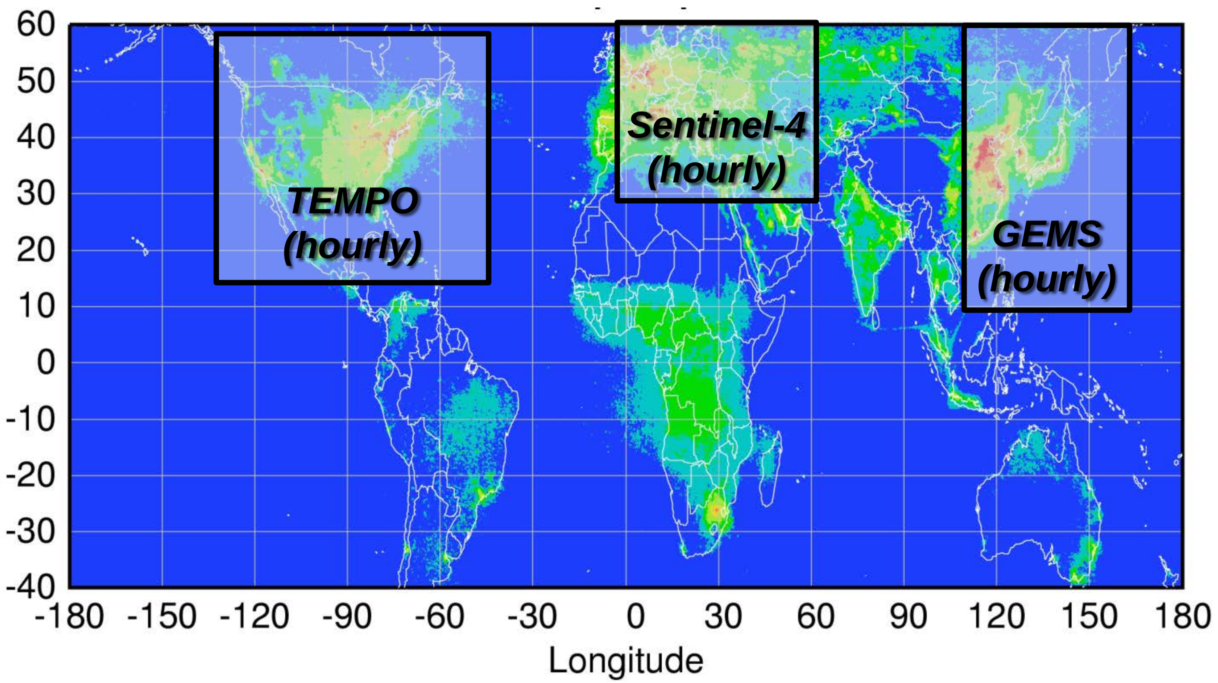
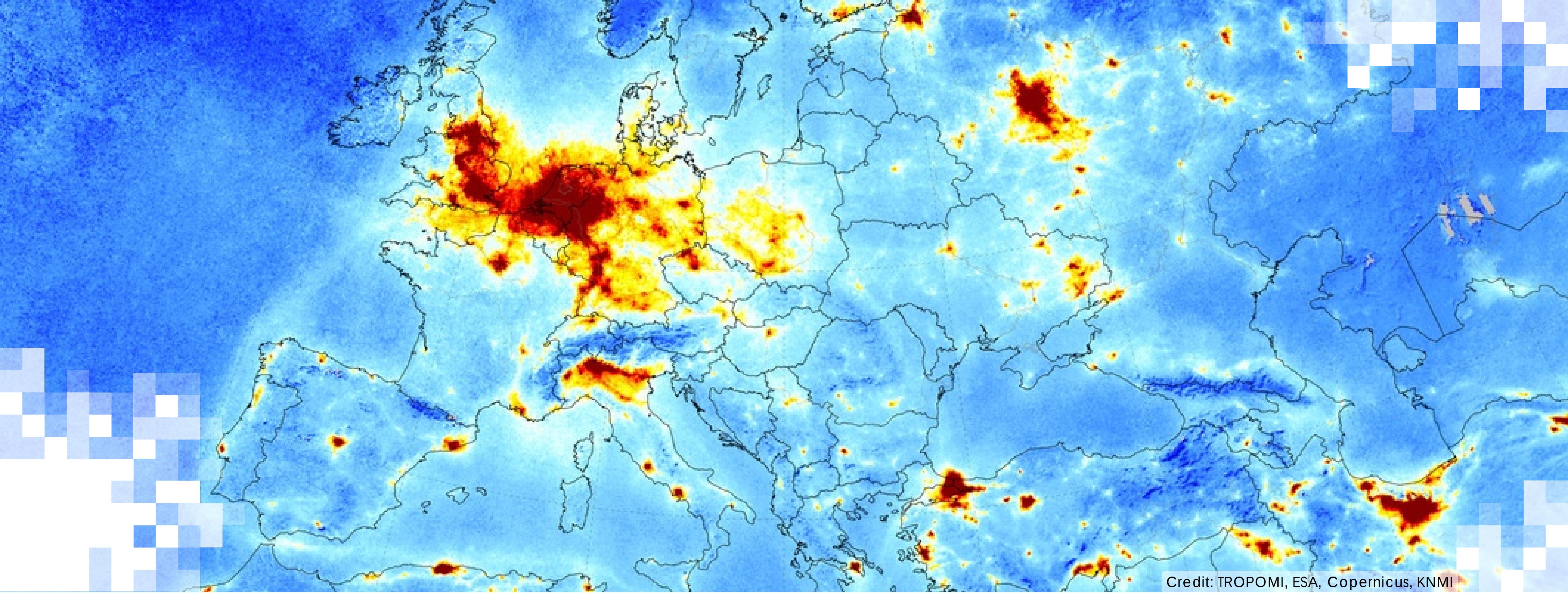


Image Credit: Courtesy Jhoon Kim, Andreas Richter



OMI

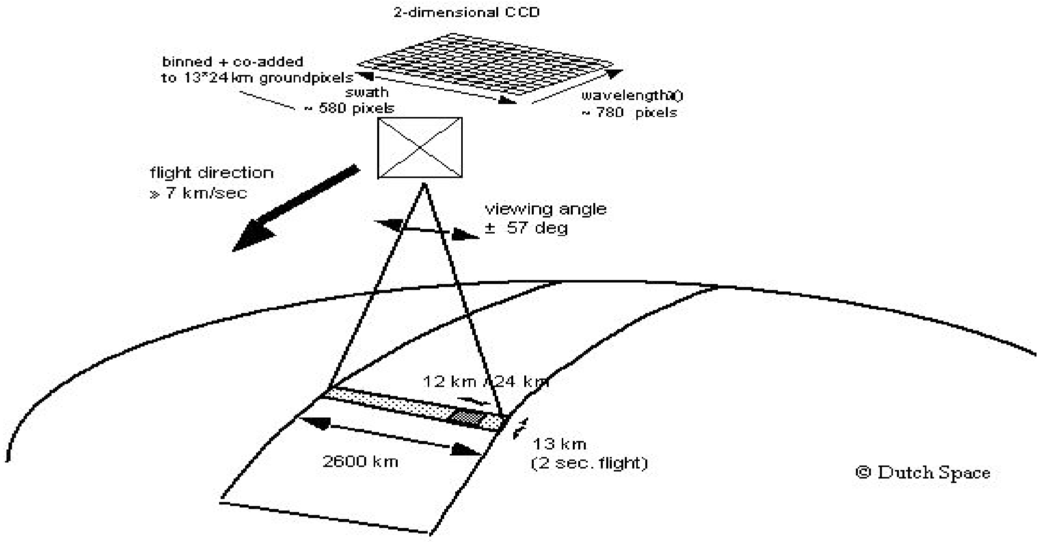
Ozone Monitoring Instrument (OMI)

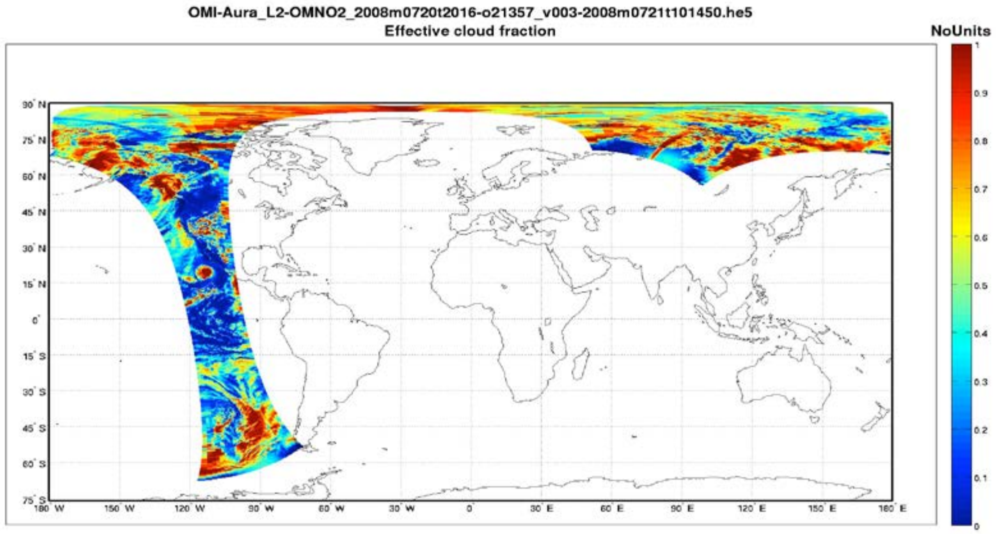
- Launched July 15, 2004
- NASA EOS Aura Satellite
- Nadir-viewing UV/Visible
  - 264 – 311 nm at 0.63 nm
  - 307 – 383 nm at 0.42 nm
  - 349 – 504 nm at 0.63 nm
- 1:45 p.m. equatorial crossing time
- 13x24 km^2 at nadir
- Daily global coverage

- Products
  - 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

Data Granule

- Product File
  - covers sunlit portion of the orbit with an approx. 2,600 km wide swath
  - contains 60 binned pixels or scenes per viewing line
- 14 or 15 granules are produced daily, providing fully contiguous coverage of the globe

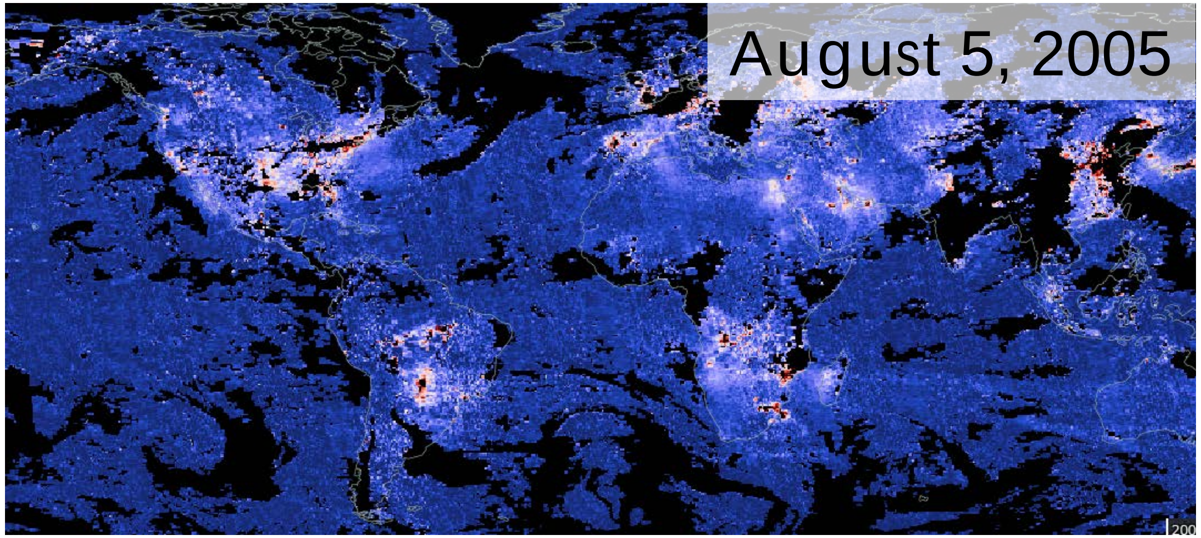


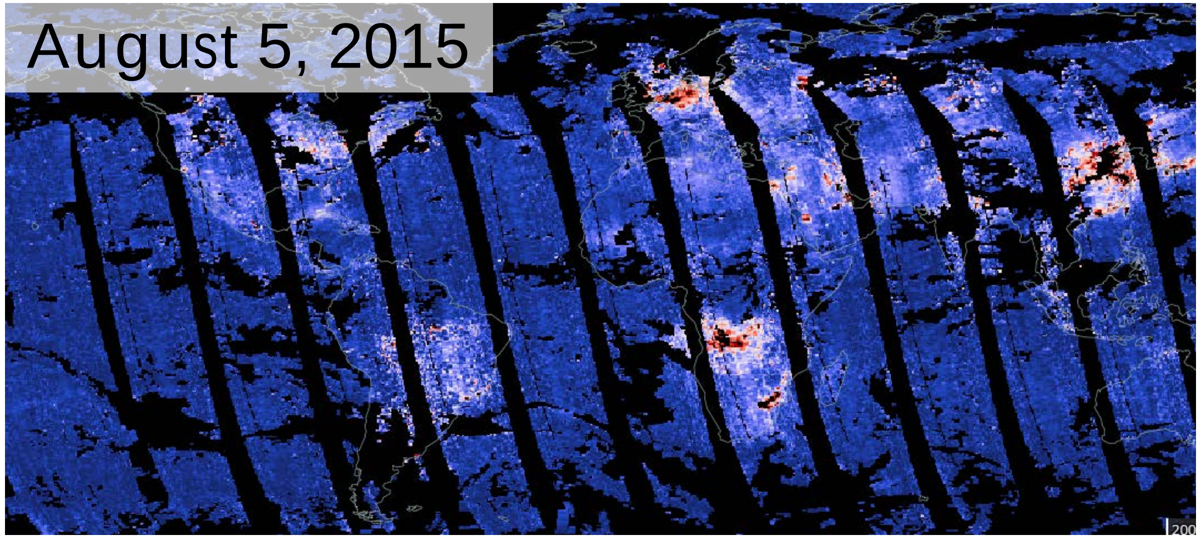


Effect of the OMI Row Anomaly

- Began in 2007 with only two rows
- Grew until 2012, at which point was affecting almost 50% of the data
- Affects all OMI products

OMI Tropospheric Column NO_2





Nitrogen Dioxide (NO_2)

- Why measure NO_2?
  - NO_2 is an ozone precursor and health irritant
  - Sources: Fires, industrial and transportation sources, stationary sources (e.g. power plants), but emissions can vary depending on fuel type and conditions
  - High concentrations in the planetary boundary layer (PBL)

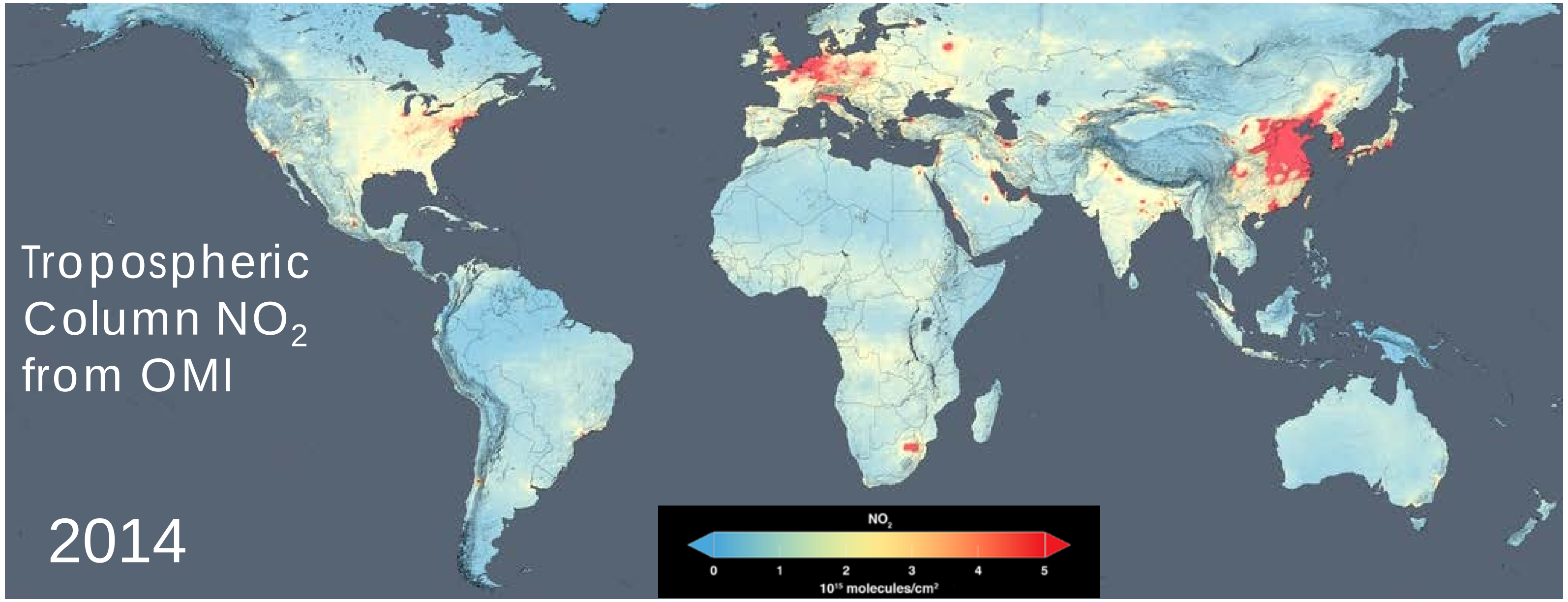
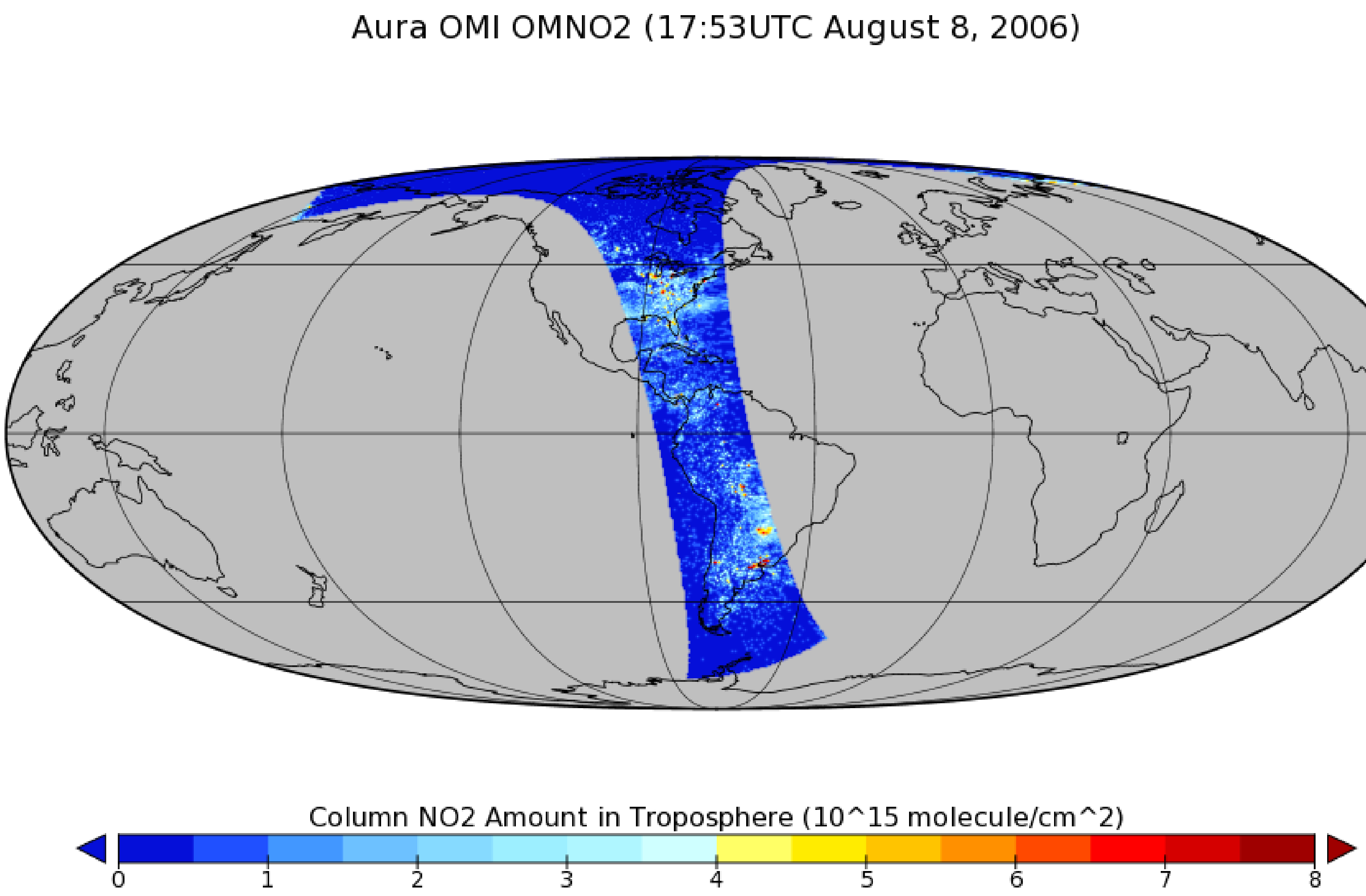
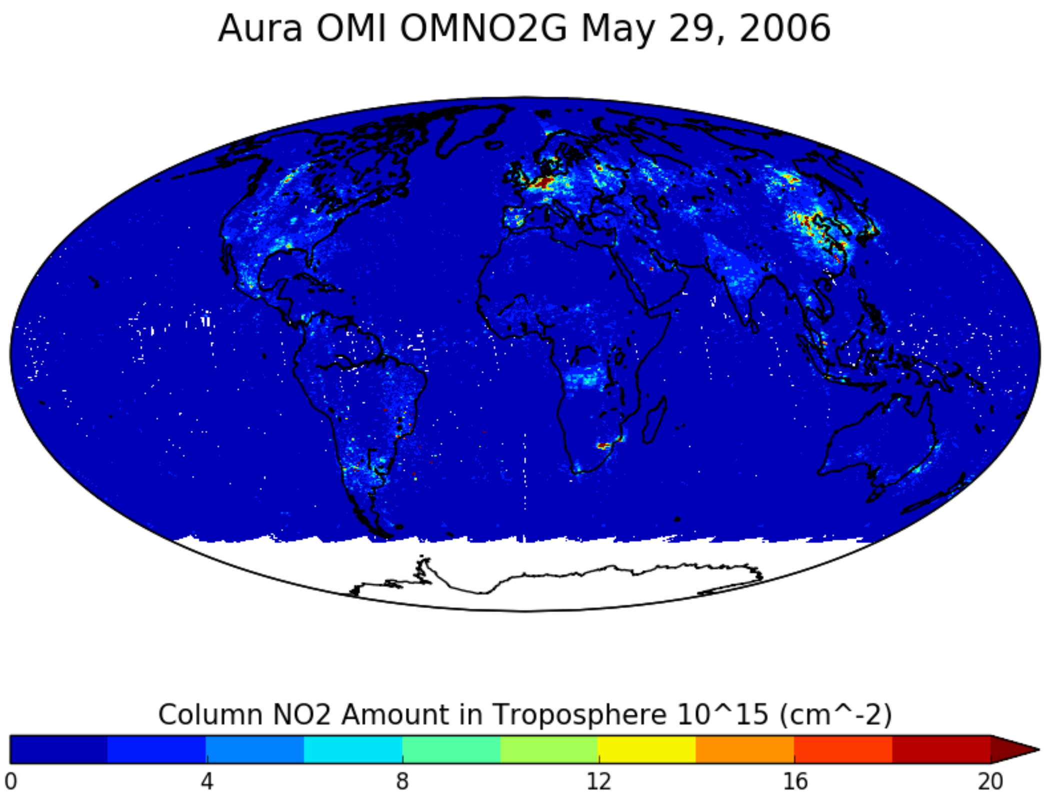


Image Credit: NASA SVS

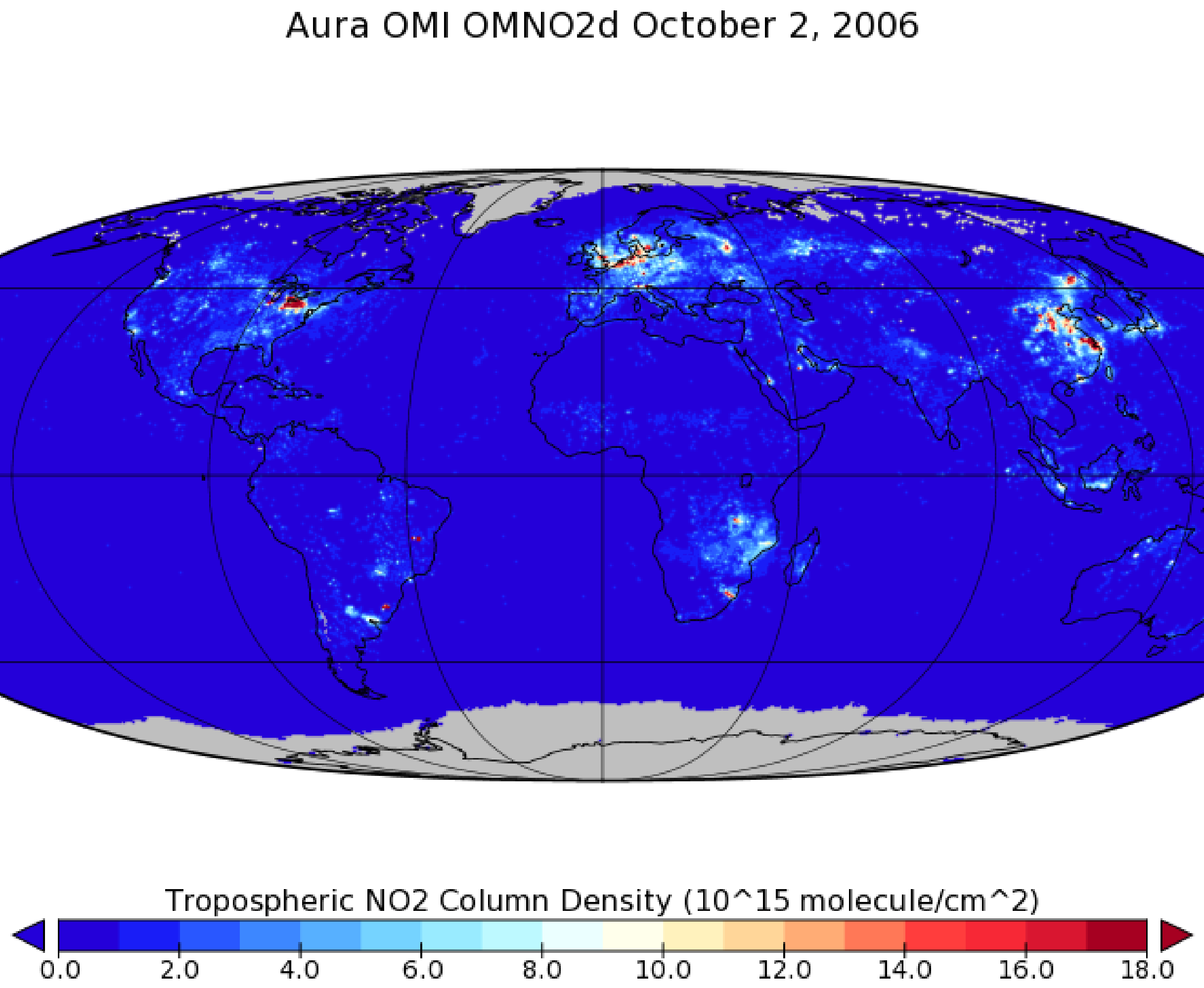
$OMNO_2$ Level 2 Product – Native Resolution



OMNO2G L2 Gridded Product (0.25° x 0.25°) – *No Pixel Averaging*



OMNO2d L3 Gridded Product (0.25° x 0.25°) – *Pixel Averaging*



Understanding an OMI File Name

OMNO2, OMSO2

Instrument ID

Data Type

Orbit #

Collection #

OMI-Aura_L2-OMNO2_2008m0720t2016-o21357_v003-2016m0820t102252.he5

Observation Date & Time

Production Date and Time

HDFLook, Panoply, IDL, Python, Fortran, MatLab, and more can be used to read the data

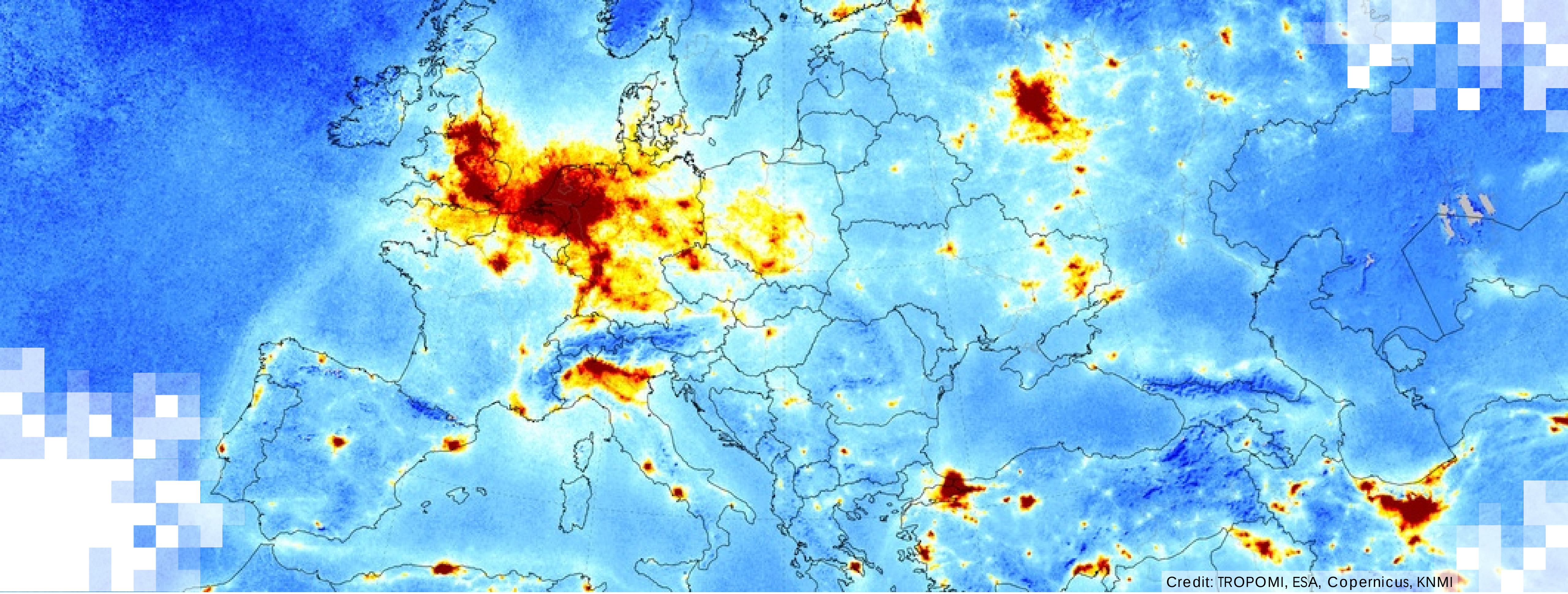
OMI NO_2 Parameter information (OMNO_2)

Name	Description	Unit	Notes
ColumnAmountNO2Trop	Tropospheric Column NO_2	Molec / cm^2	• Use only scenes with: radiative cloud fraction < 0.5 solar zenith angle < 85° terrain reflectivity < 0.3
TerrainReflectivity		Unitless	Scale factor: 0.001
CloudRadianceFraction		Unitless	Scale factor: 0.001
SolarZenithAngle		Deg	In geolocation fields

- All fill values are high negative numbers: ($-2.^{100} \approx -1.26765\times10^{30}$)

OMNO2_HR Gridded High Resolution OMI NO_2 (0.1° x 0.1°)

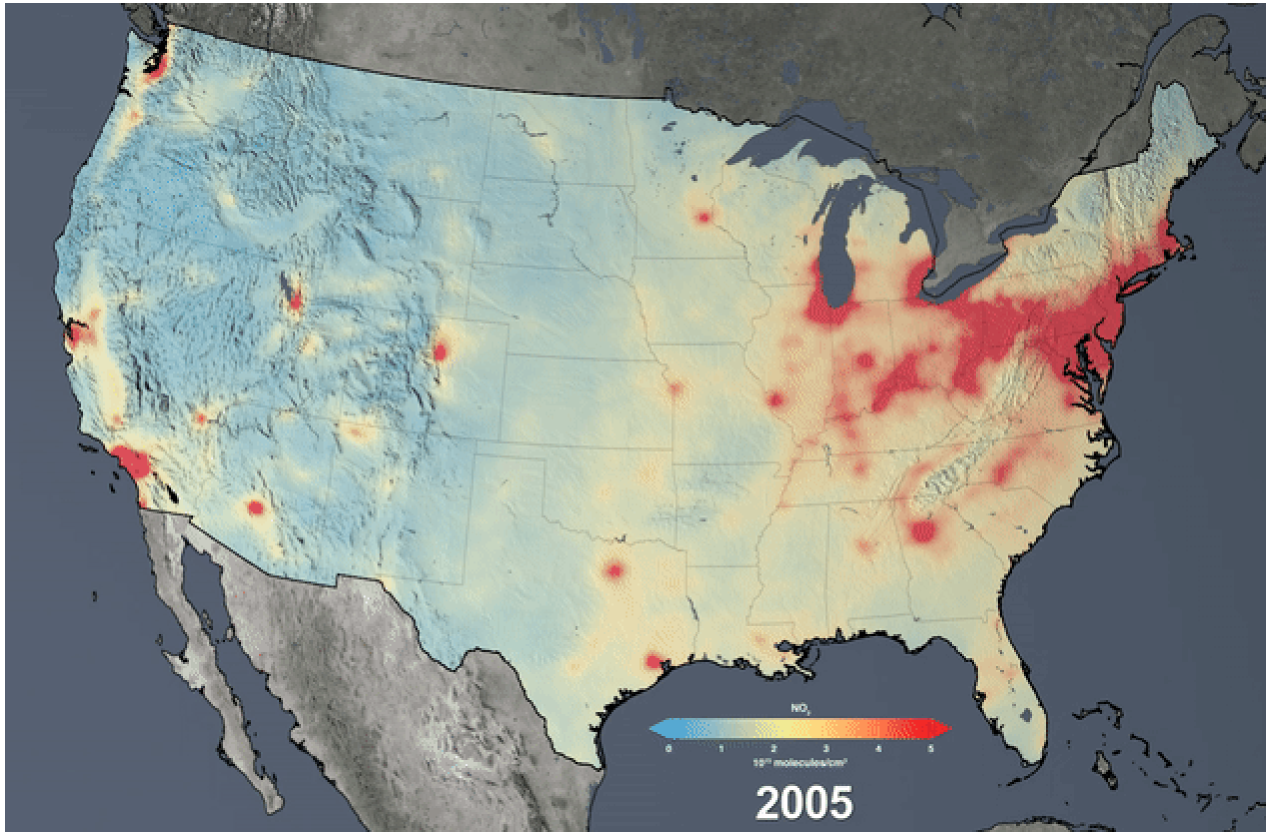
- Based on NASA standard product
- Daily:
  - https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L3/OMNO2D_HR/OMNO2D_HRD/
  - Available in hdf5 format
- Monthly:
  - https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L3/OMNO2D_HR/OMNO2D_HRM/
  - Available in ASCII (text) and NetCDF format



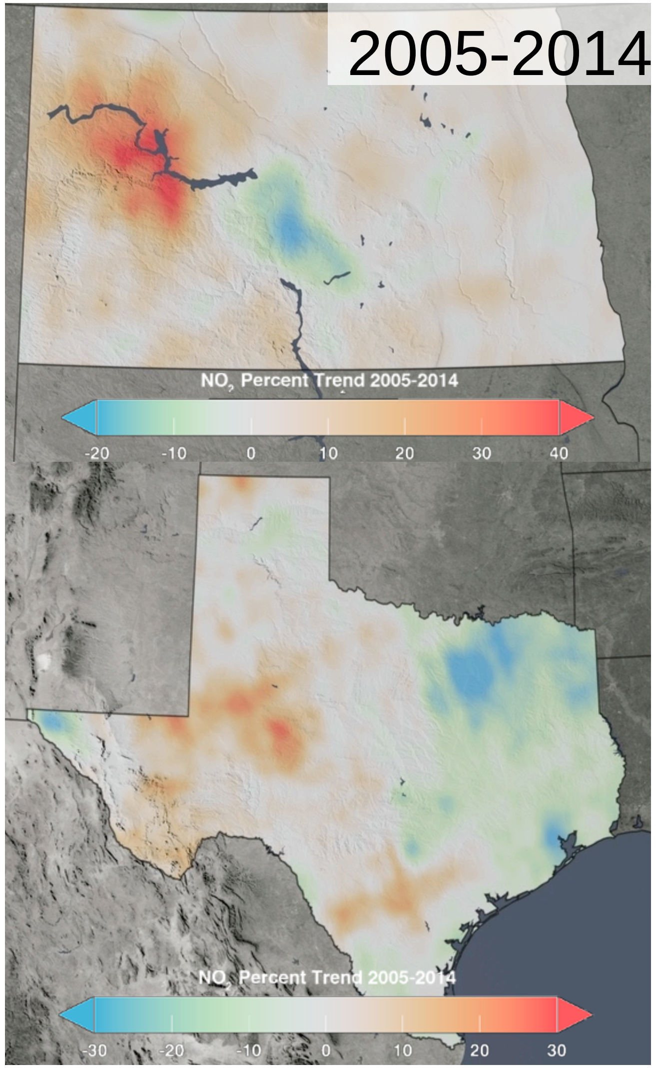
Applications and Research Using OMI data

OMI Detects NO_2 Changes in Pollution Over Time

2005 – 2016



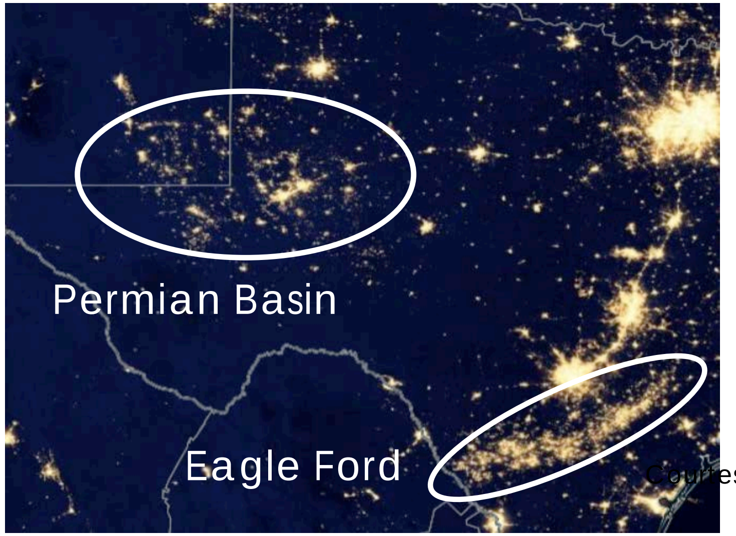
OMI Detects NO_2 Increases from ONG Activities



North Dakota

Suomi NPP VIIRS Lights at Night

Texas



Courtesy of: Bryan Duncan

OMI NO_2 Used to Update Inventory Trends

- Creating a bottom-up emissions inventory is time consuming and labor intensive
  - e.g., Currently the most up-to-date U.S. emissions inventory is the NEI 2017
- Satellite observations and trends can be used to update bottom-up emissions inventories until a new inventory is completed
- Example: Lamsal et al. 2011 used a chemistry transport model to estimate how changes in emissions related to changes in the atmospheric column
- Then they applied this relationship using post-inventory satellite observations

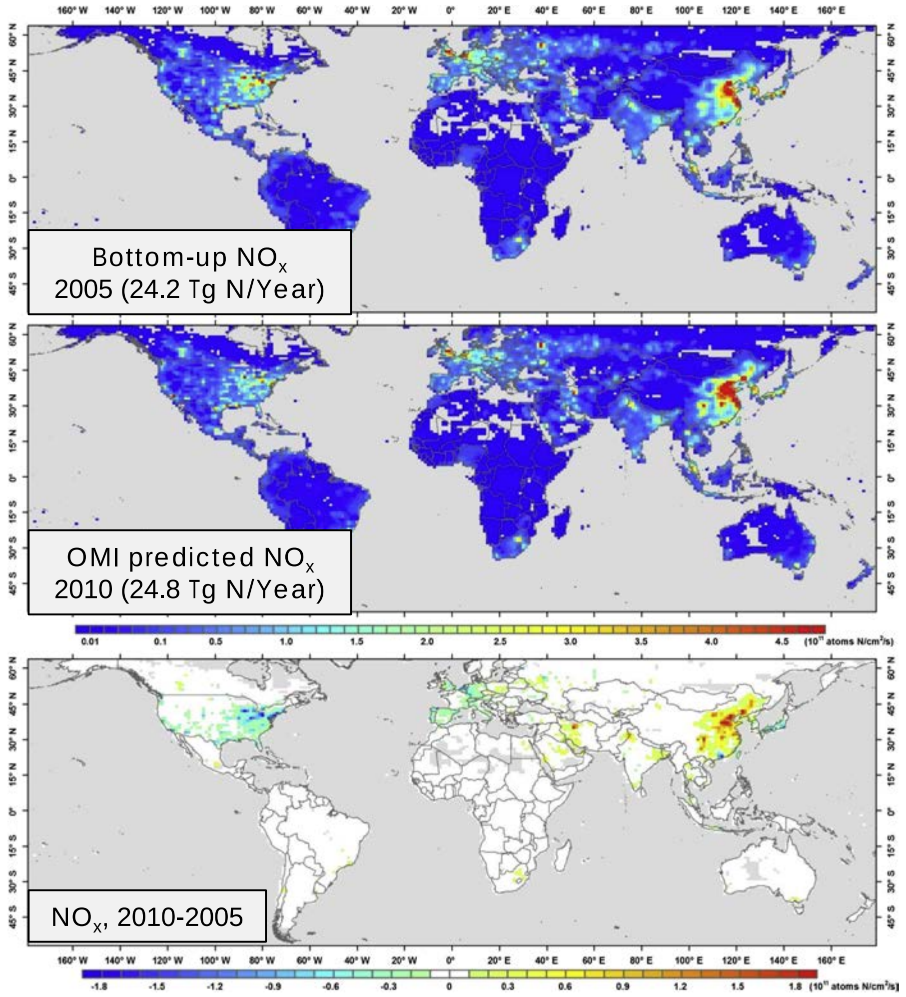
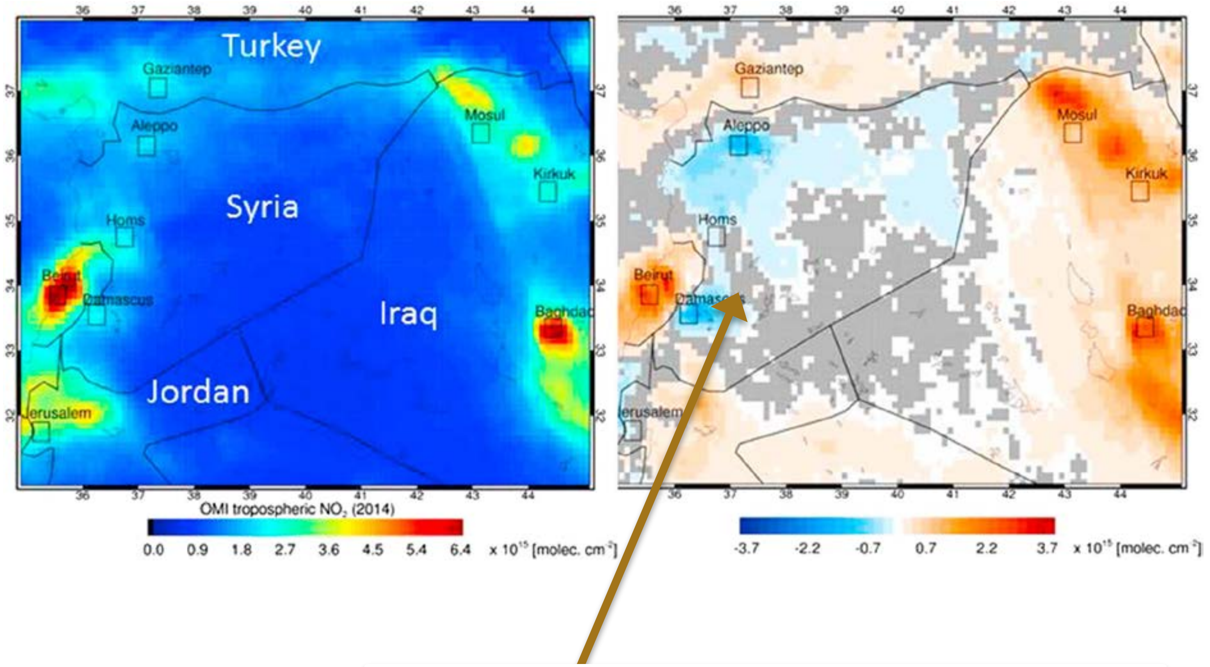


Image credit: Figure 5 from Streets et al. 2013

Temporal Variations

- Satellite observations can also be used to detect potential short term and unexpected changes in trends, such as reductions in activity due to:
  - economic recession
  - natural disasters (e.g., Hurricane Katrina)
  - policy interventions (e.g., Beijing Olympics)
  - civil unrest

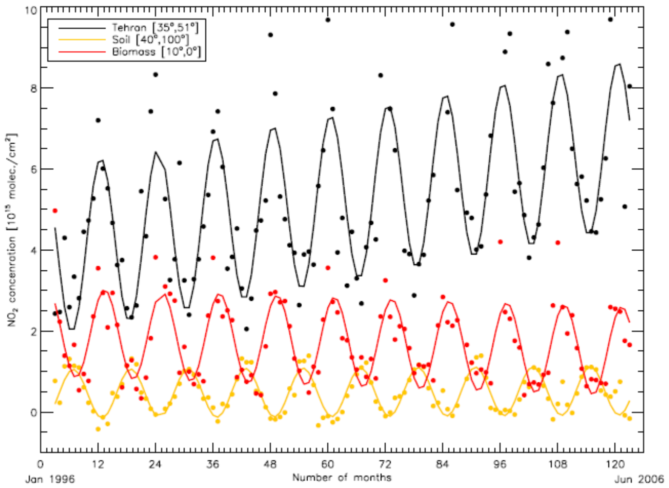


NO_2 Trends from OMI
Damascus: -37.1 ± 10.9%
Aleppo: -40.2 ± 13.6%

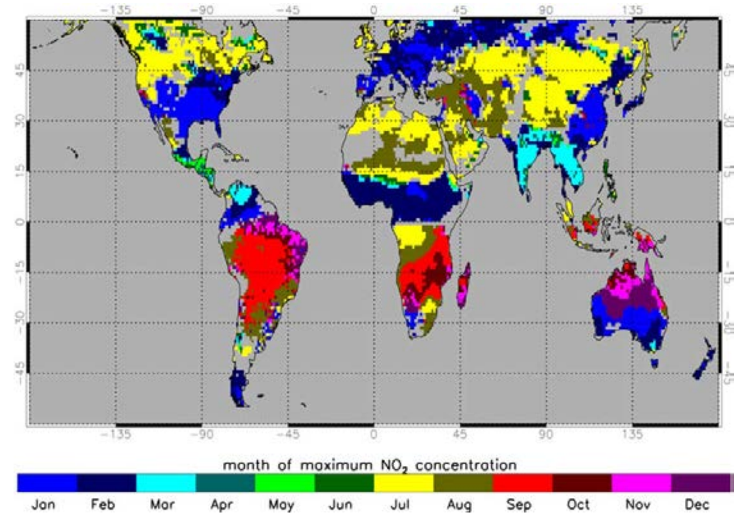
Image credit: Figure 11 from Duncan et al. 2016

Temporal Variations

- Examine finer temporal emissions cycles
  - Weekly cycles
  - Seasonal cycles of different sources
    - Anthropogenic – Winter
    - Soil – Summer
    - Biomass Burning – Dry Season



Anthropogenic
Soil
Biomass Burning



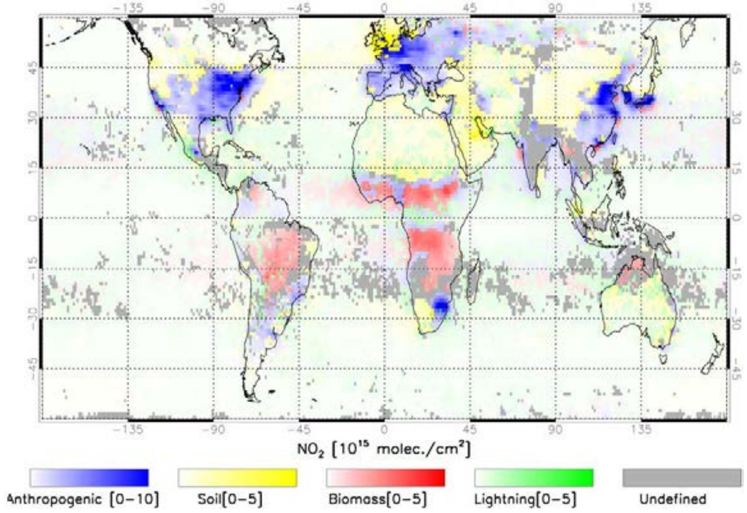
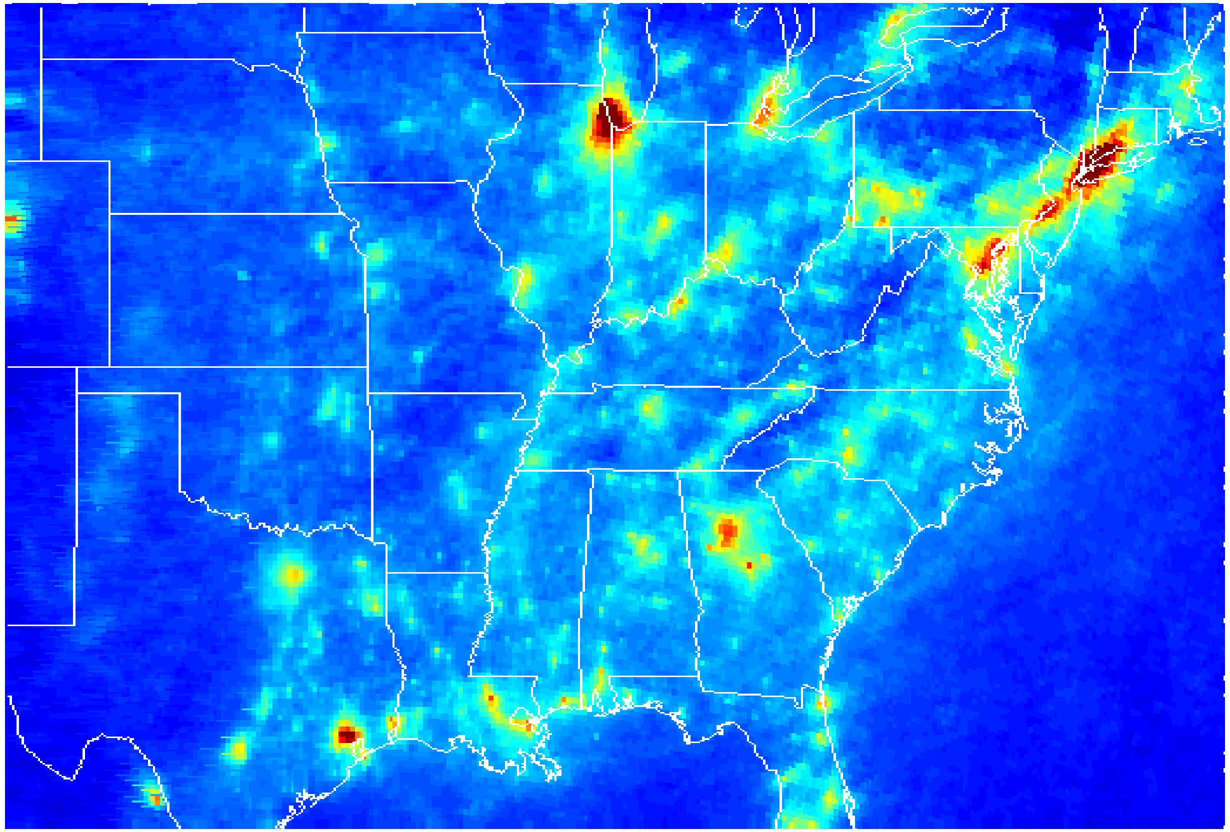


Image credit: Figures 3, 5, and 7 from van der A. et al. 2008

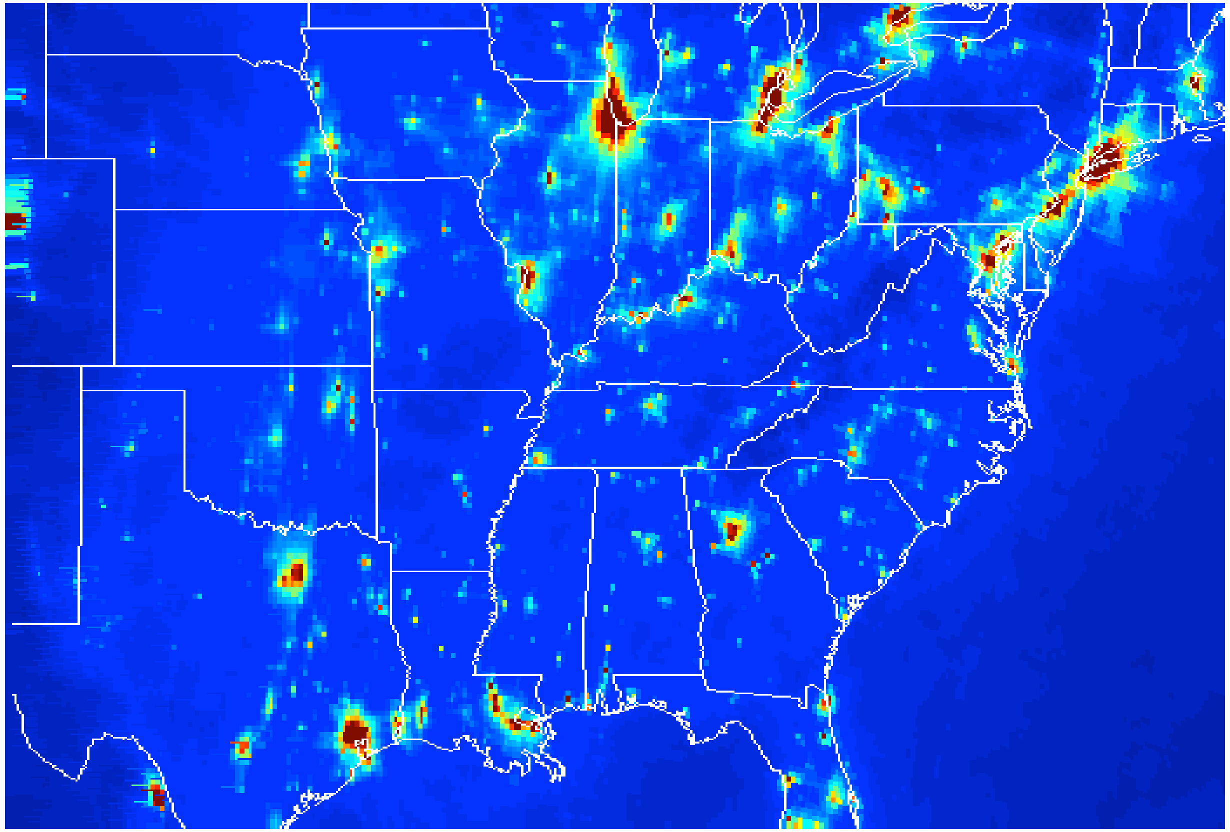
NASA's Applied Remote Sensing Training Program

Model-Satellite Inter-Comparison

OMI NO_2



CMAQ Model NO_2



OMI Trends in NO_2 Correlate Well With Surface Trends

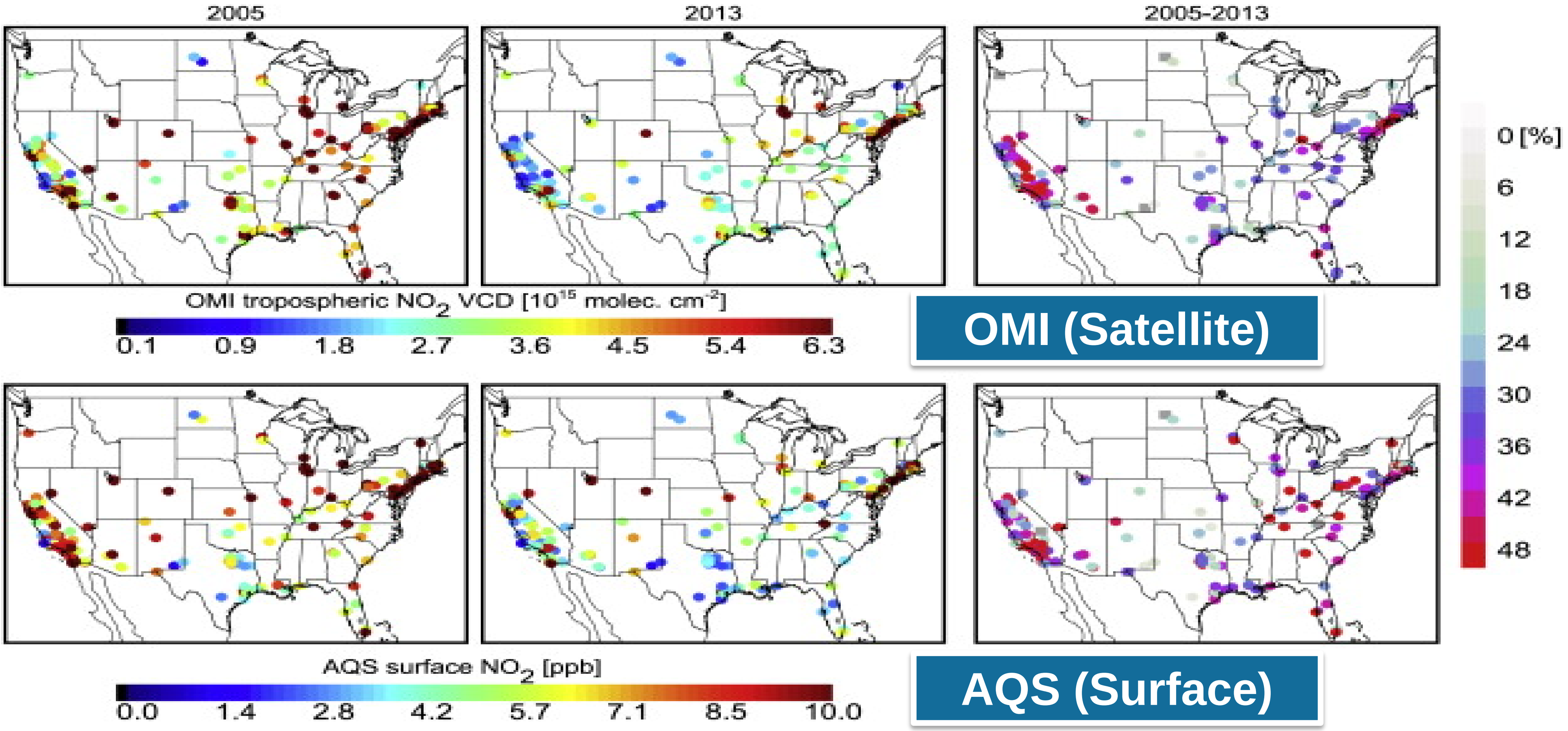
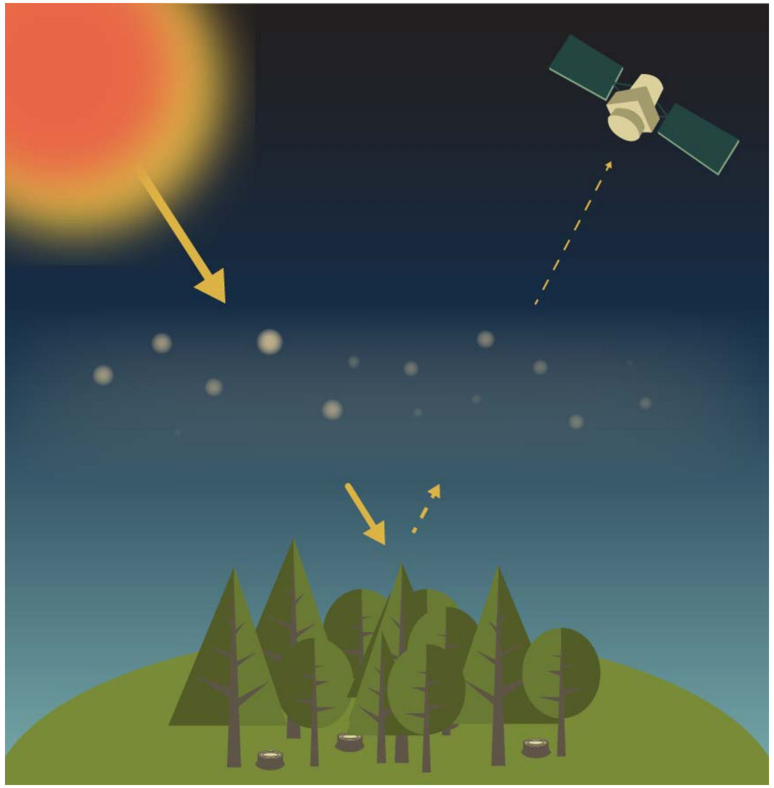
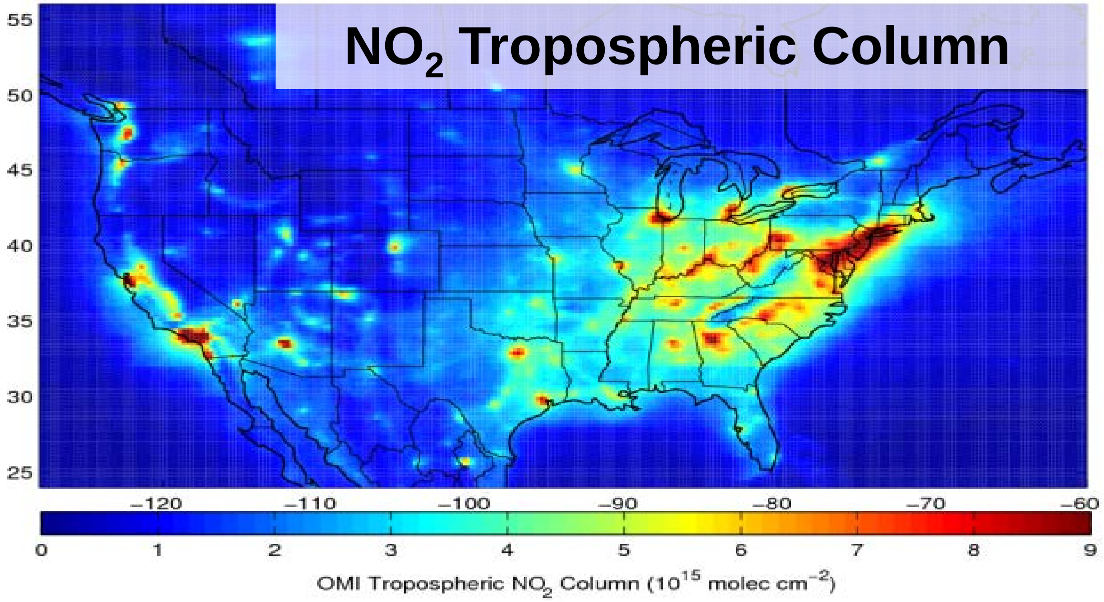


Image credit: Lamsal et al. (2015)

Estimating Surface NO_2 From the Tropospheric Column

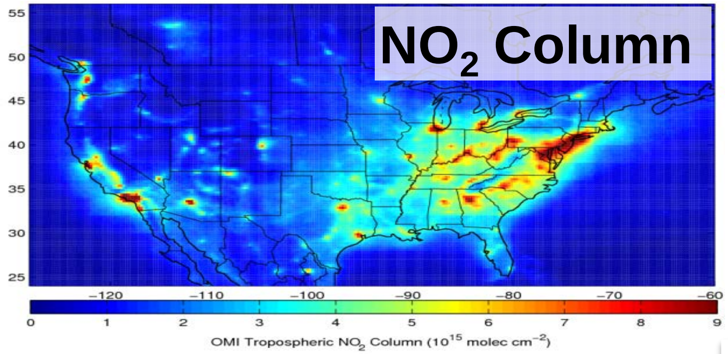




Satellites measure backscattered radiation, from which vertical column densities can be calculated

- Courtesy of Randall Martin

Estimating Surface NO_2 From the Tropospheric column



$$v = \frac{\Omega_{Satellite}}{\Omega_{Model}}$$

$$S = \Omega_{Sat}\ x \left[\frac{vS_{Model}}{v\Omega_{Model} - (v-1)\Omega_{FT\ (Model)}}\right]$$

Lamsal et al. (2008)

Use vertical information from an atmospheric chemistry model to estimate the relationship between the column and the surface

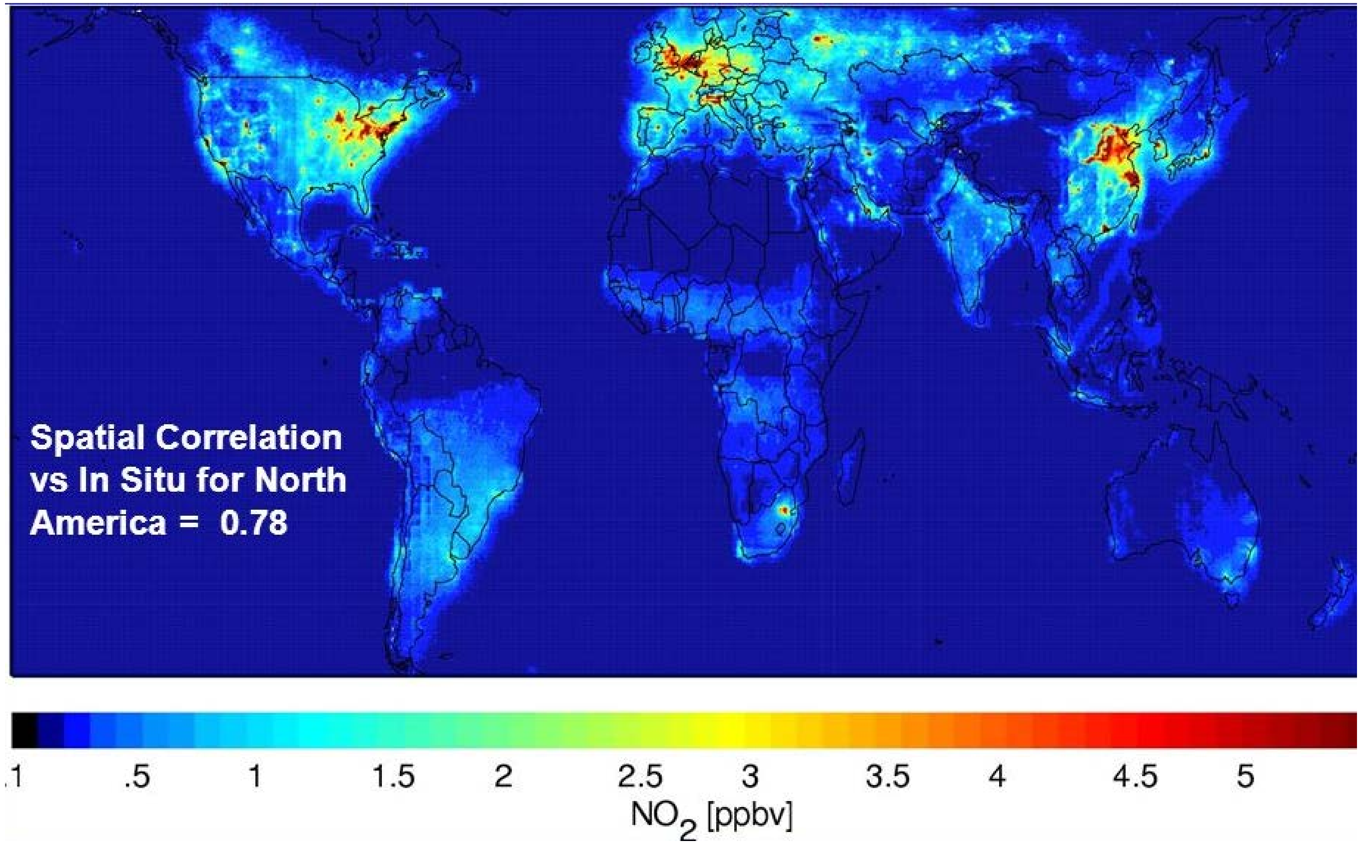
S = Surface Concentration

Ω = Tropospheric Column

FT = Free Troposphere

Courtesy of Randall Martin

Ground-Level Afternoon NO_2 Inferred from OMI for 2005



- Note: this is a research product and not an official NASA product

Source: Lok Lamsal

Satellite-Based Surface NO_2 Datasets

Time Period	1996-2012	2005-2007	2005-2016
Available Product	Annual Mean, 3-Yr Running Mean	Annual Mean (North America and global)	Monthly Mean
Instruments	GOME, SCIAMACHY, GOME-2	OMI	OMI
Overpass Time	~9:30-10:30	~13:30	~13:30
Product Resolution	0.1^{o} x 0.1^{o}	0.1^{o} x 0.1^{o}	0.1^{o} x 0.1^{o}
Reference	Geddes et al. (2015)	Lamsal et al. (2008, 2010)	
Website	https://sedac.ciesin.columbia.edu/		https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L4/OMI_Surface_NO2/Monthly/
	http://fizz.phys.dal.ca/~atmos/martin/?page_id=232		

Satellite-Derived Surface NO_2 Used in Health Applications

- Anenberg et al. (2018) used annual average surface NO_2, along with annual average $PM_{2.5}$ and annual average ozone from a model
- Used to estimate the number of global asthma-related emergency room visits due to $PM_{2.5}$, O_3, and NO_2 exposure
- Noted that NO_2 impacts are likely underestimated because of the relatively coarse OMI resolution

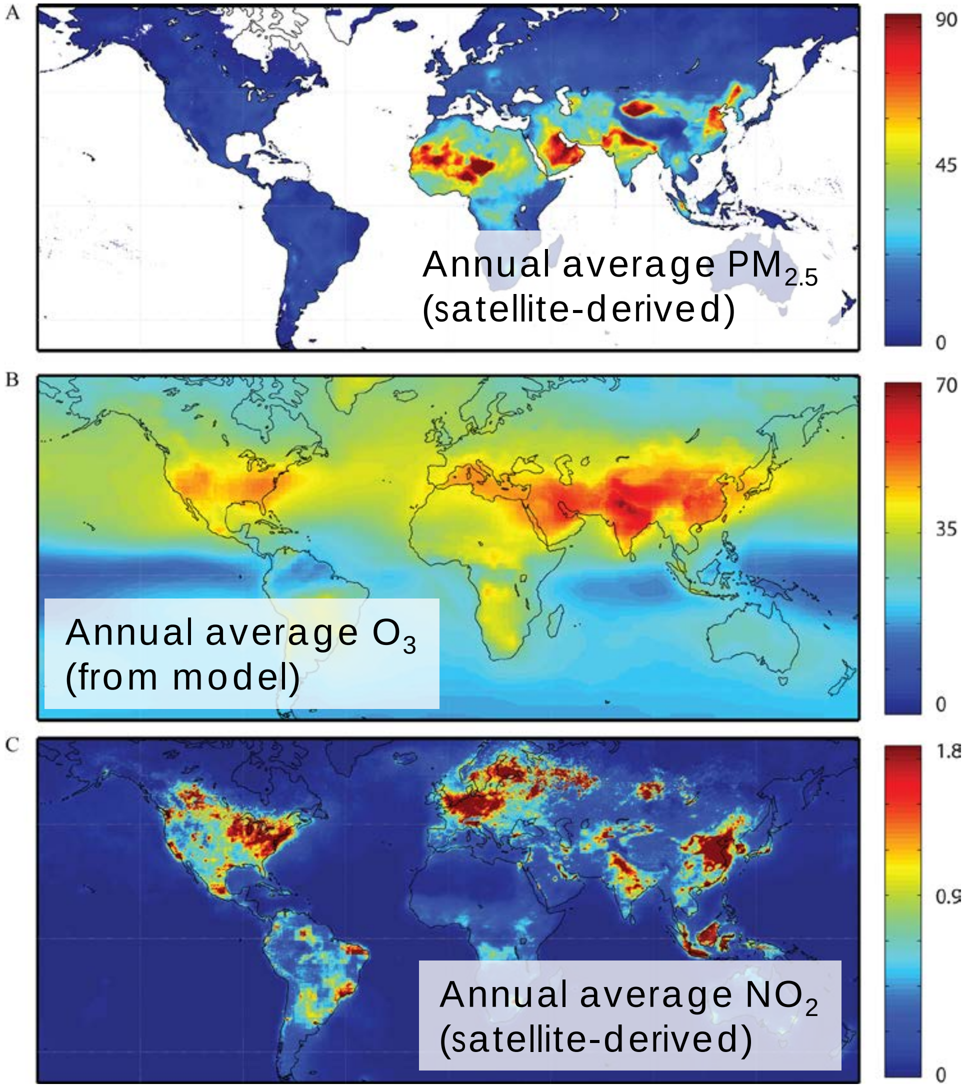
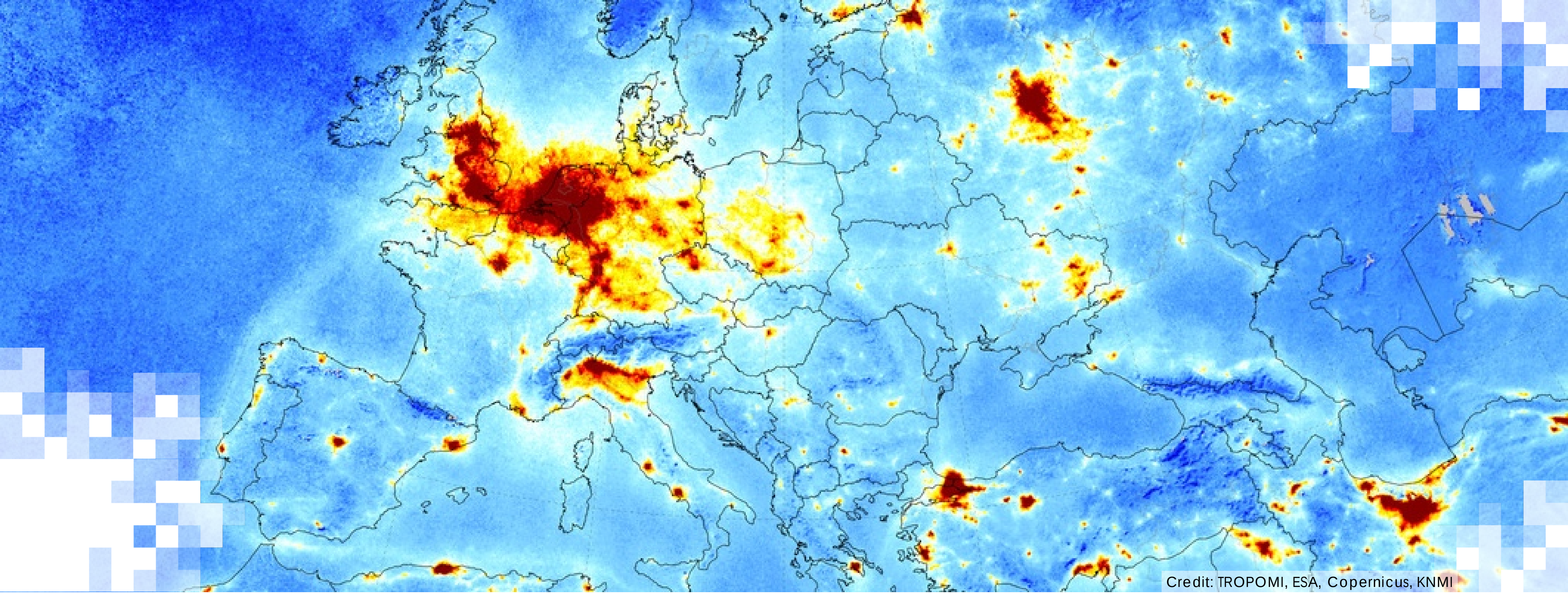


Image credit: Anenberg et al. 2018



Data Access

Step 1: 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

Step 2: Add NASA GESDISC to Your Applications

- Login to Earthdata
- Click on **My Applications**
- Click on **Approve More Applications**
- Look for NASA GESDISC DATA ARCHIVE in the list or search
- Add NASA GESDISC DATA ARCHIVE to your applications

You should see NASA GESDISC DATA ARCHIVE in list of approved applications

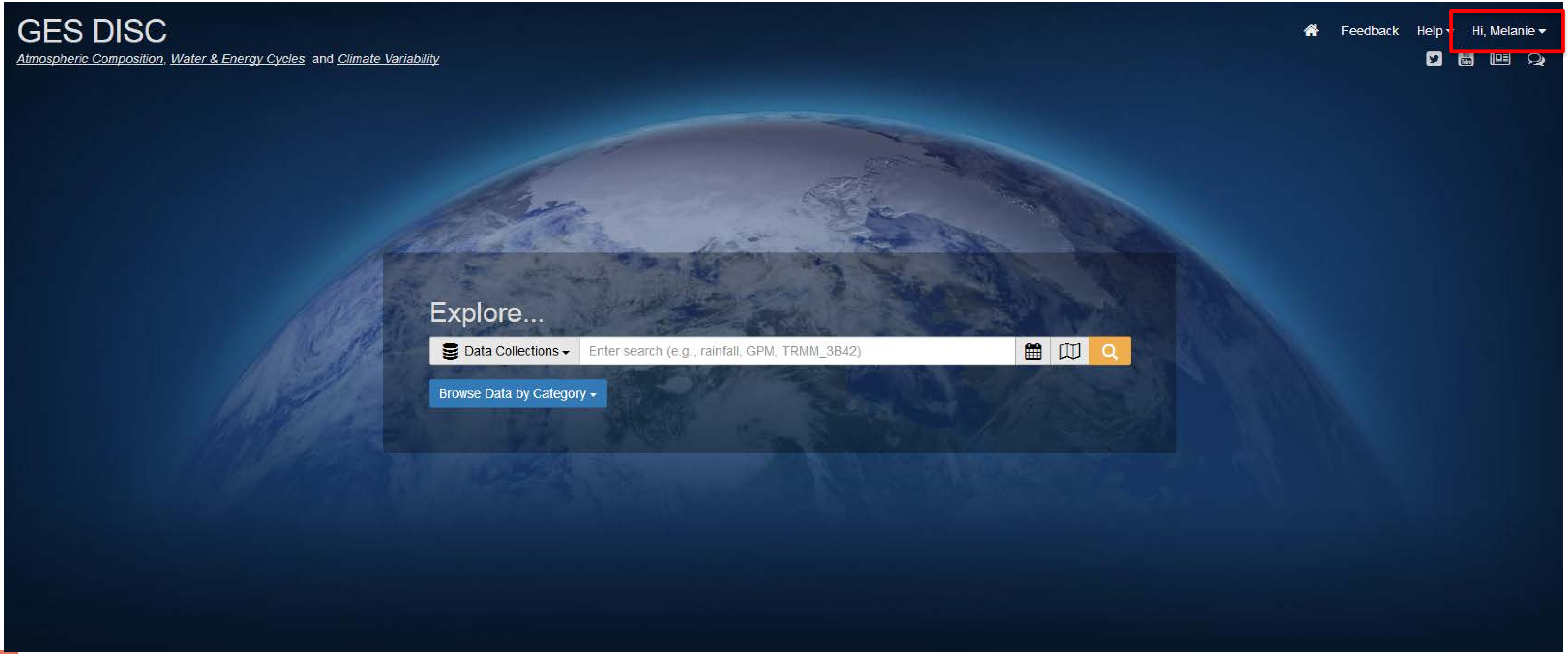
My Applications

Approved Applications

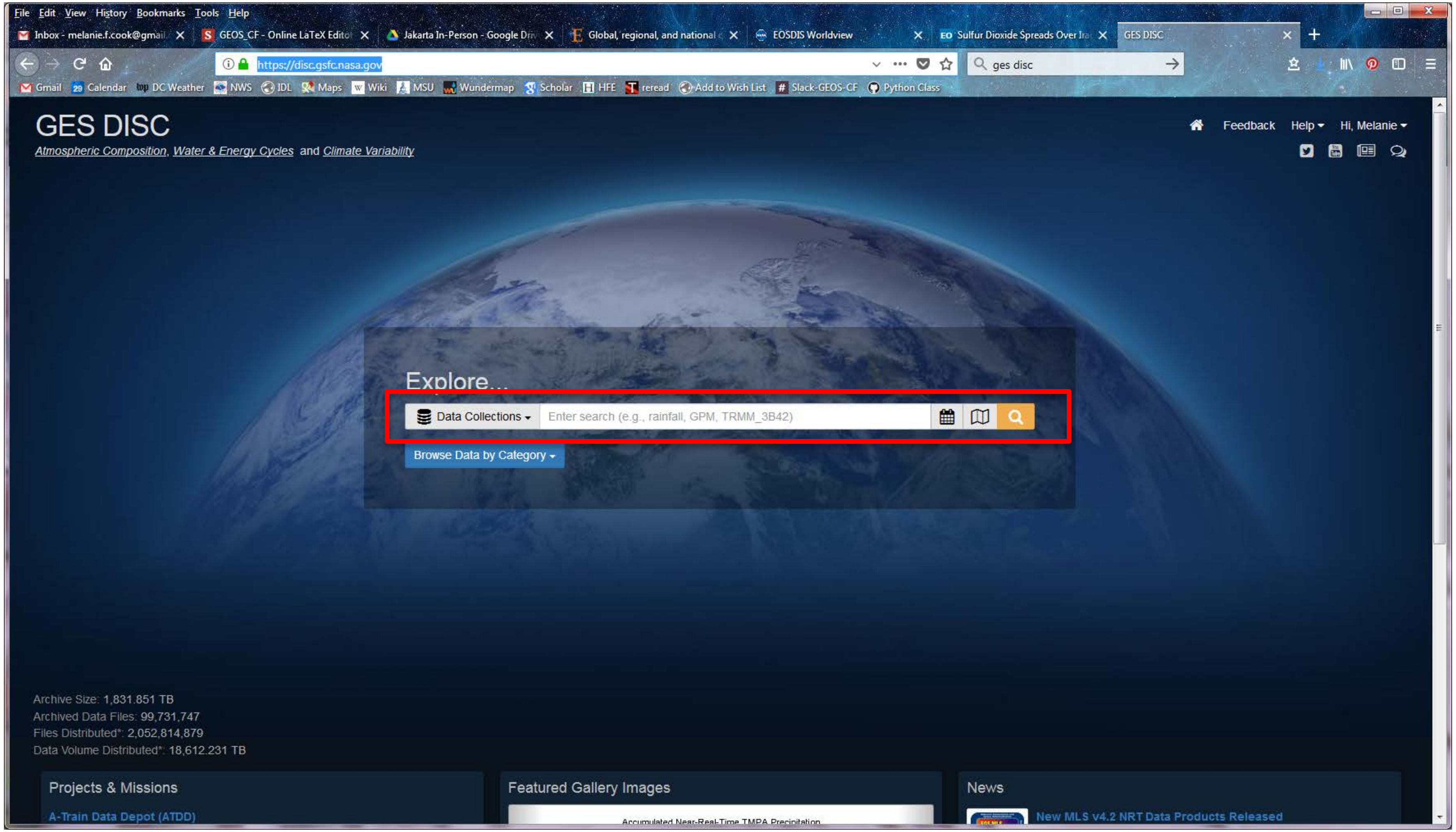
Applications that use your Earthdata Login profile for authentication.

Earthdata Feedback Module	
Earthdata Website	
Earthdata Code Collaborative	
Metadata Management Tool	
Earthdata Wiki	
SEDAC Website	
Earthdata Search	
LAADS Web	
Toolsets for Airborne Data (TAD)	
Earthdata Search Prod (new)	
NASA GESDISC DATA ARCHIVE	

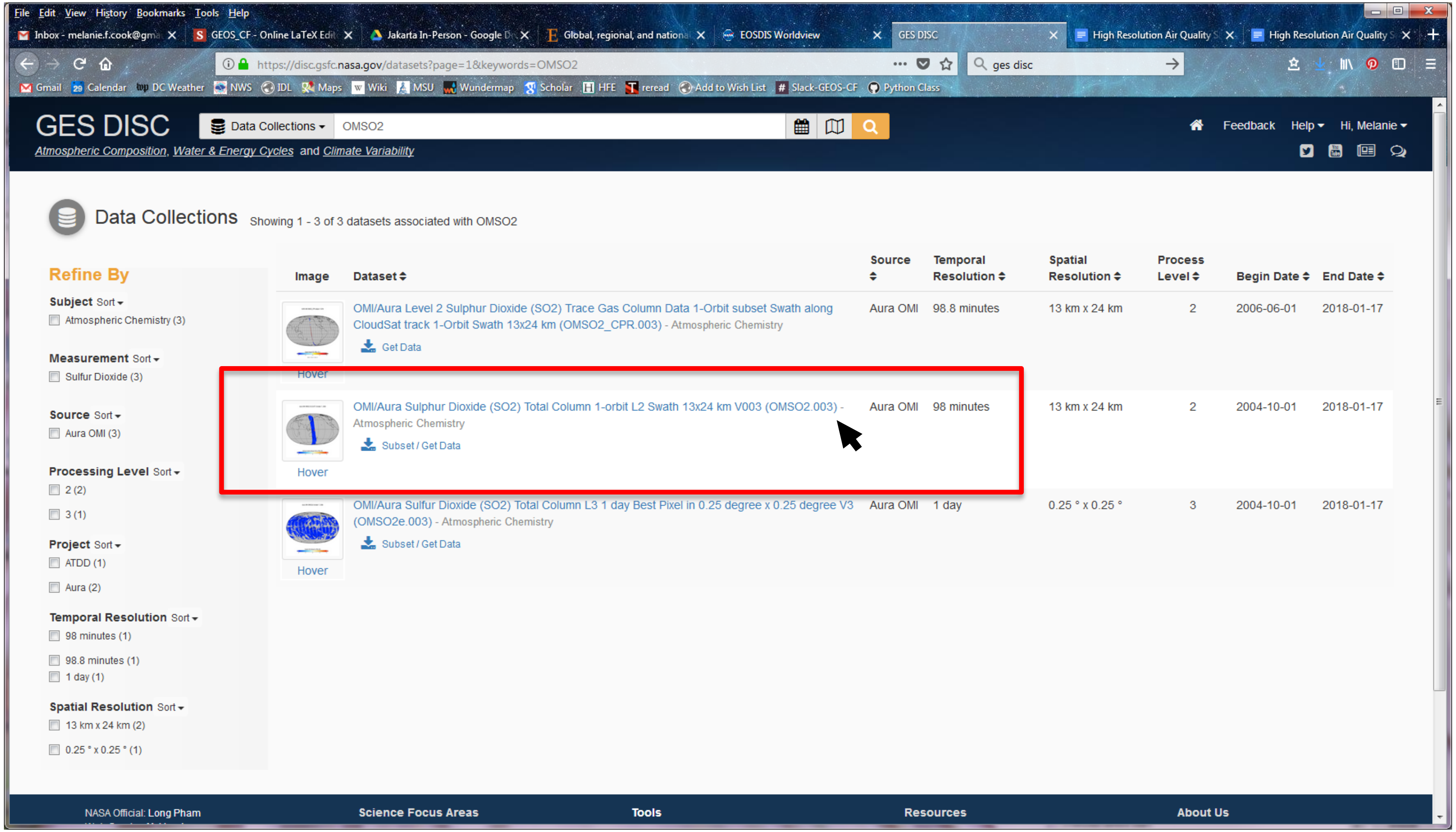
Step 3: Login at https://disc.gsfc.nasa.gov/



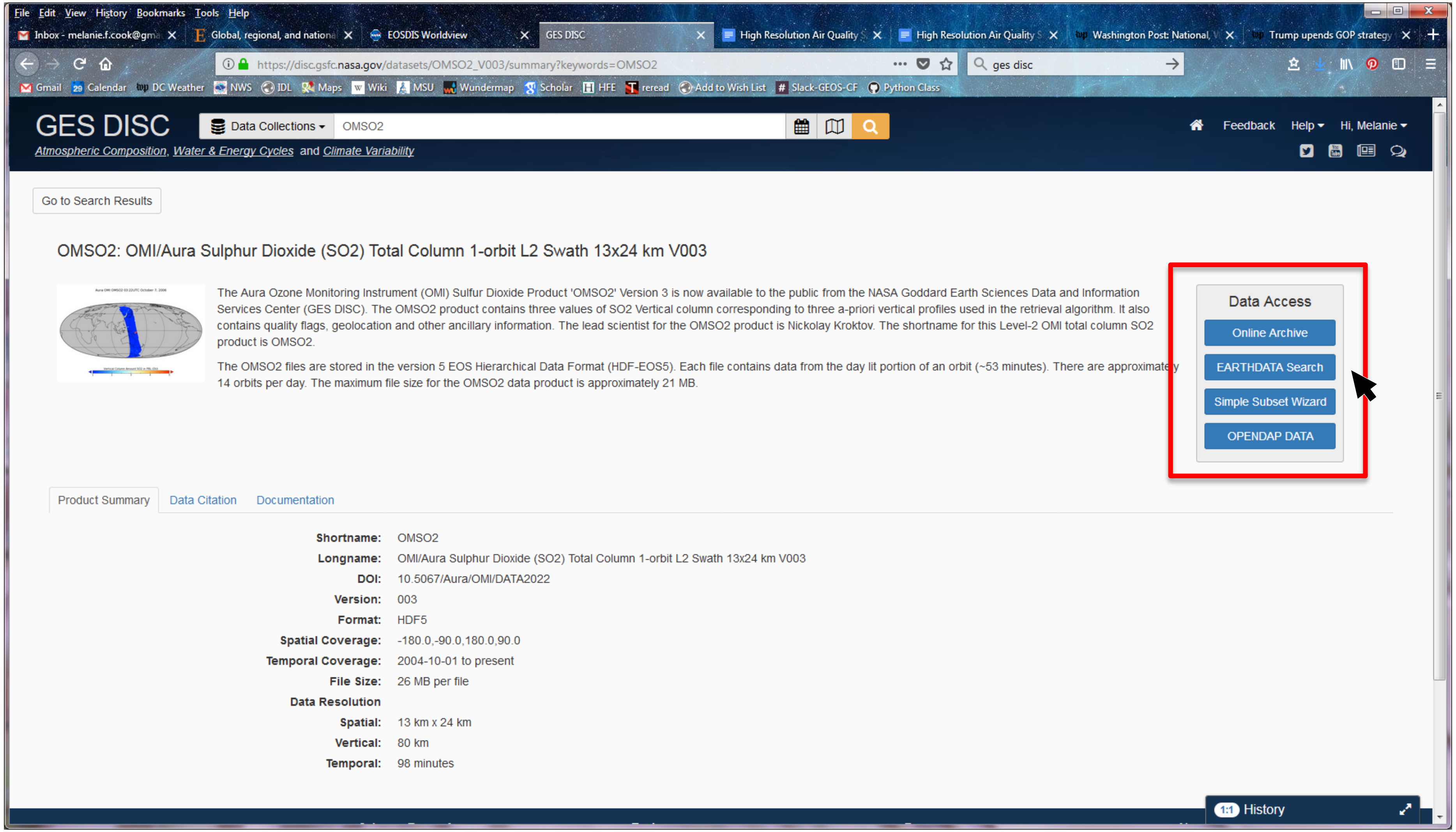
Step 4: Enter Search Keywords (e.g. $OMNO_2$ or $OMSO_2$)



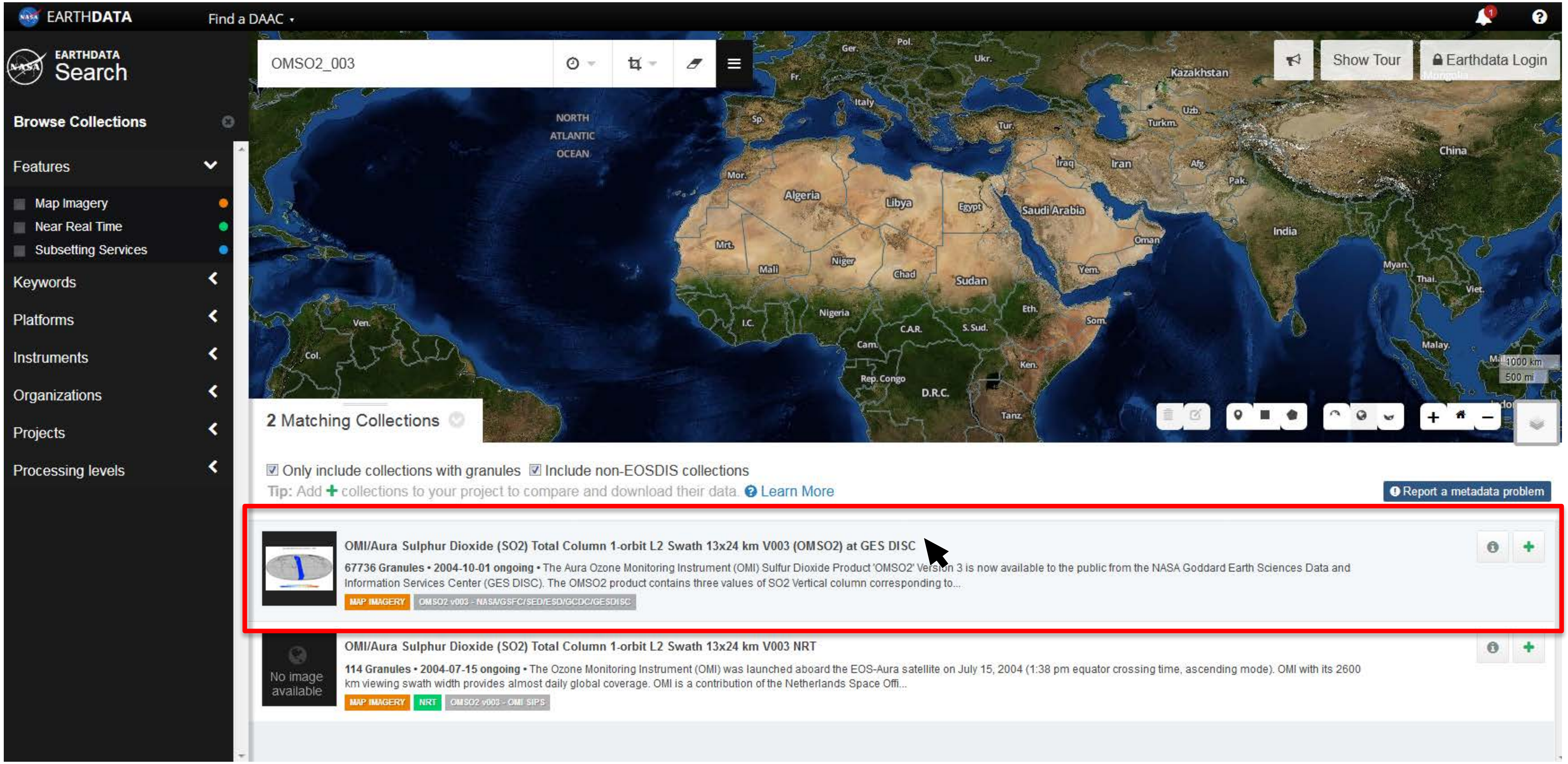
Step 5: Make a Product Selection



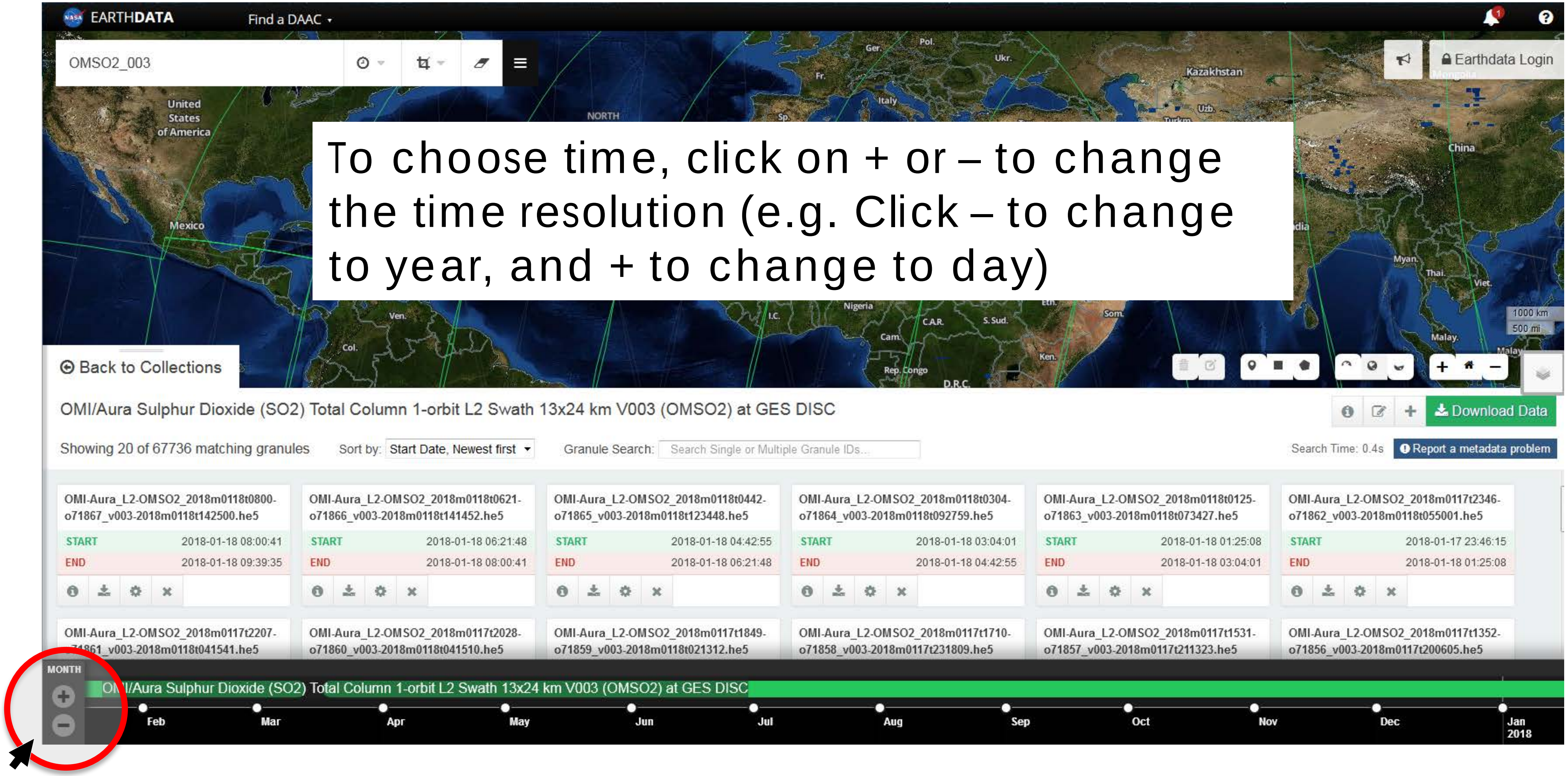
Step 6: Choose Data Access (We Will Use EARTHDATA)



Step 7: Select Product



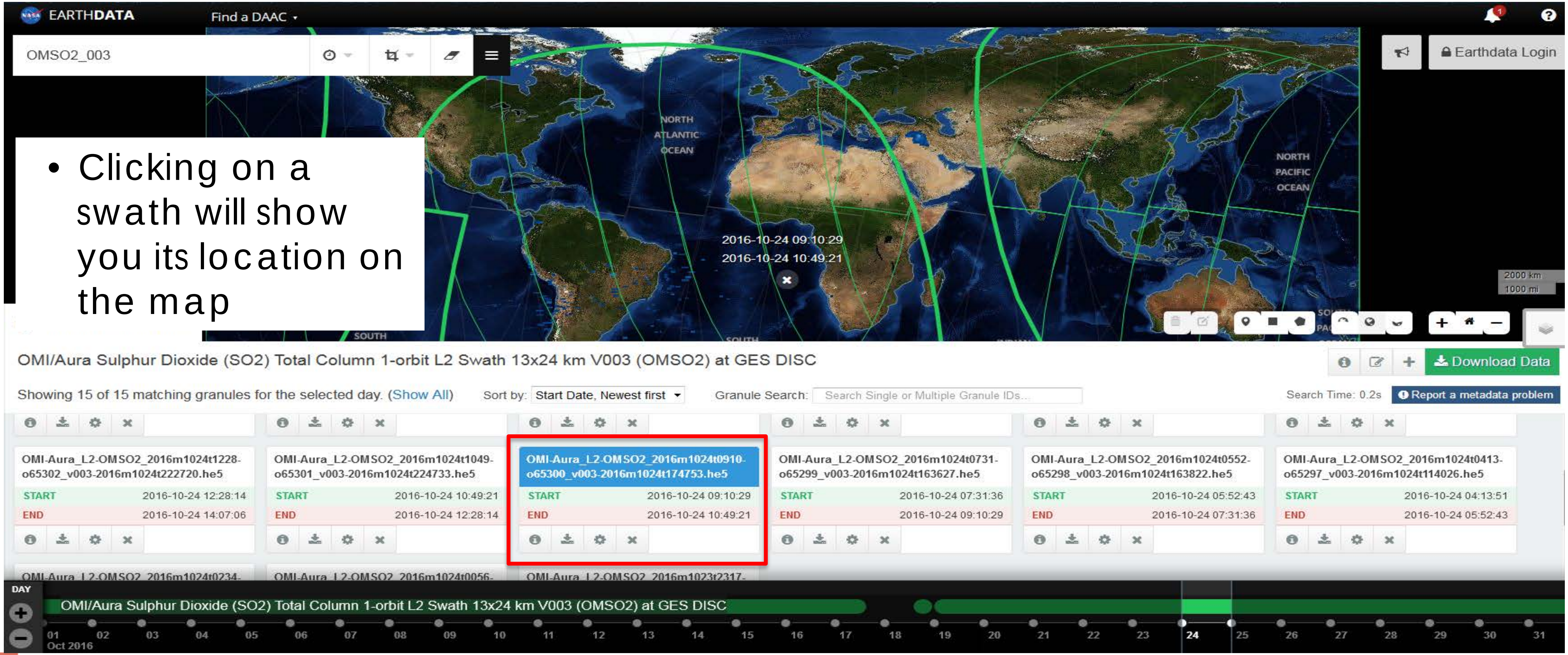
Step 8: Select Time



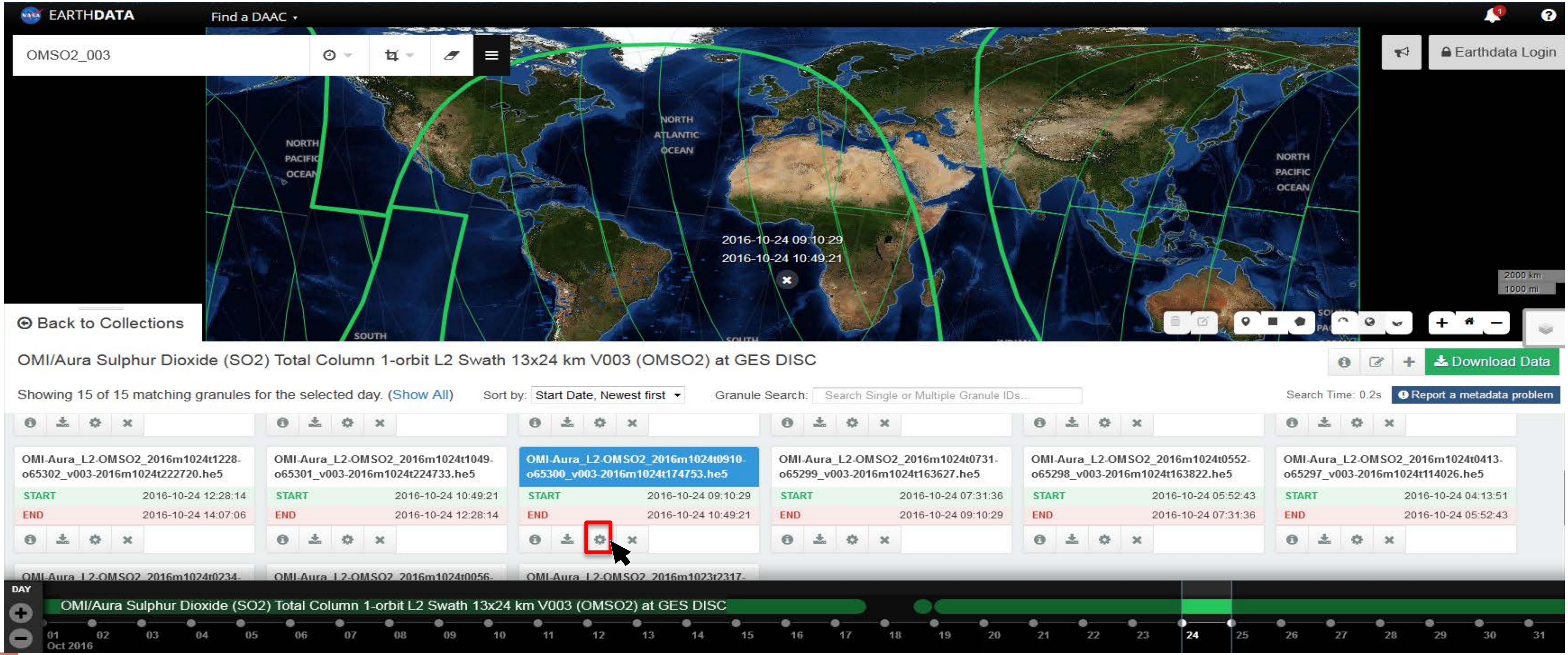
To choose time, click on + or – to change the time resolution (e.g. Click – to change to year, and + to change to day)

Step 9: Select Swath

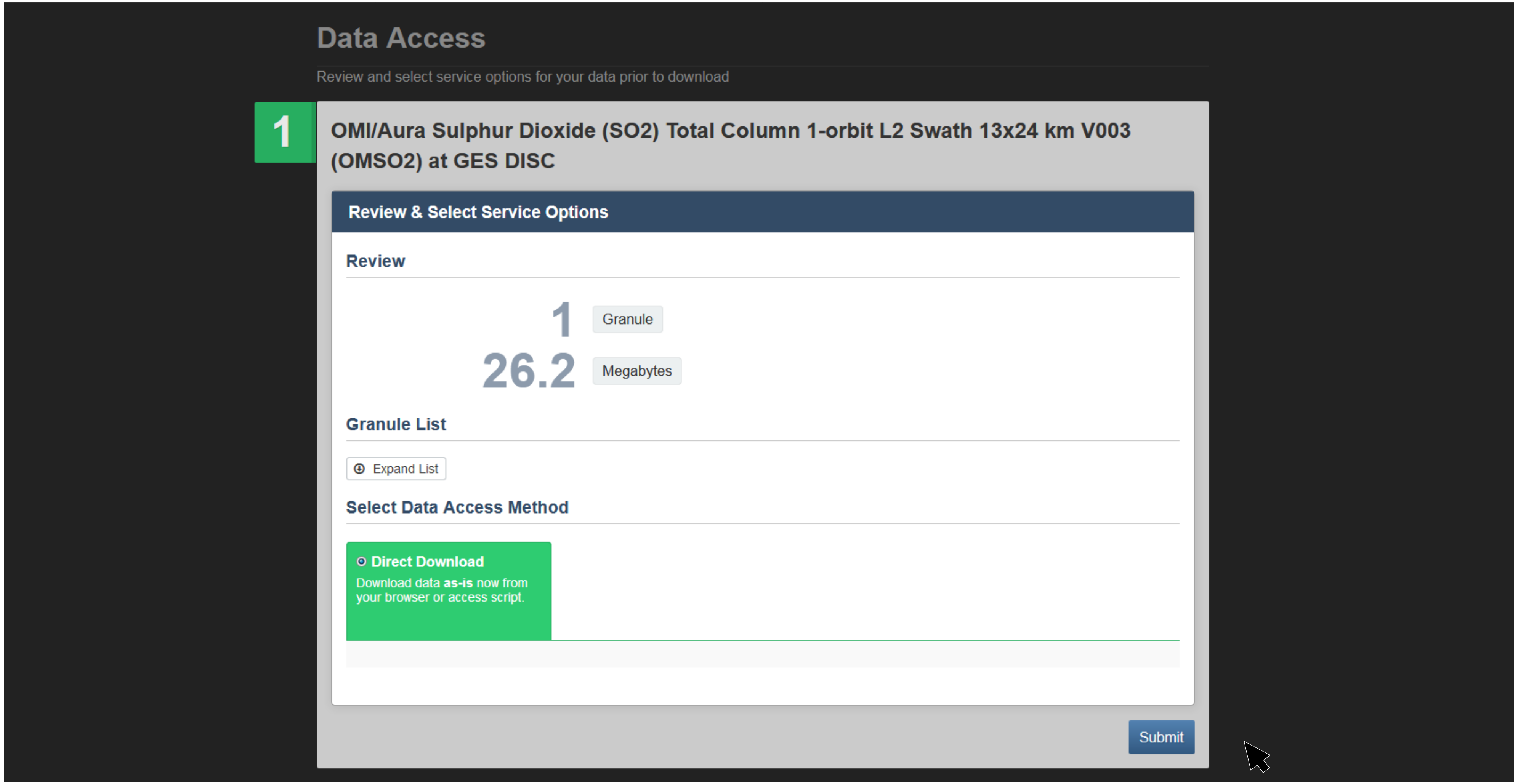
- Clicking on a swath will show you its location on the map



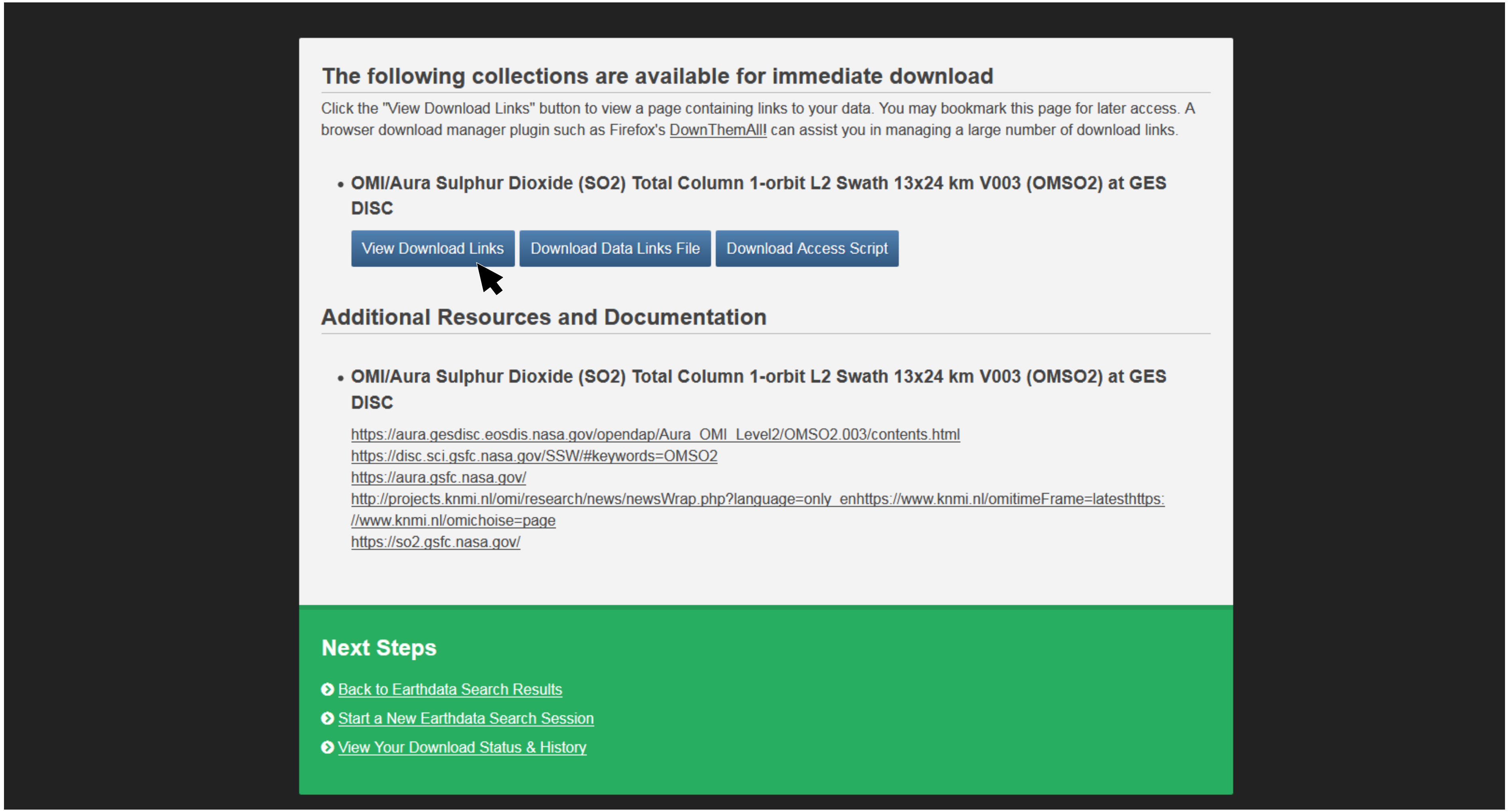
Step 10: Download Single Granule by Clicking Gear Icon



Step 11: Choose "Direct Download" and Click "Submit"



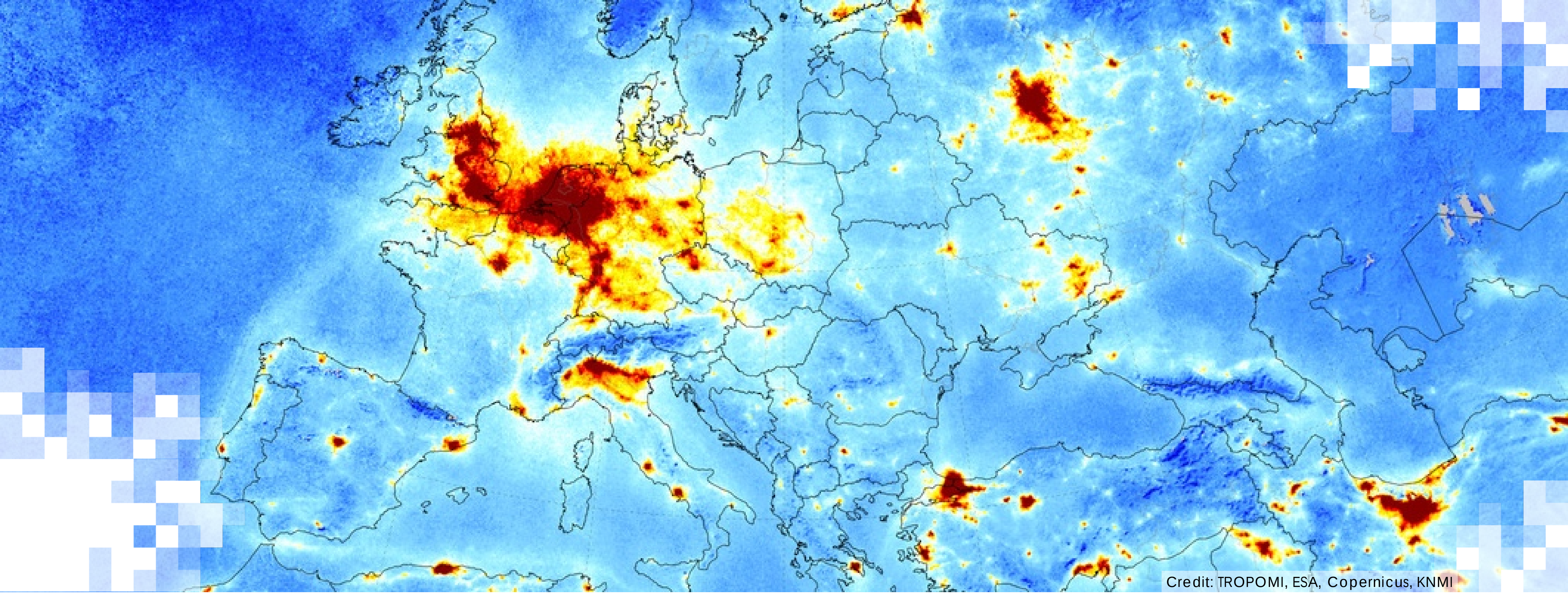
Step 12: Click “View Download Link” to Download



Step 13: Download the Data

- http://aura.gesdisc.eosdis.nasa.gov/data//Aura_OMI_Level2/OMSO2.003/2016/298/OMI-Aura_L2-OMSO2_2016m1024t0910-o65300_v003-2016m1024t174753.he5

Click on the provided link and save the data in your directory where you will run your python scripts

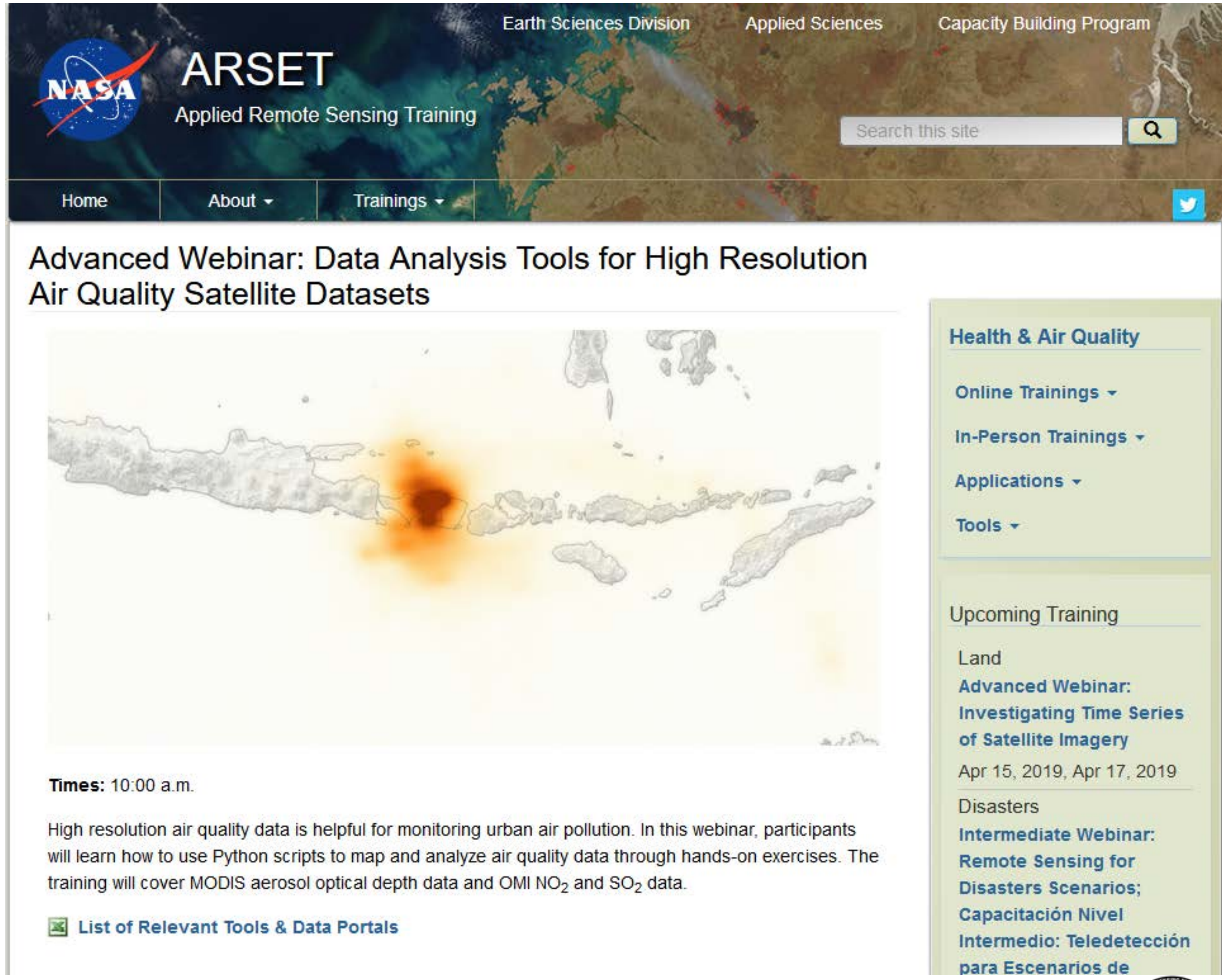


Python Tools

ARSET Advanced Webinar

https://arset.gsfc.nasa.gov/airquality/webinars/2018-hiresdatasets

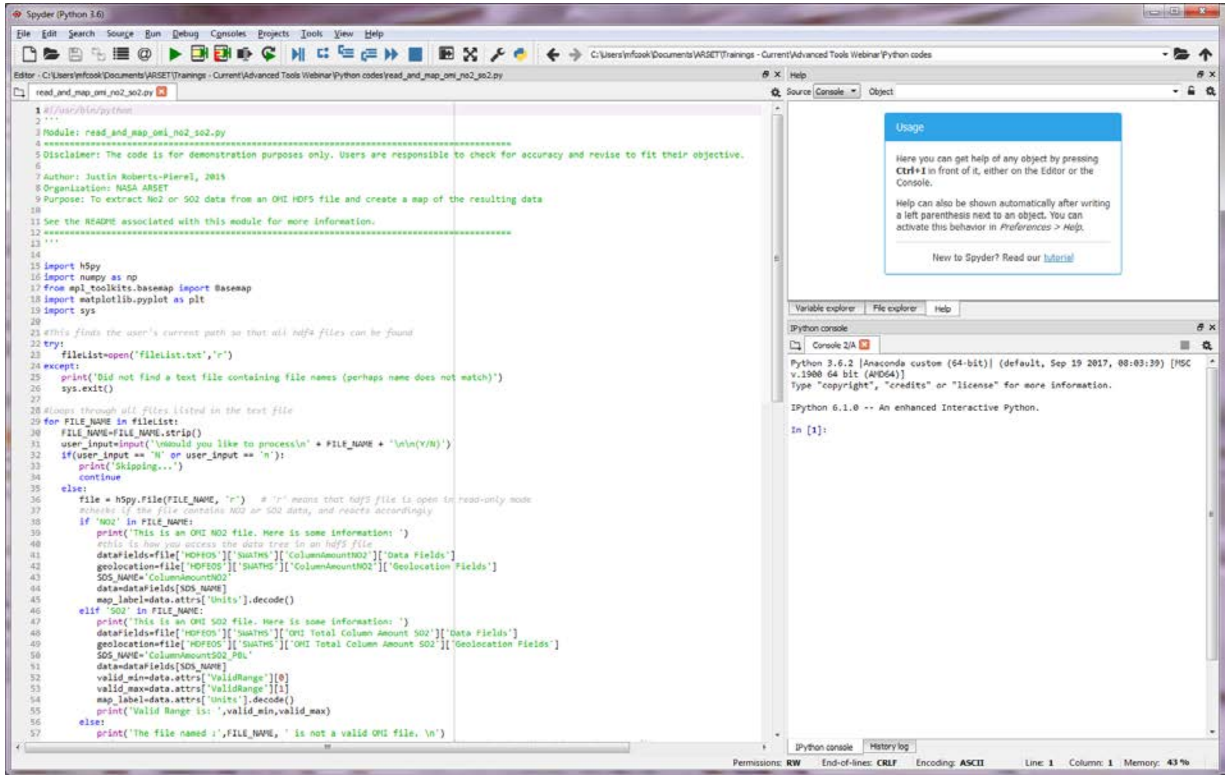
- This previous online training guided users through
  - Using available Python scripts to read, map, and analyze Level-2 data (OMI NO_2 and SO_2 and MODIS)
  - Modifying available scripts for future use
- All past webinar recordings, presentations, and Q&A transcripts are available for download



ARSET Advanced Webinar

https://arset.gsfc.nasa.gov/airquality/webinars/2018-hiresdatasets

- Example scripts:
  - Prints contents of HDF files
  - Plot and save a map
  - Extract data at a single point (e.g. the location of a ground station)
  - Extract variables to a text (.csv) file



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OMI NO_2 V3 paper:

Krotkov, N. A., et al. (2017), The version 3 OMI NO_2 standard product, Atmos. Meas. Tech., 10, 3133-3149, https://doi.org/10.5194/amt-10-3133-2017.