

Credit: TROPOMI, ESA, Copernicus, KNMI

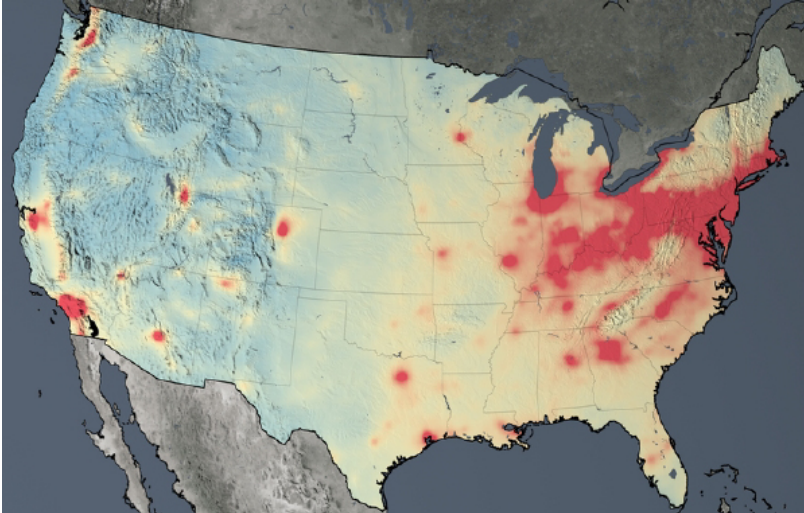


Remote Sensing of NO₂, OMI Data Products, and Tools

Melanie Follette-Cook, Pawan Gupta

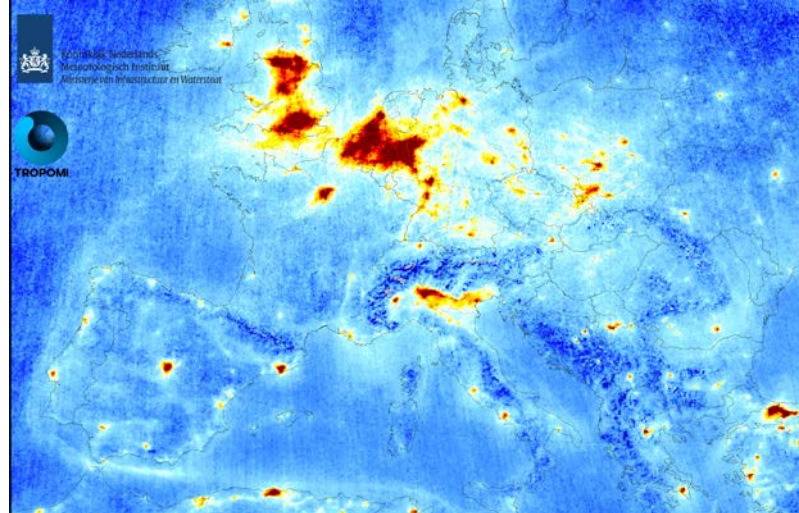
Webinar Agenda

Session 1



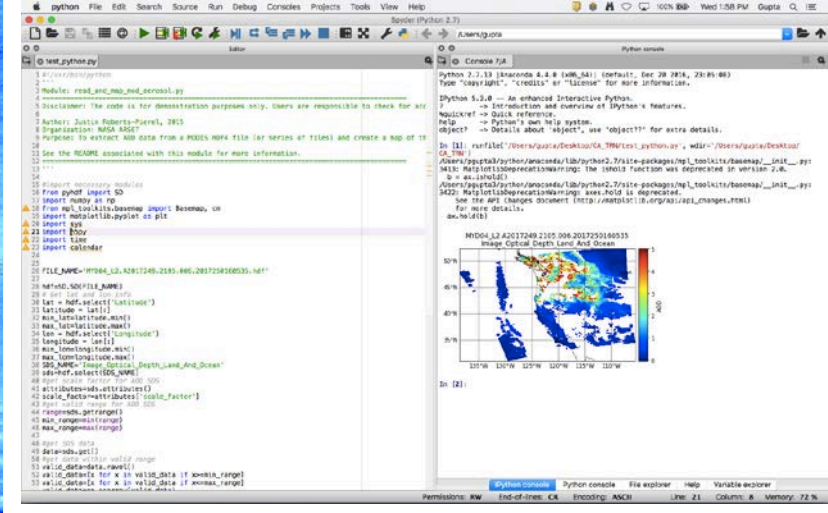
Remote sensing of NO₂, OMI Data Products, and Tools

Session 2



Introducing TROPOMI - High Resolution NO₂ Observations from Space

Session 3



Python Tools - TROPOMI

Session 2 Image Credit: [TROPOMI](#)

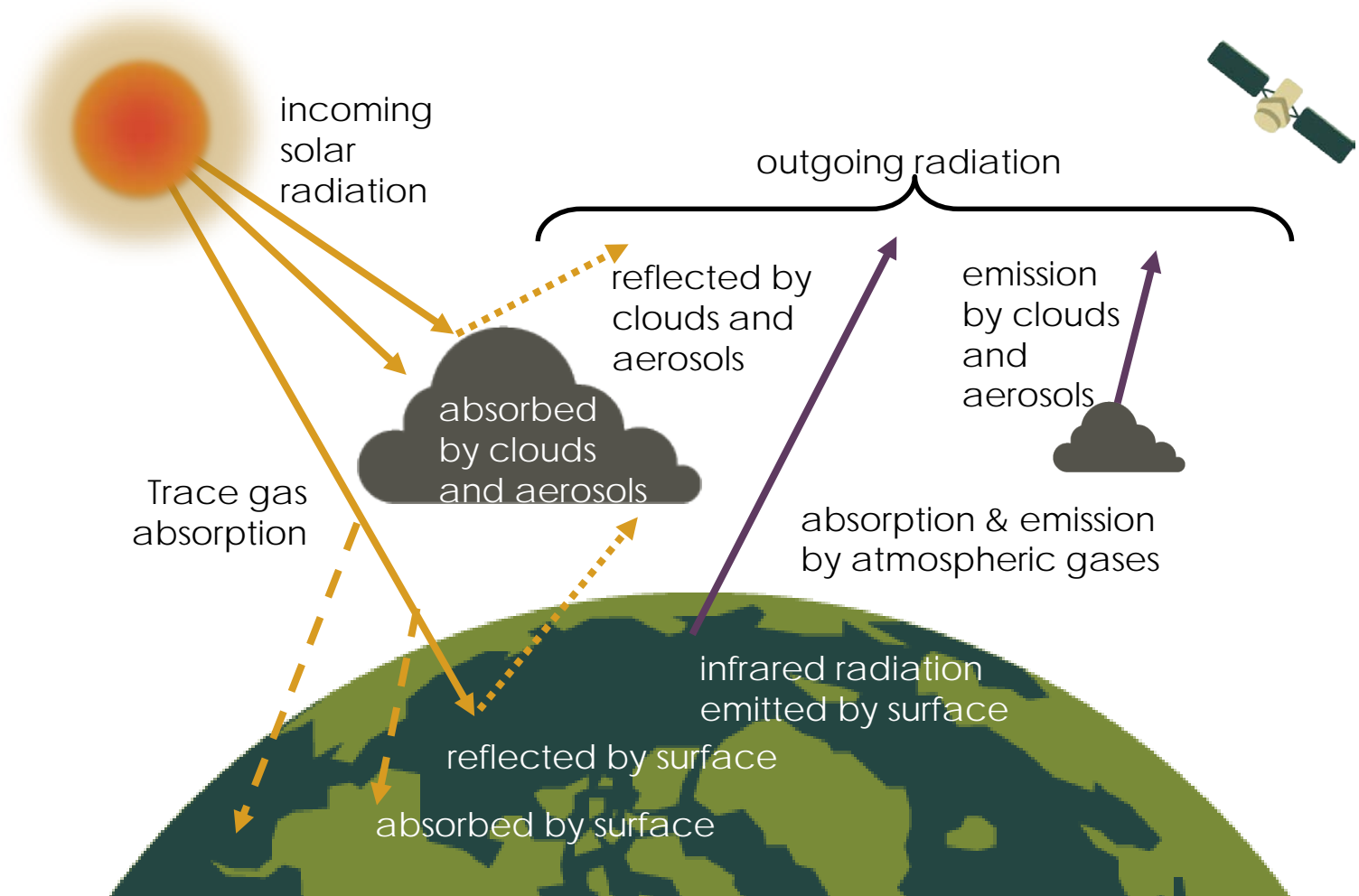
Learning Objectives

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

- Describe existing satellite capabilities for global NO₂ observations
- Describe the current NO₂ data products available from the Ozone Monitoring Instrument (OMI)
- Identify various air quality monitoring applications utilizing OMI NO₂ observations
- Perform a data download of OMI and/or TROPOMI data

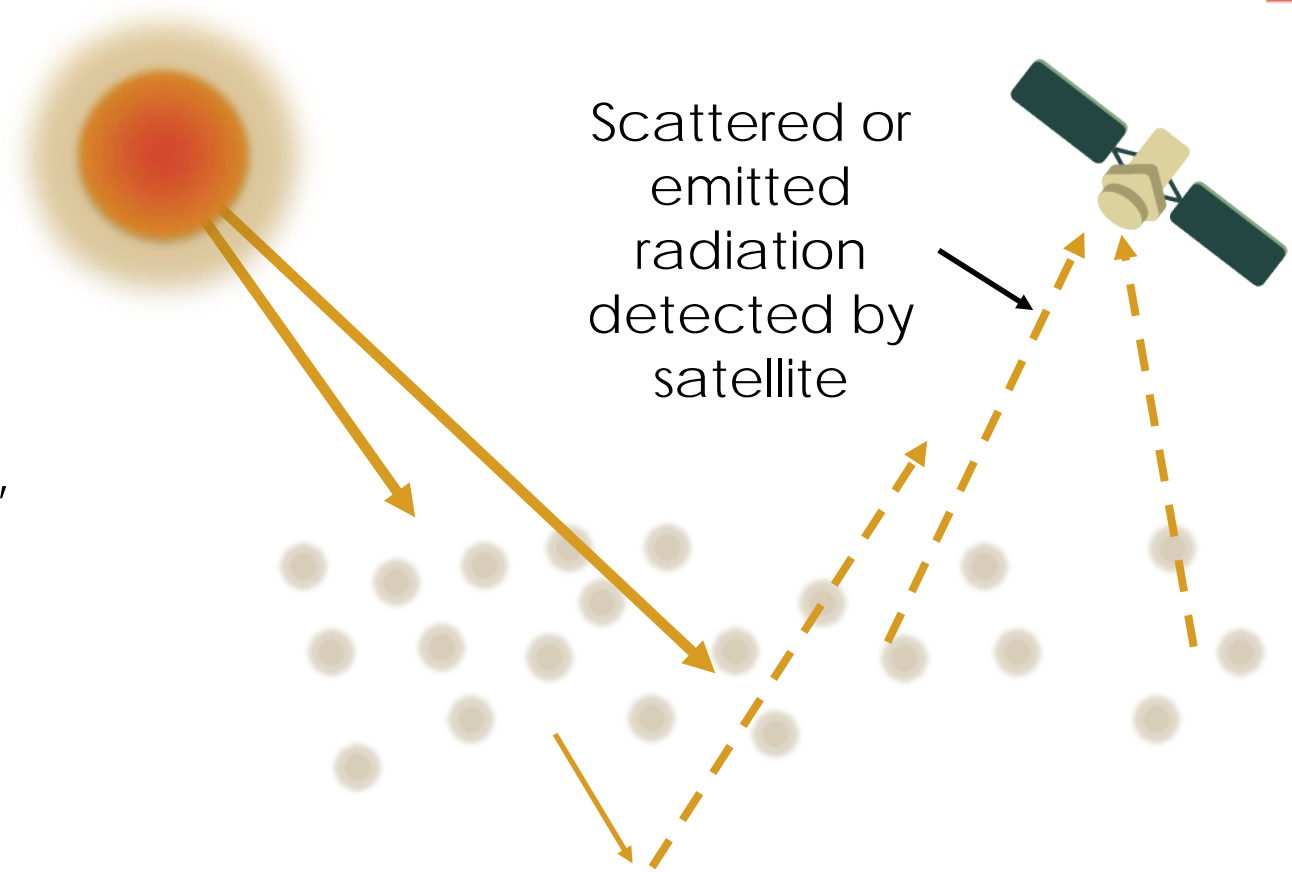
What do Satellites Measure?

- 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

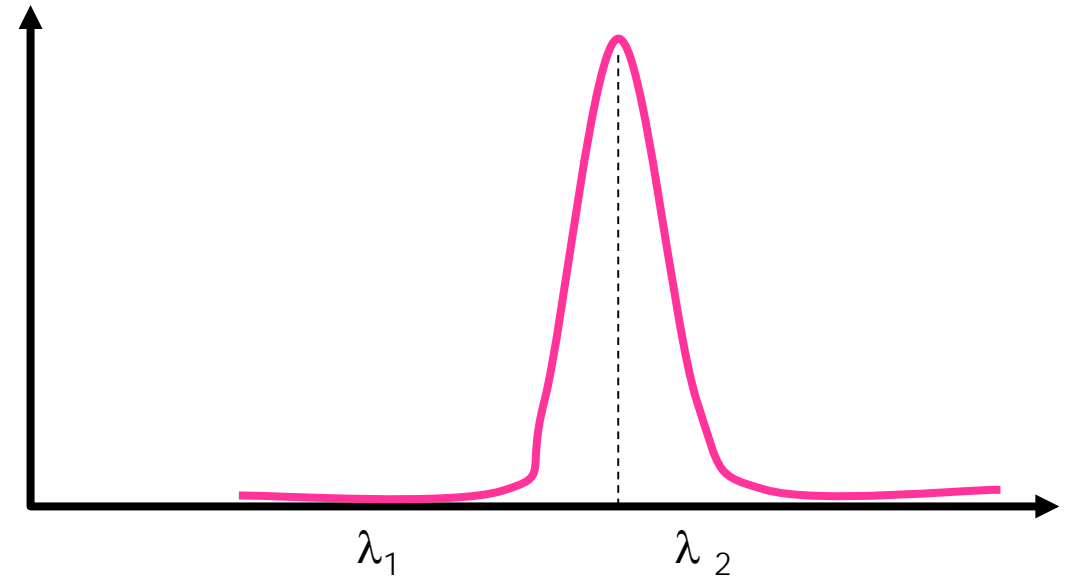


- One fingerprint on a drink can allow the owner to be identified
- If a lot of people touch the drink can, it can be very difficult to identify any one person. This is the case for trace gases as spectral signatures often overlap.

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

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

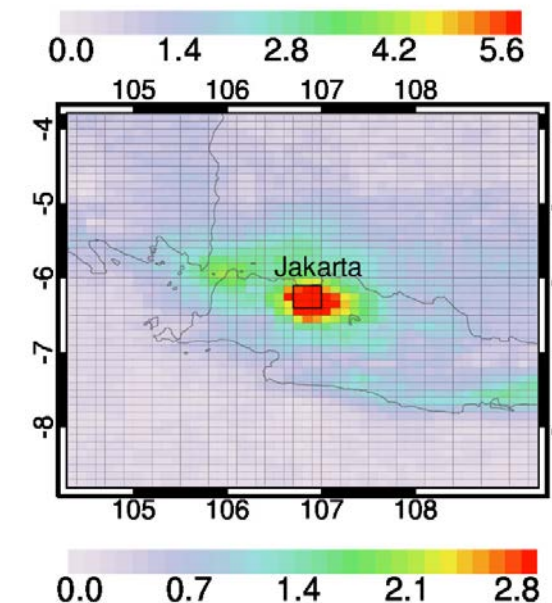
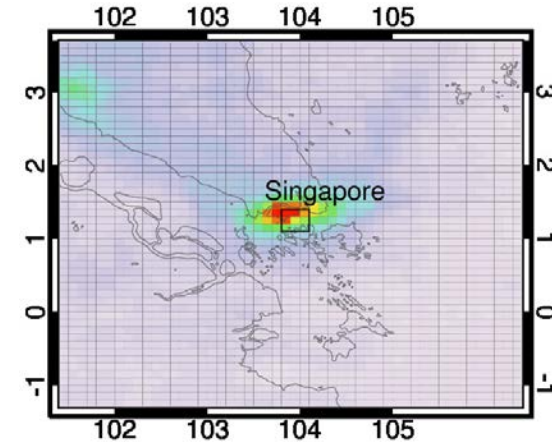
- Two wavelengths (λ) are used in retrievals
 - λ_1 is NOT absorbed by trace gas
 - λ_2 is absorbed by trace gas



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:
 - NO₂ is short-lived and primarily emitted from fossil fuel combustion (e.g., cars, power plants), so most NO₂ is found near the surface

OMI NO₂ (x10¹⁵ molec/cm²)



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

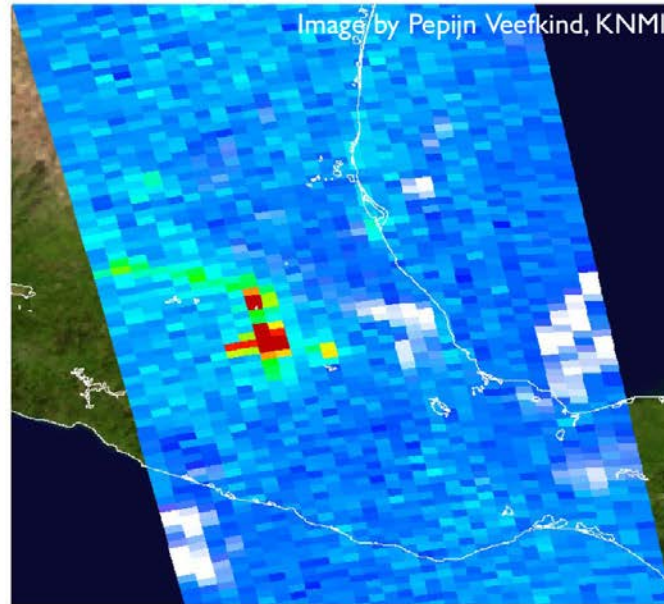
Spatial Resolution: Trace Gases

- 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

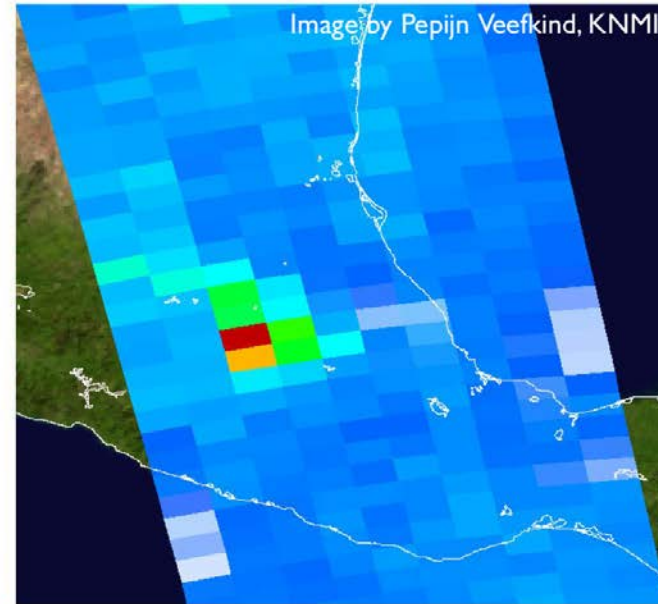
Perspective...



Spatial Resolution



OMI 24x13 km²



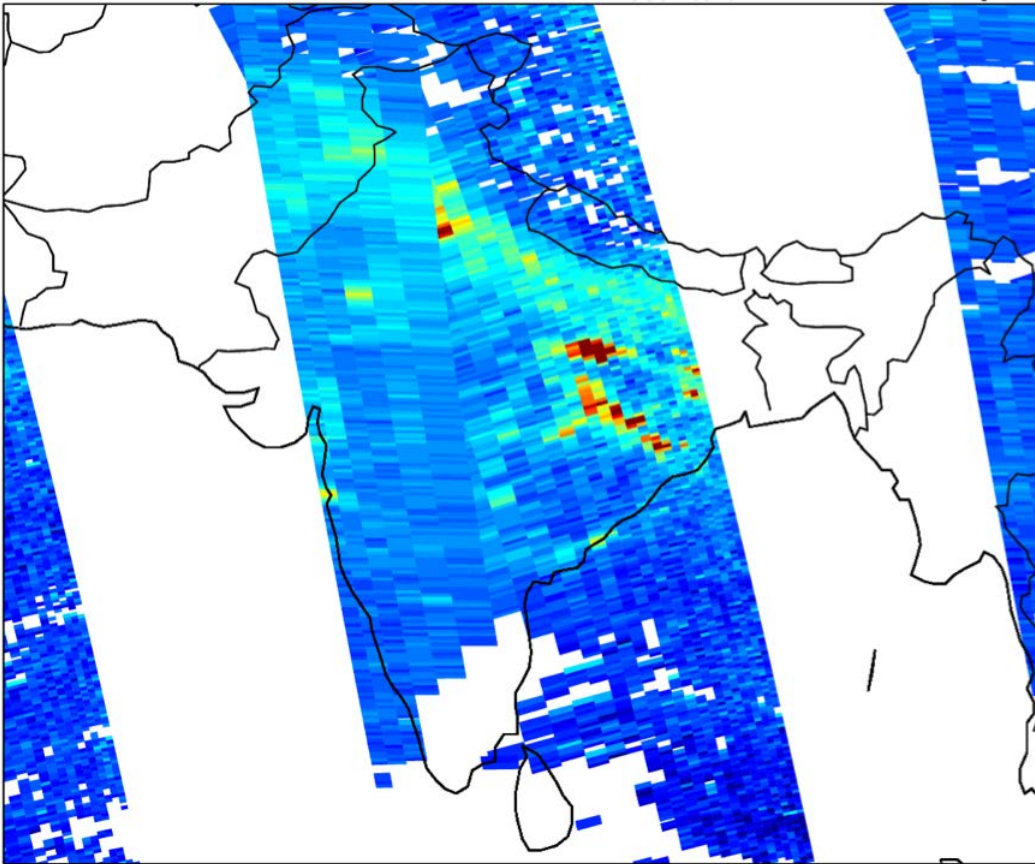
Approx. GOME-2 72x39 km²

Mexico City, Jan. 20, 2005

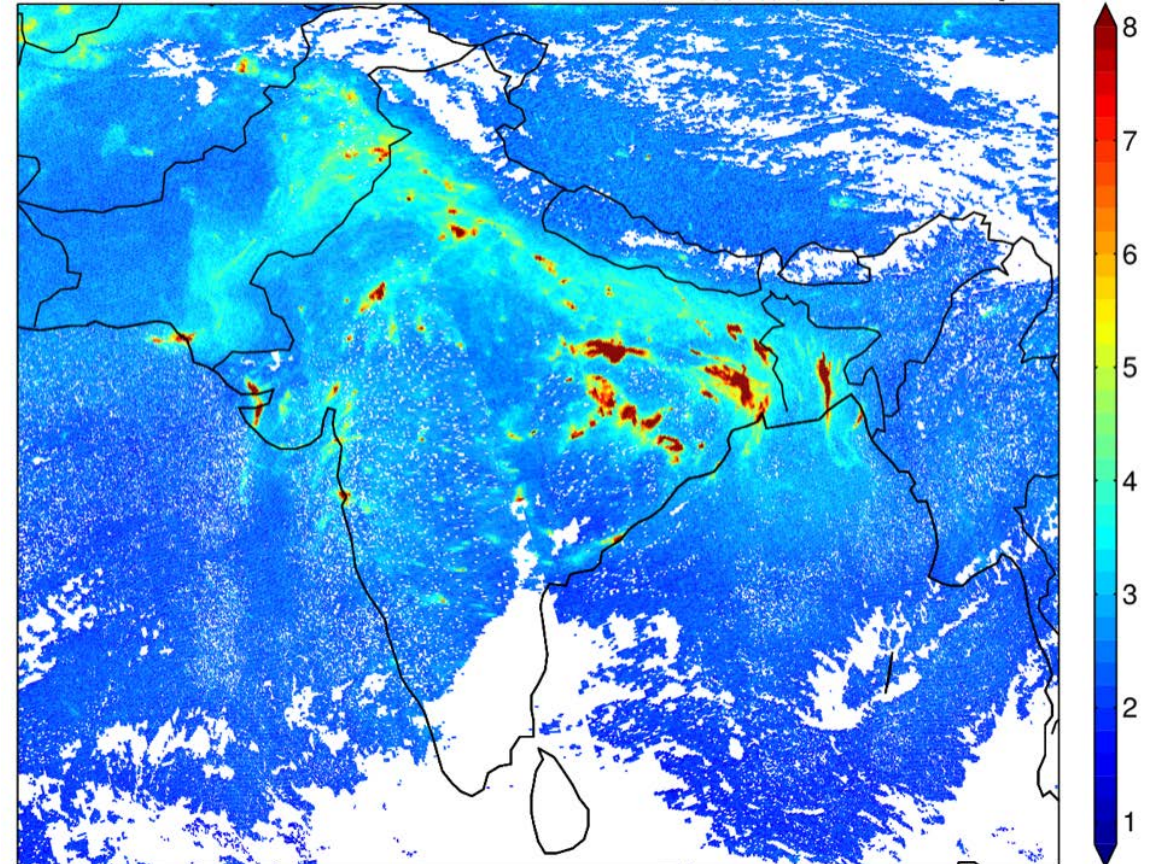
TROPOMI: Impact of Resolution

November 28, 2017

OMI NO₂



TROPOMI NO₂



Spatial Resolution = 3.5 x 7.0 km²

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

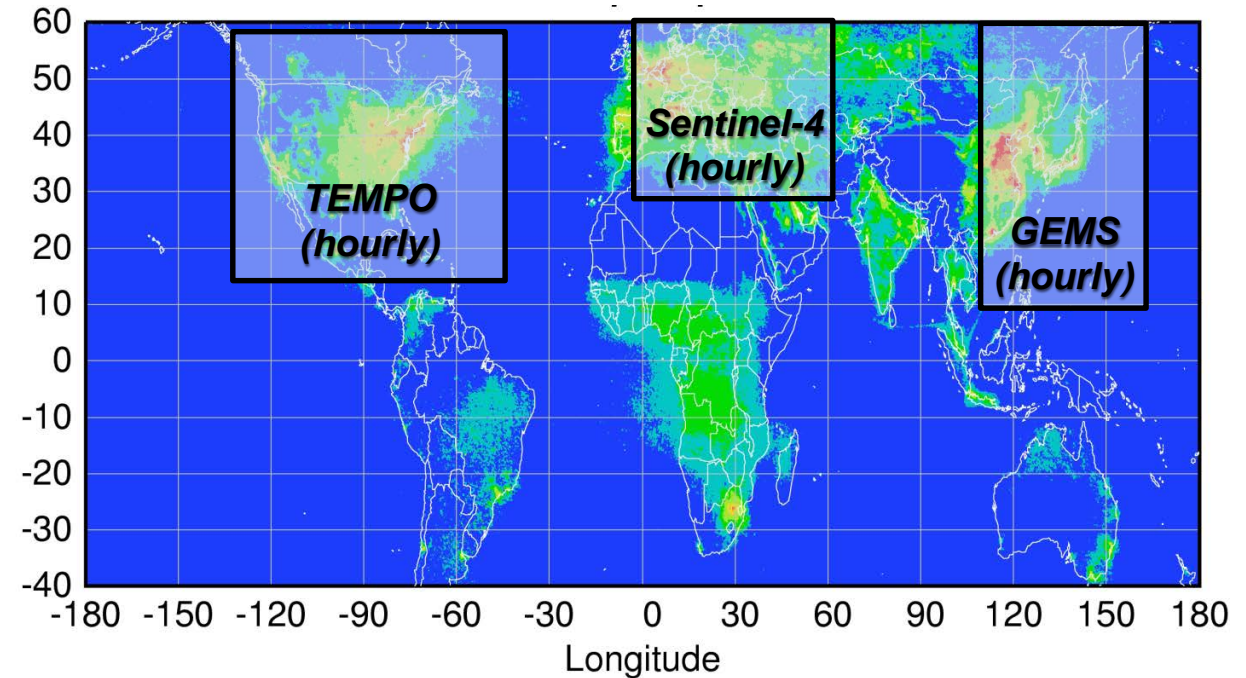
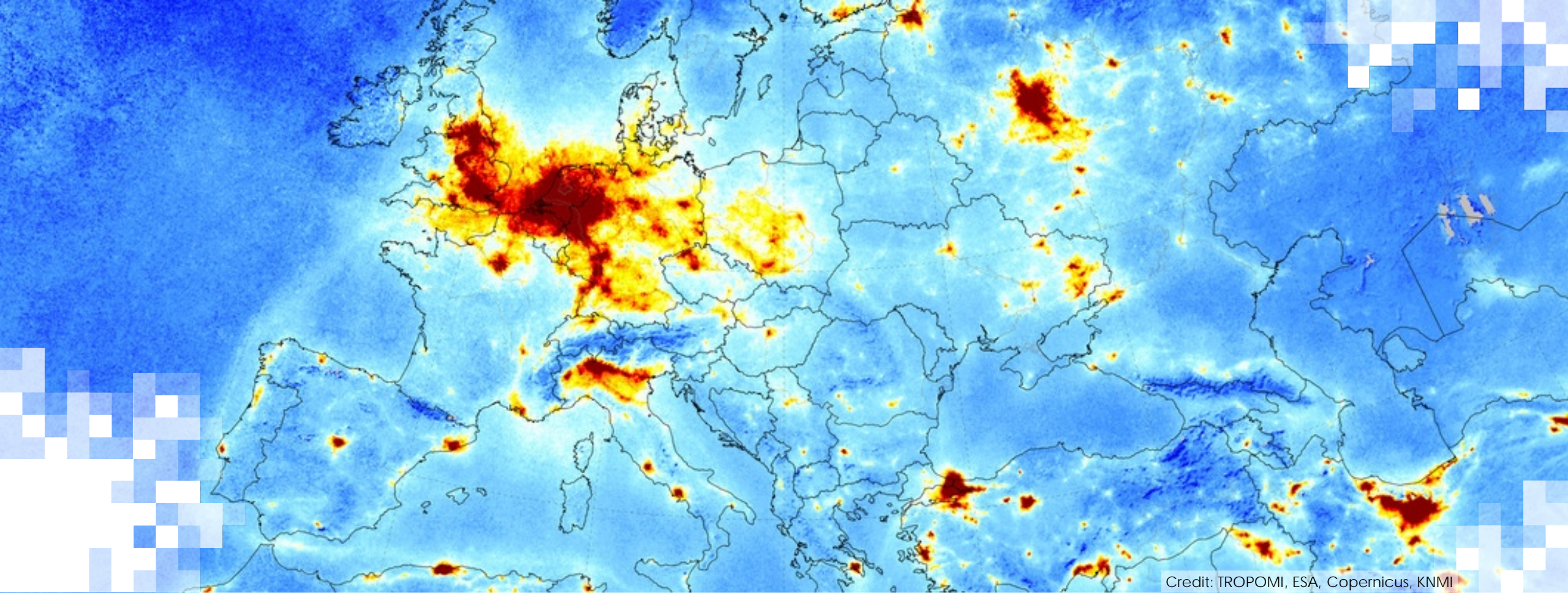


Image Credit: Courtesy Jhoon Kim, Andreas Richter

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Credit: TROPOMI, ESA, Copernicus, KNMI

OMI

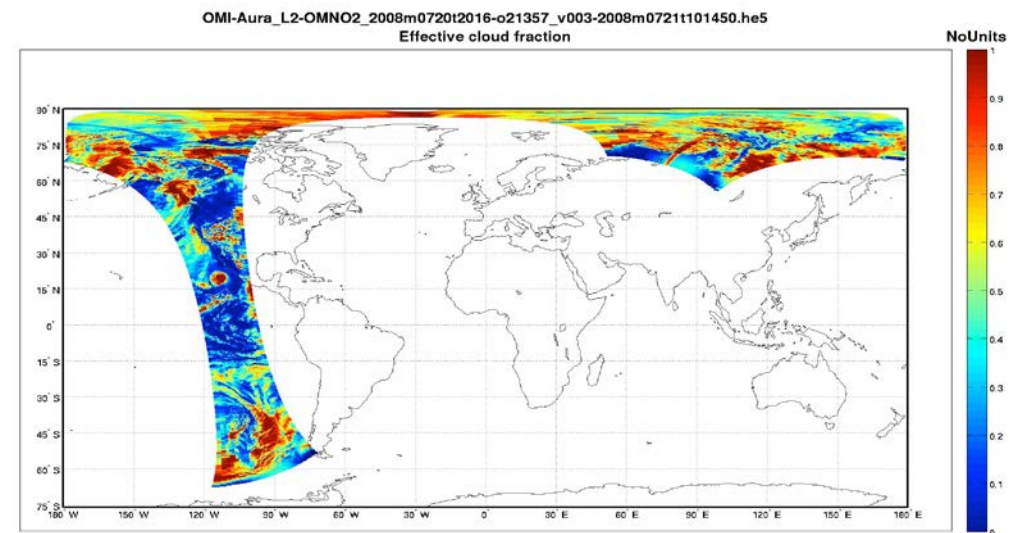
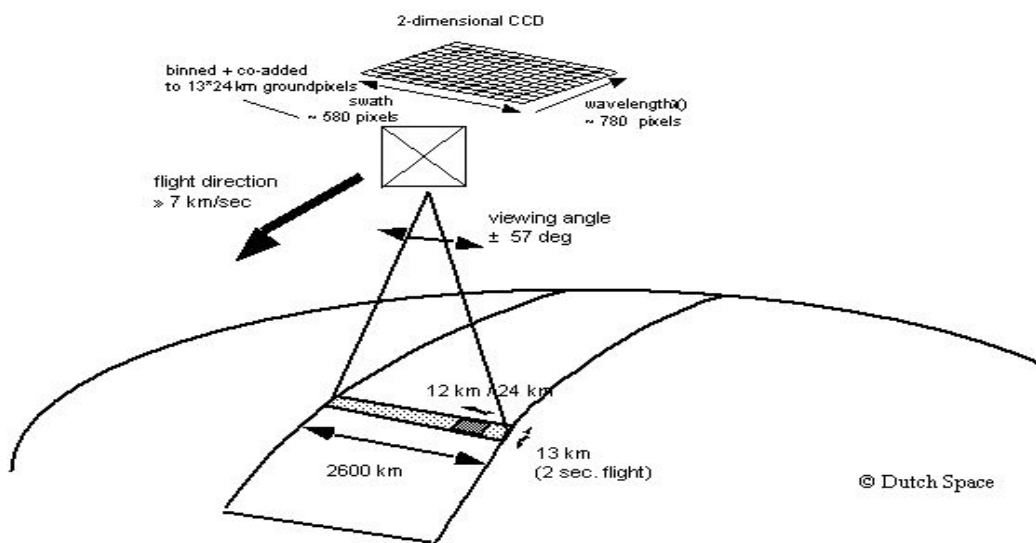
Ozone Monitoring Instrument (OMI)

- 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 km² at nadir
 - Daily global coverage
- Products
 - Total Column O₃
 - Tropospheric Column O₃
 - Aerosol optical depth (in UV)
 - Column Formaldehyde
 - Column NO₂
 - Tropospheric column NO₂
 - Column SO₂



Data Granule

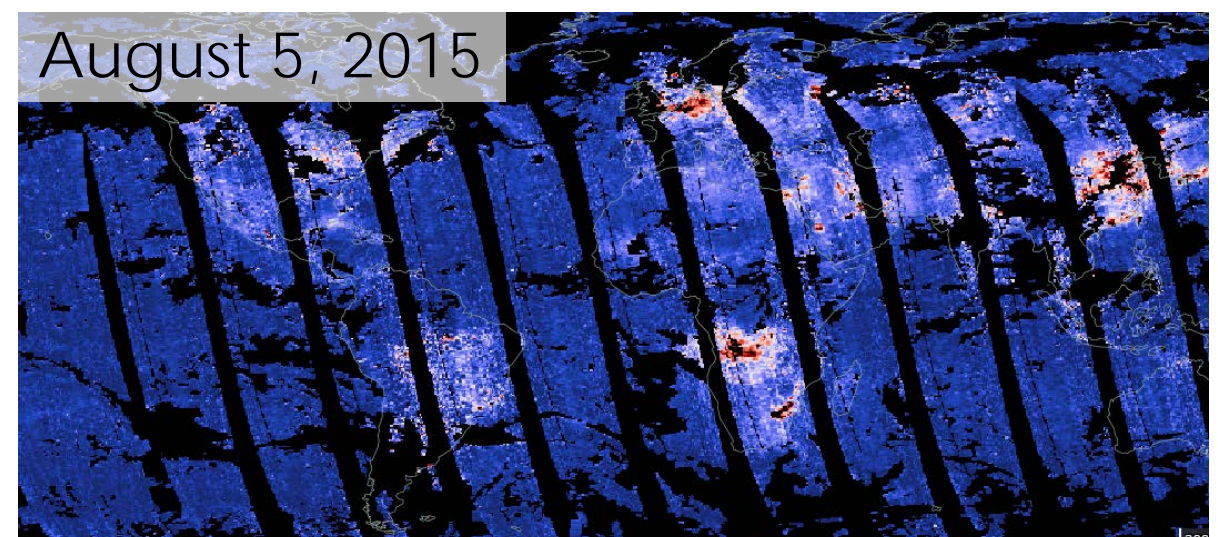
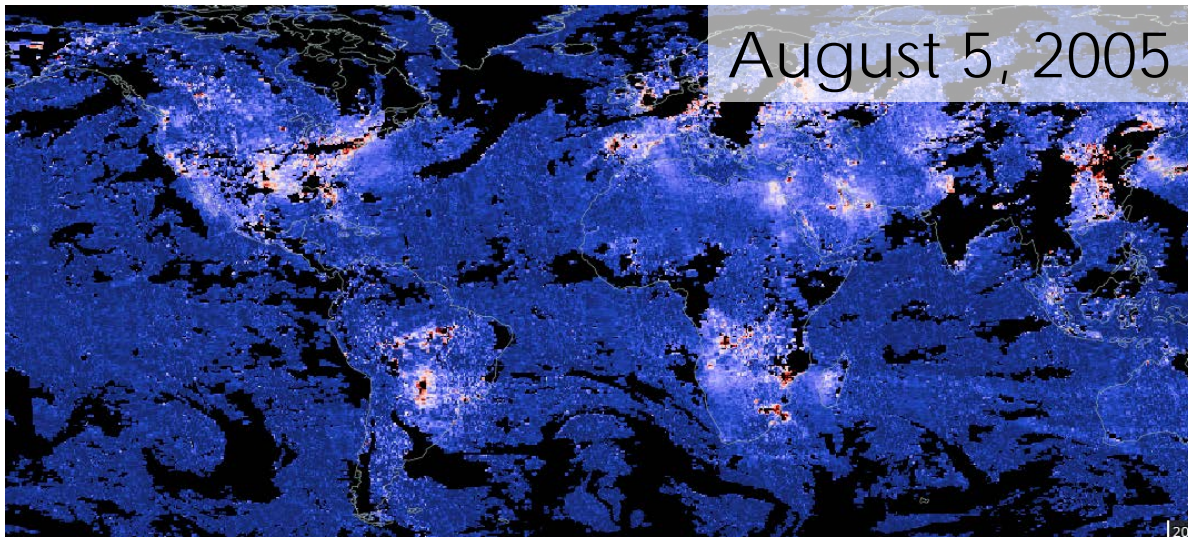
- Product File
 - covers sunlit portion of the orbit with an approx. 2,600 km wide swath
 - contains 60 binned pixels or scenes per viewing line
- 14 or 15 granules are produced daily, providing fully contiguous coverage of the globe



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 NO₂



Nitrogen Dioxide (NO₂)

- Why measure NO₂?
 - NO₂ 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)

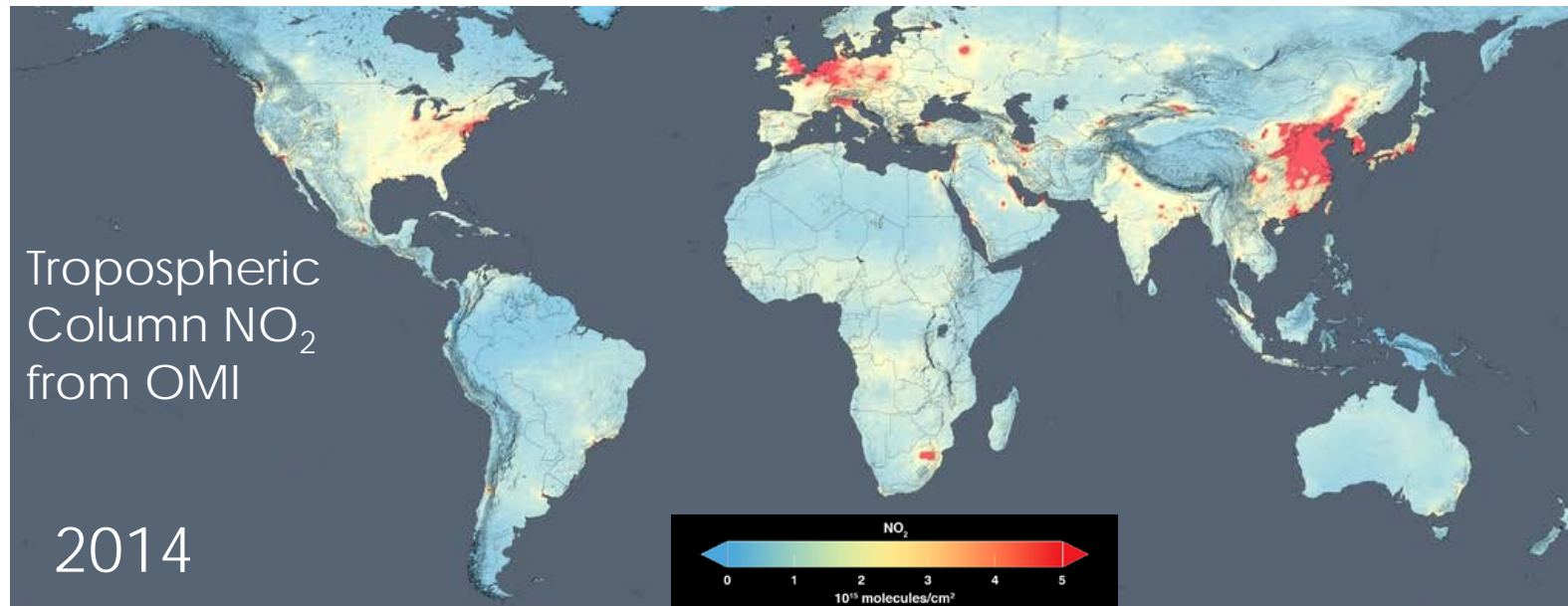
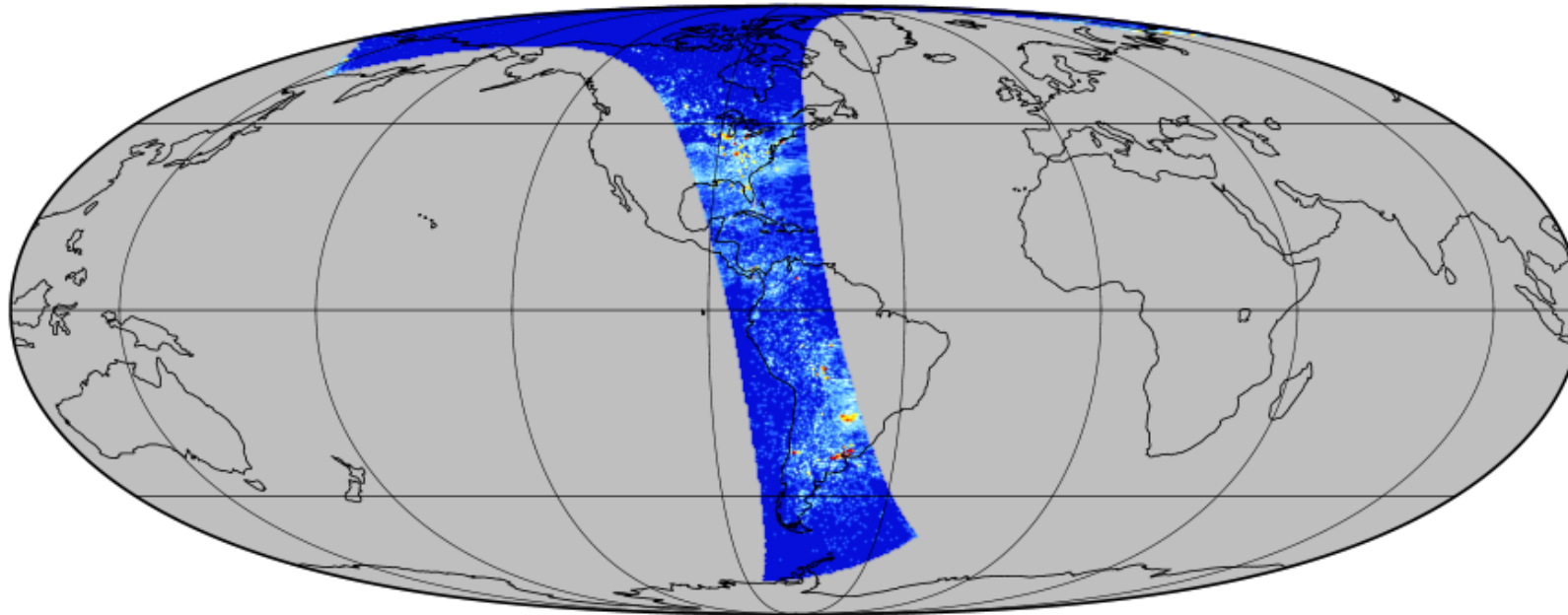


Image Credit: [NASA SVS](#)

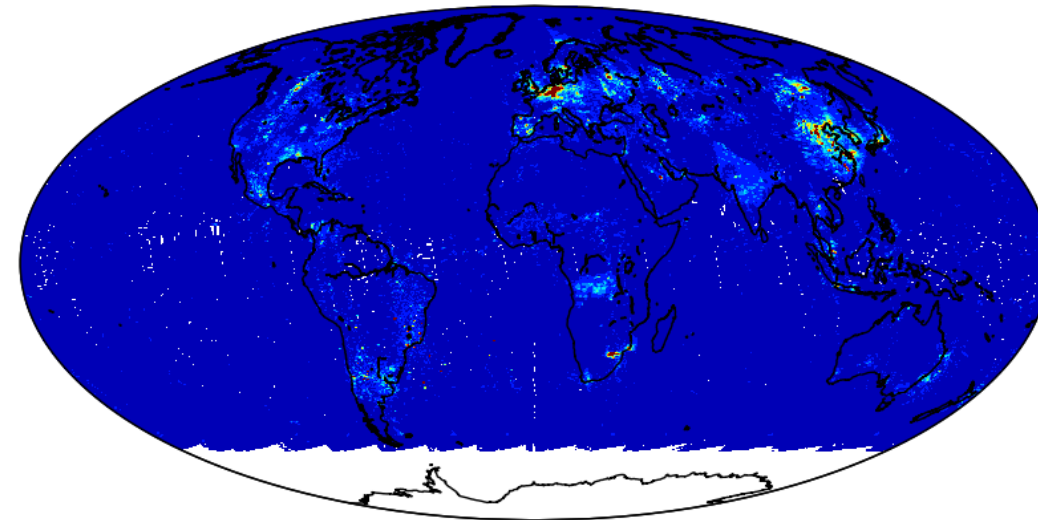
OMNO₂ Level 2 Product – Native Resolution

Aura OMI OMNO2 (17:53UTC August 8, 2006)



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

Aura OMI OMNO2G May 29, 2006

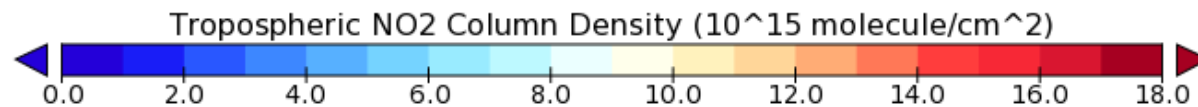
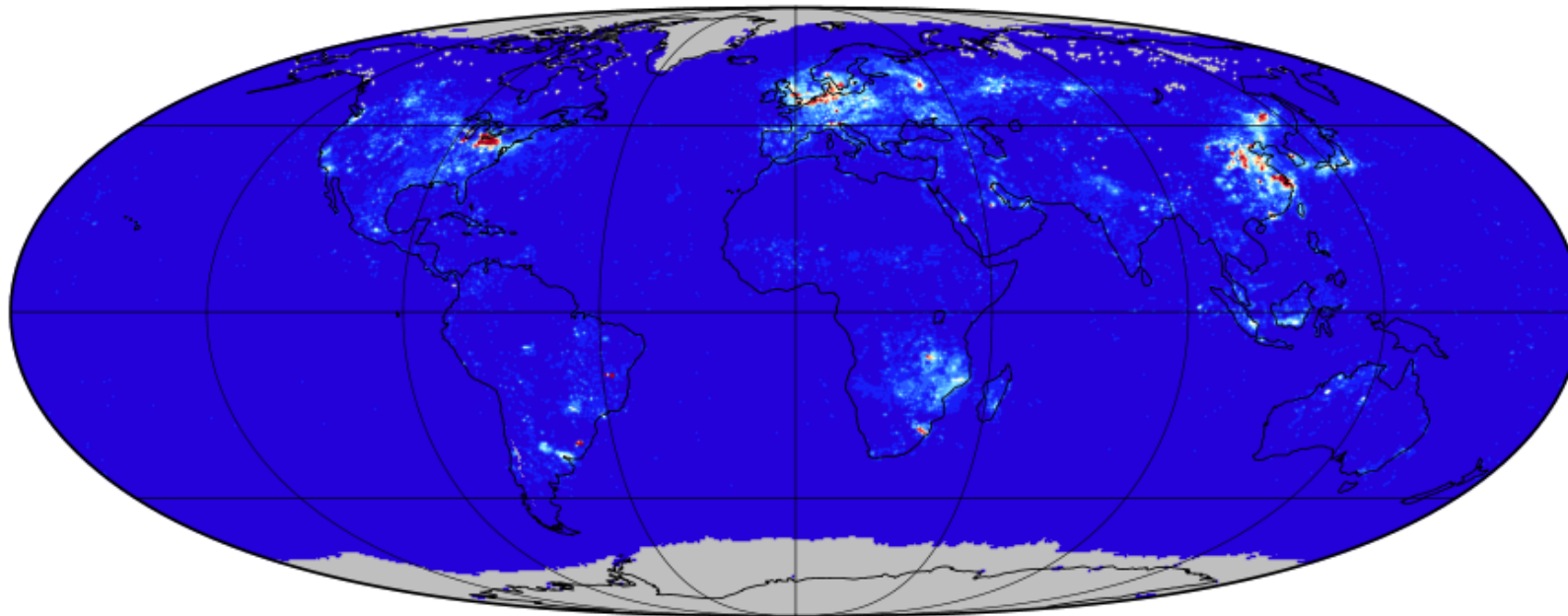


Column NO2 Amount in Troposphere 10^{15} (cm⁻²)



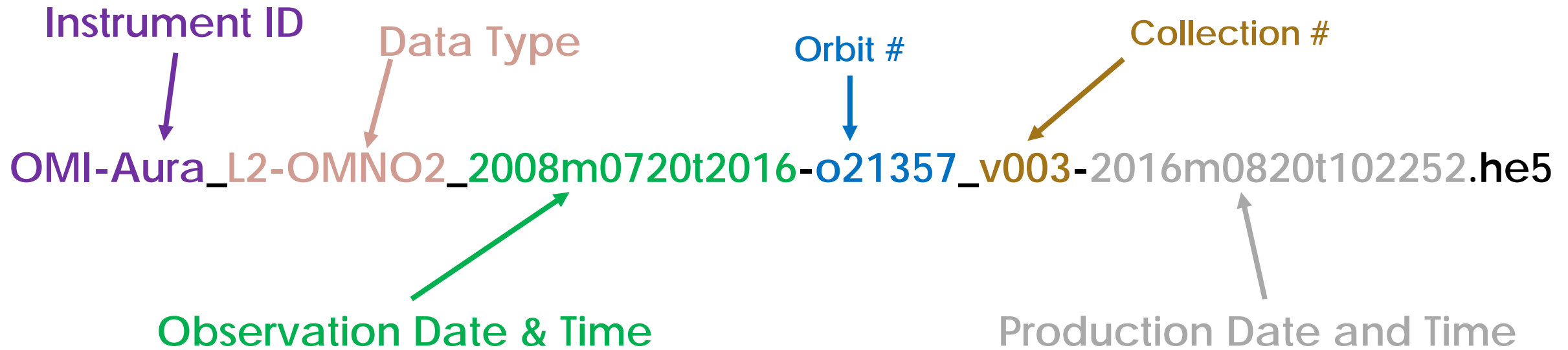
OMNO2d L3 Gridded Product (0.25° x 0.25°) – Pixel Averaging

Aura OMI OMNO2d October 2, 2006



Understanding an OMI File Name

OMNO2, OMSO2



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

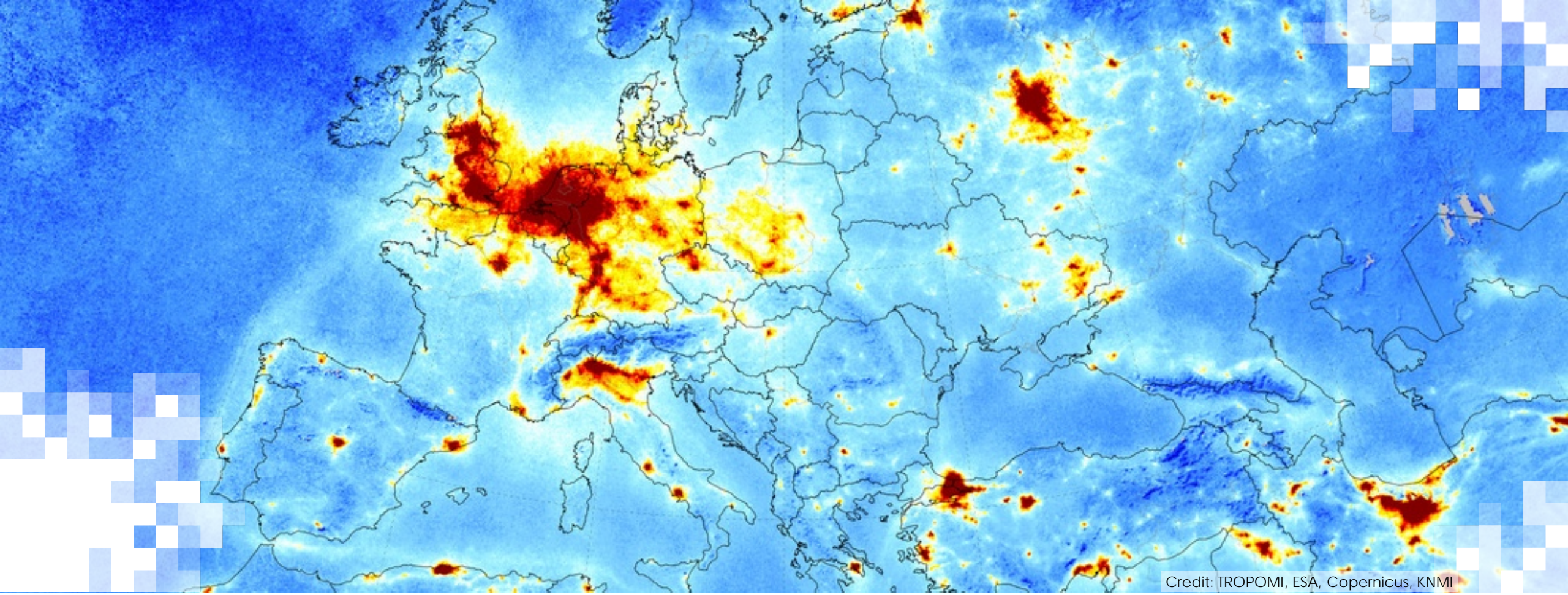
OMI NO₂ Parameter information (OMNO₂)

Name	Description	Unit	Notes
ColumnAmountNO2Trop	Tropospheric Column NO ₂	Molec / cm ²	<ul style="list-style-type: none">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: ($-2.100 \approx -1.26765 \times 10^{30}$)

OMNO2_HR Gridded High Resolution OMI NO₂ (0.1° x 0.1°)

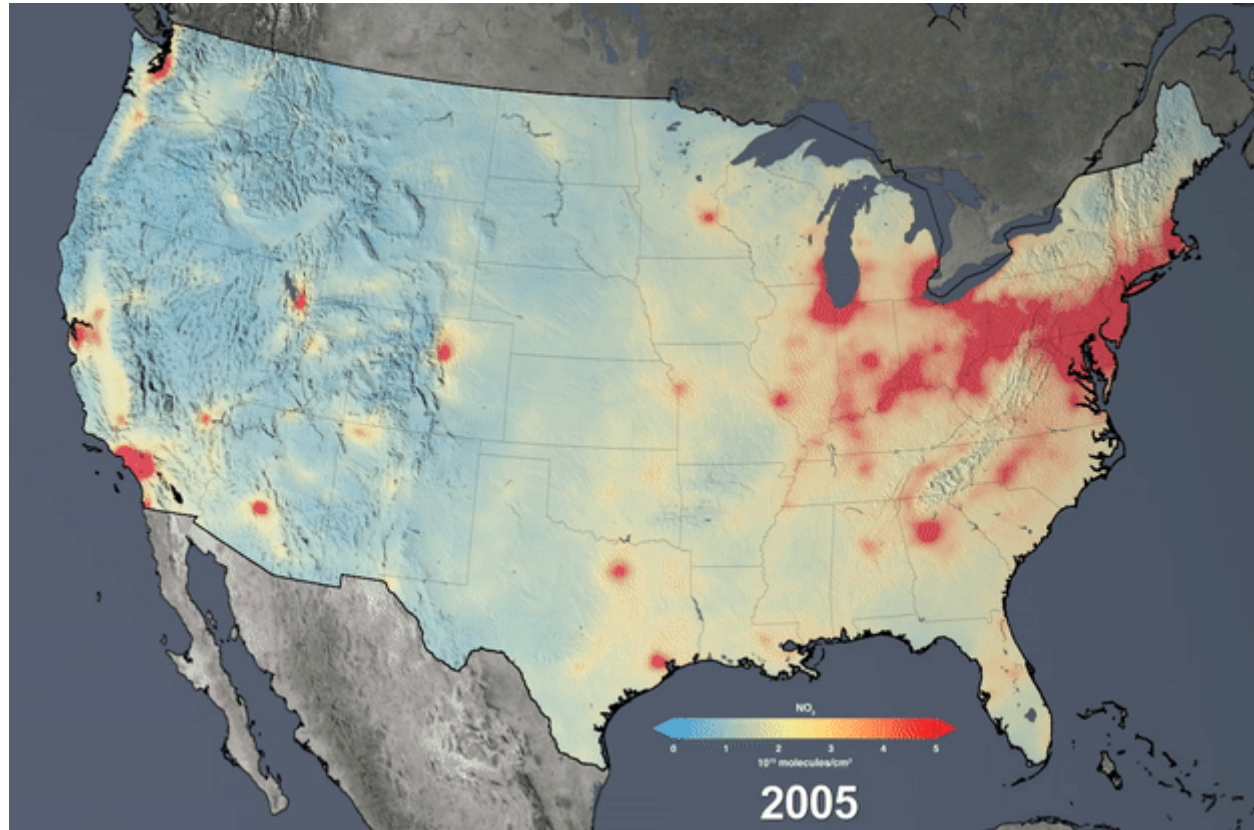
- Based on NASA standard product
- Daily:
 - https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L3/OMNO2D_HR/OMNO2D_HRD/
 - Available in hdf5 format
- Monthly:
 - https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L3/OMNO2D_HR/OMNO2D_HRM/
 - Available in ASCII (text) and NetCDF format



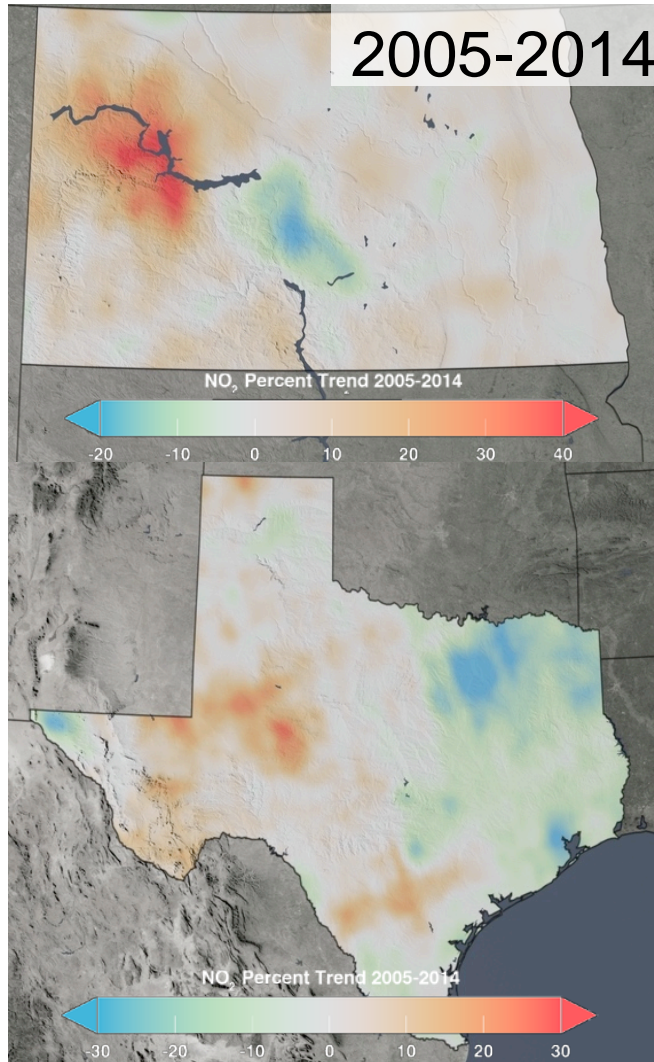
Applications and Research Using OMI data

OMI Detects NO₂ Changes in Pollution Over Time

2005 – 2016



OMI Detects NO₂ Increases from ONG Activities

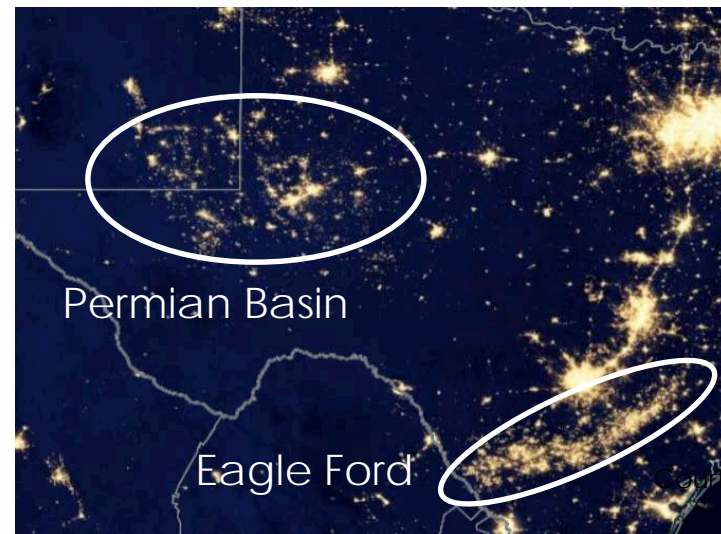


North
Dakota



Suomi NPP VIIRS Lights at Night

Texas



Courtesy of: Bryan Duncan

OMI NO₂ 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

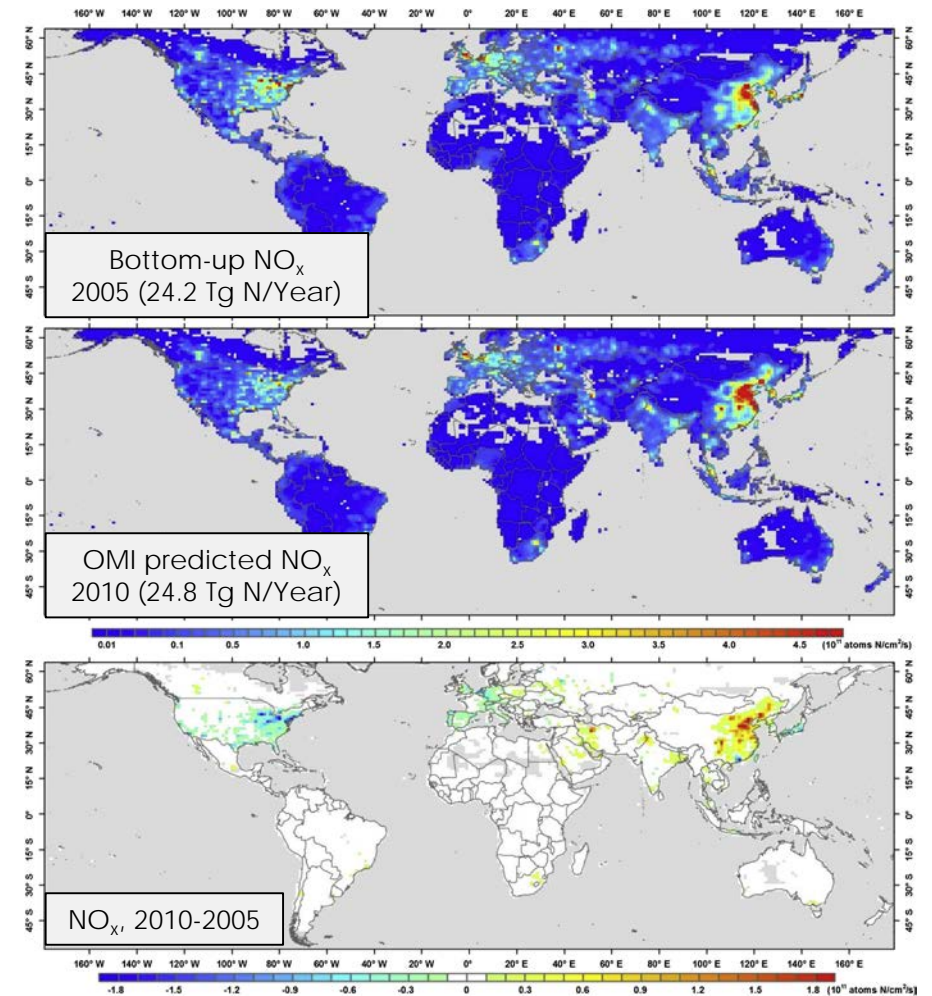
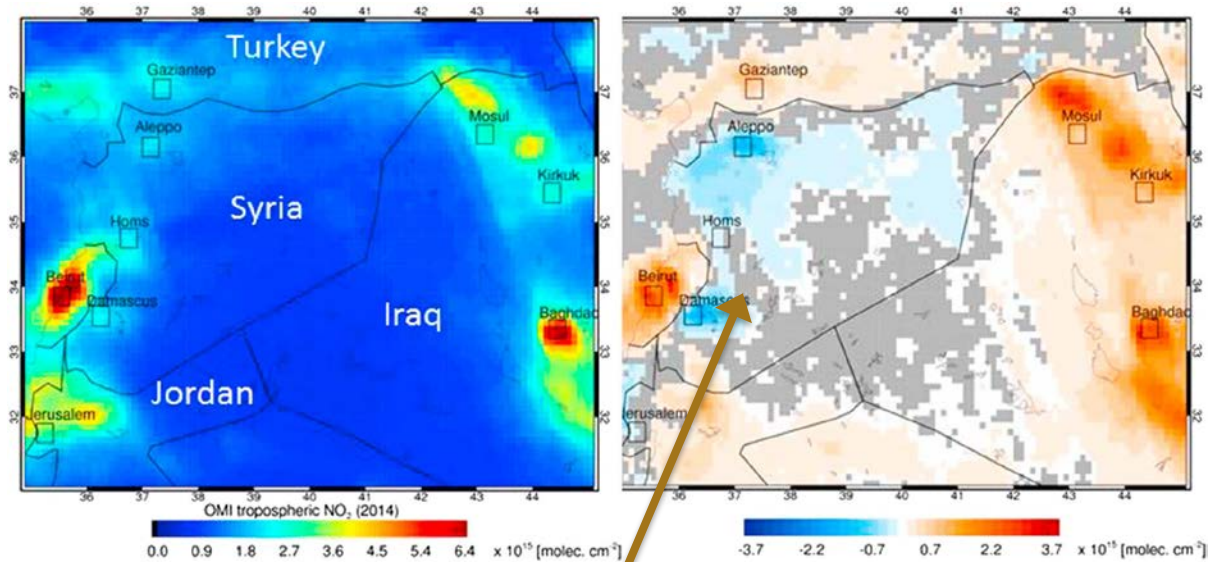


Image credit: Figure 5 from Streets et al. 2013

Temporal Variations

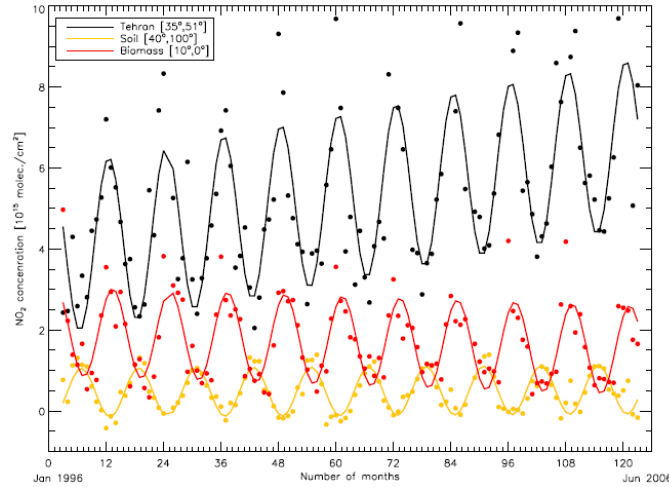
- Satellite observations can also be used to detect potential short term and unexpected changes in trends, such as reductions in activity due to:
 - economic recession
 - natural disasters (e.g., Hurricane Katrina)
 - policy interventions (e.g., Beijing Olympics)
 - civil unrest



NO₂ Trends from OMI
Damascus: $-37.1 \pm 10.9\%$
Aleppo: $-40.2 \pm 13.6\%$

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

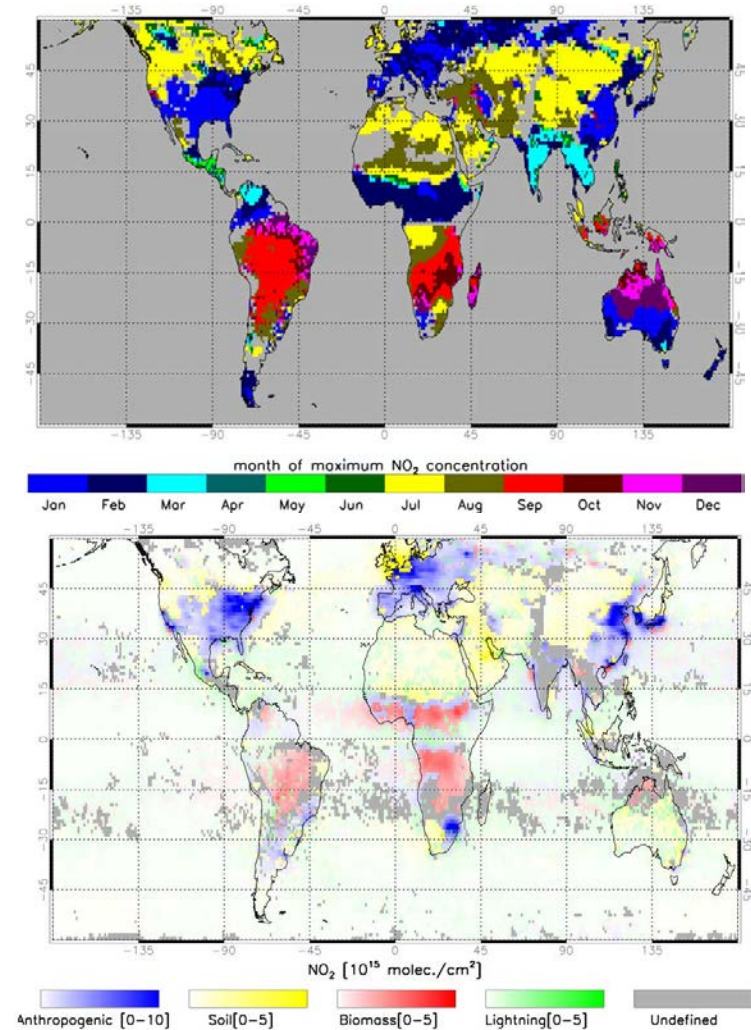
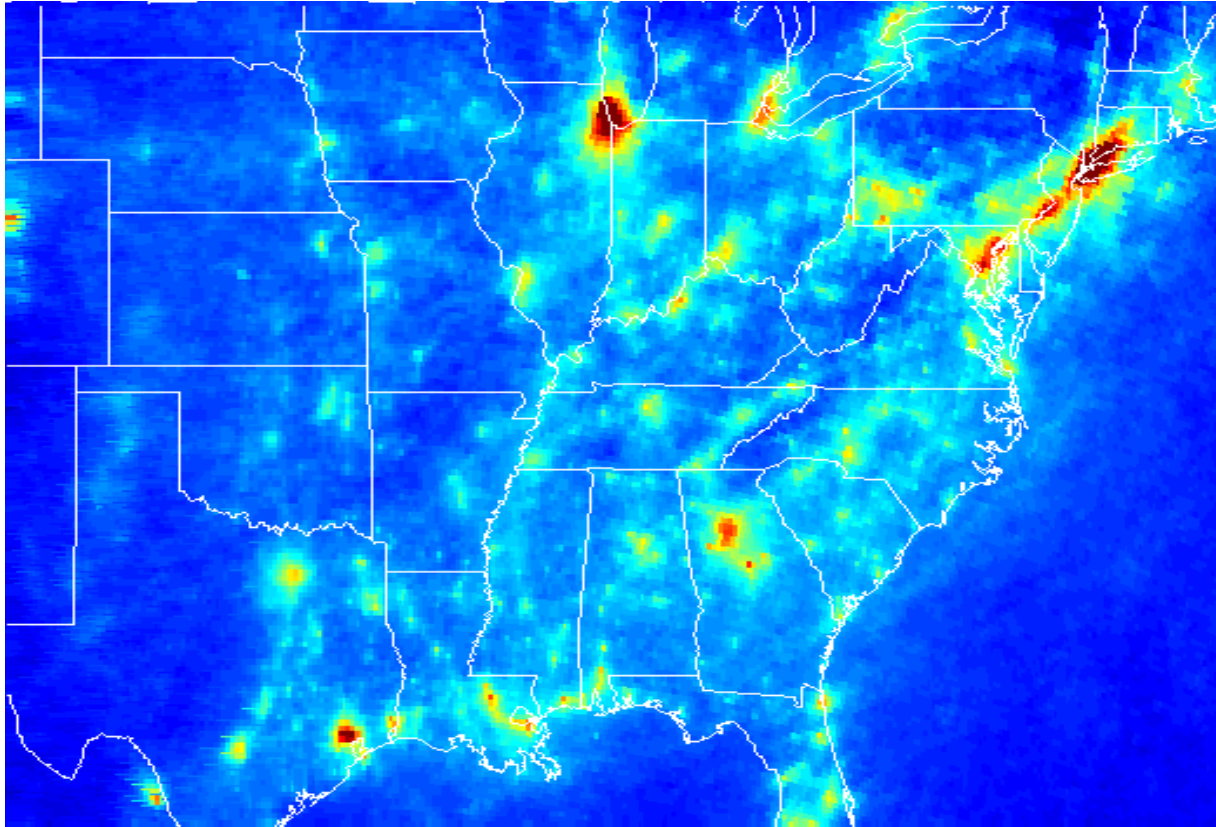


Image credit: Figures 3, 5, and 7 from van der A. et al. 2008

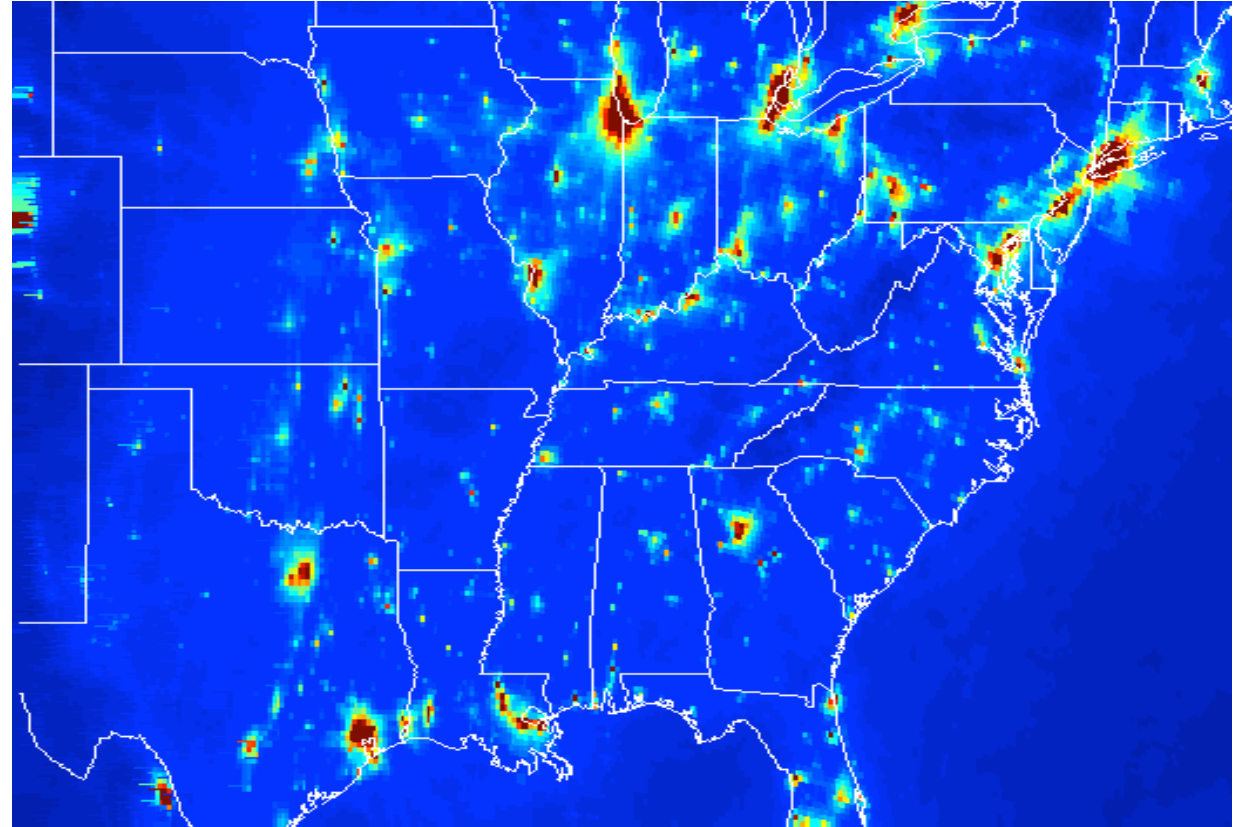
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Model-Satellite Inter-Comparison

OMI NO₂



CMAQ Model NO₂



OMI Trends in NO₂ Correlate Well With Surface Trends

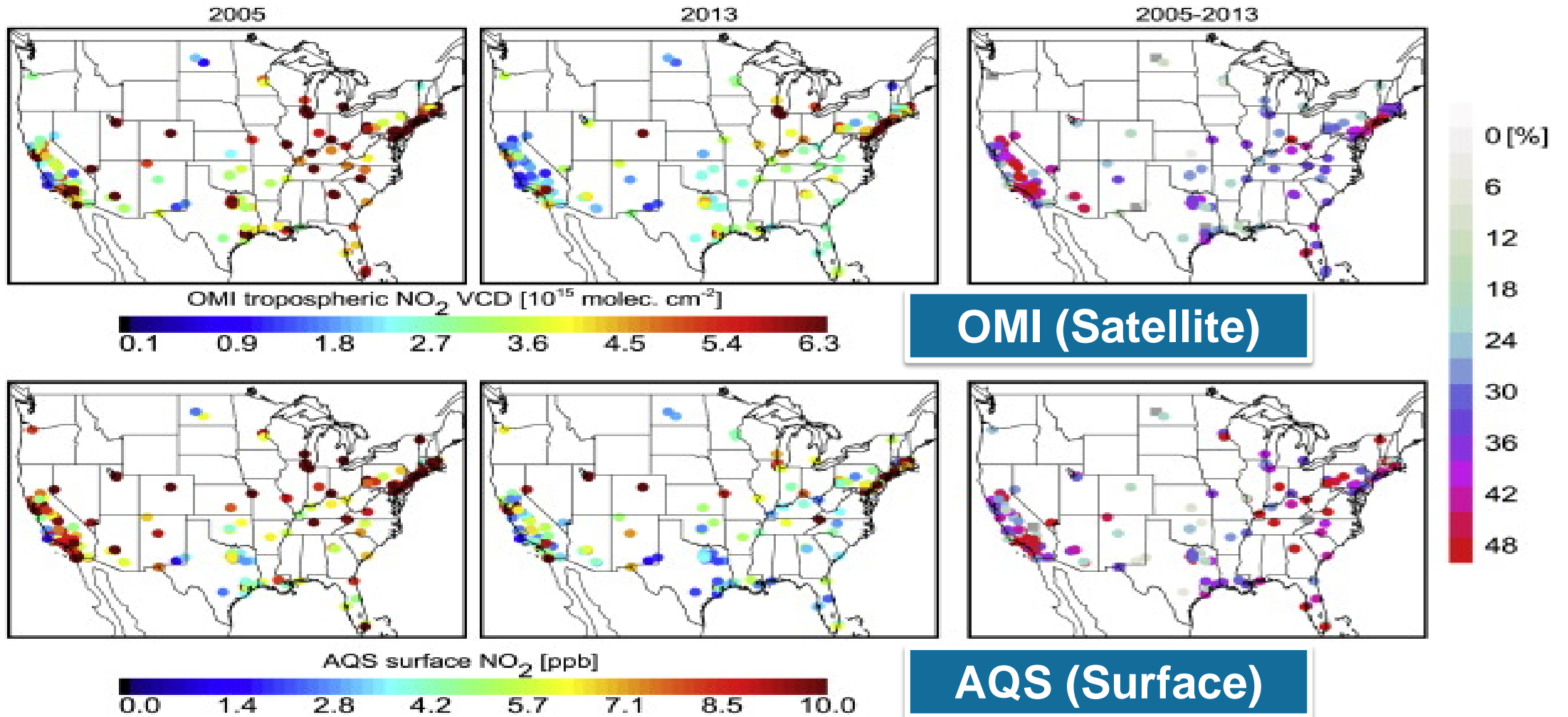
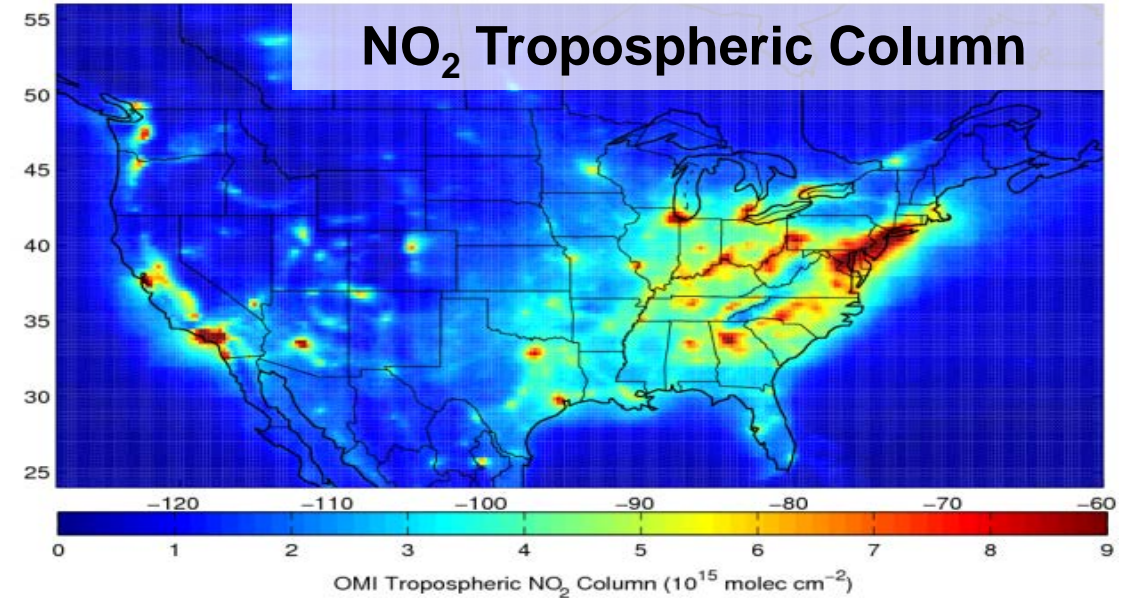
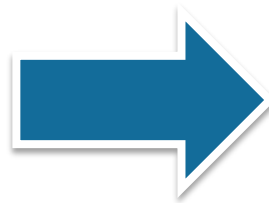
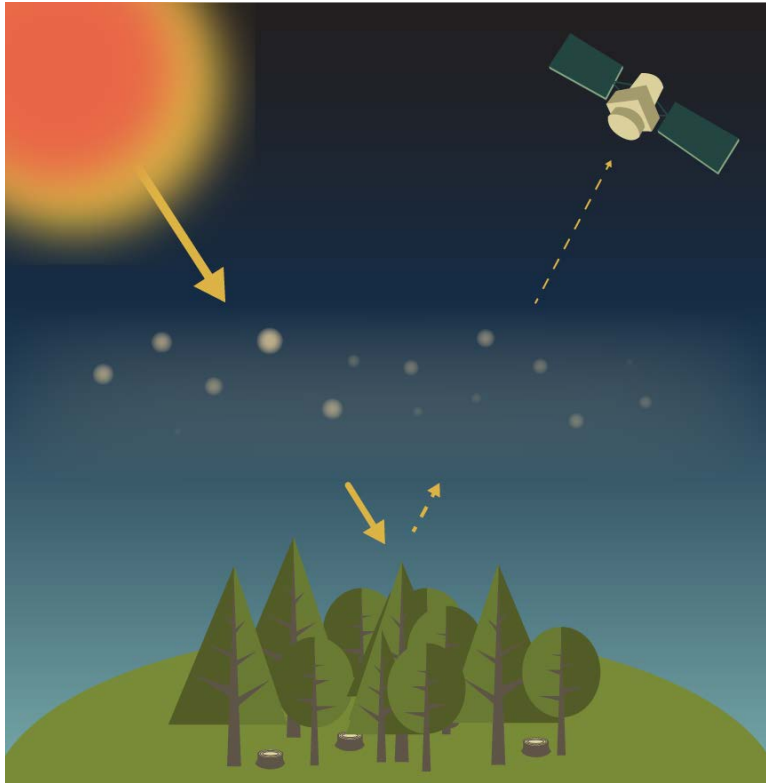


Image credit: Lamsal et al. (2015)

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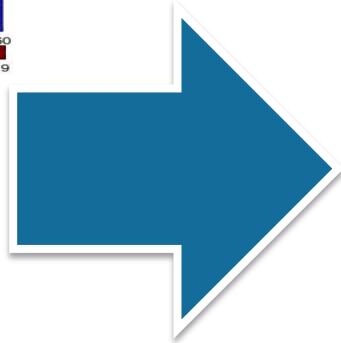
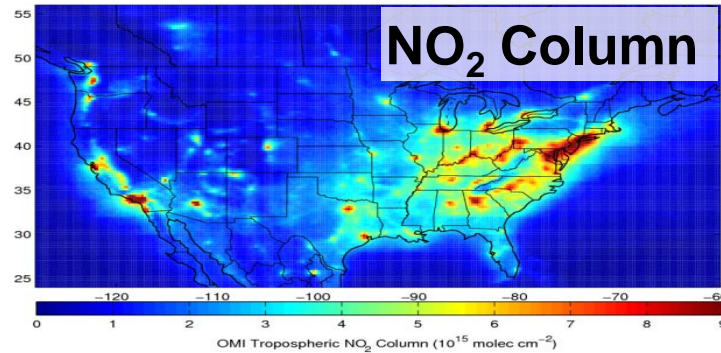
Estimating Surface NO₂ From the Tropospheric Column



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

- Courtesy of Randall Martin

Estimating Surface NO₂ From the Tropospheric column



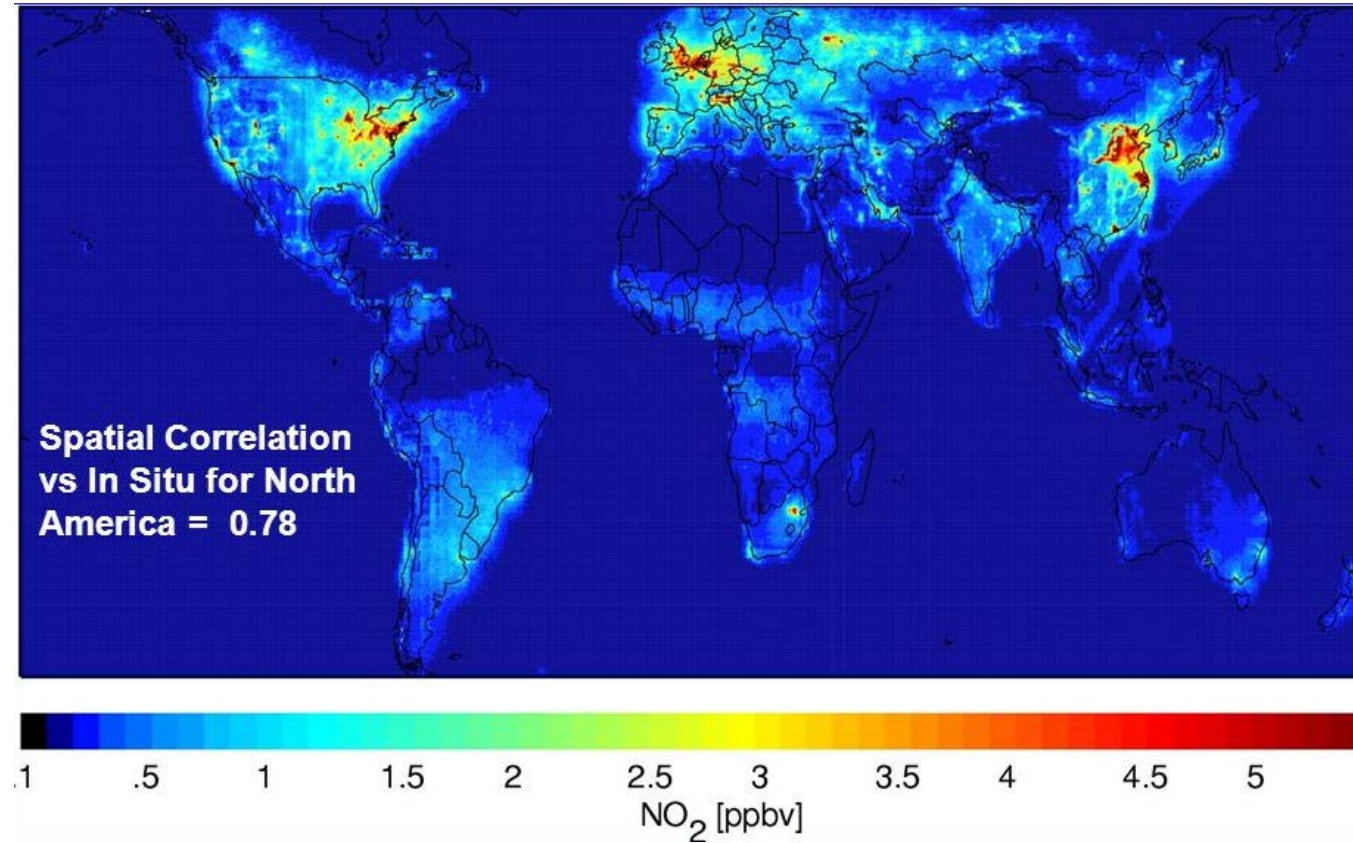
$$S = \Omega_{sat} \times \left[\frac{v S_{Model}}{v \Omega_{Model} - (v - 1) \Omega_{FT} (Model)} \right]$$

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

Ground-Level Afternoon NO₂ Inferred from OMI for 2005



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

Source: Lok Lamsal

Satellite-Based Surface NO₂ 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° x 0.1°	0.1° x 0.1°	0.1° x 0.1°
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 NO₂ Used in Health Applications

- Anenberg et al. (2018) used annual average surface NO₂, 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}, O₃, and NO₂ exposure
- Noted that NO₂ impacts are likely underestimated because of the relatively coarse OMI resolution

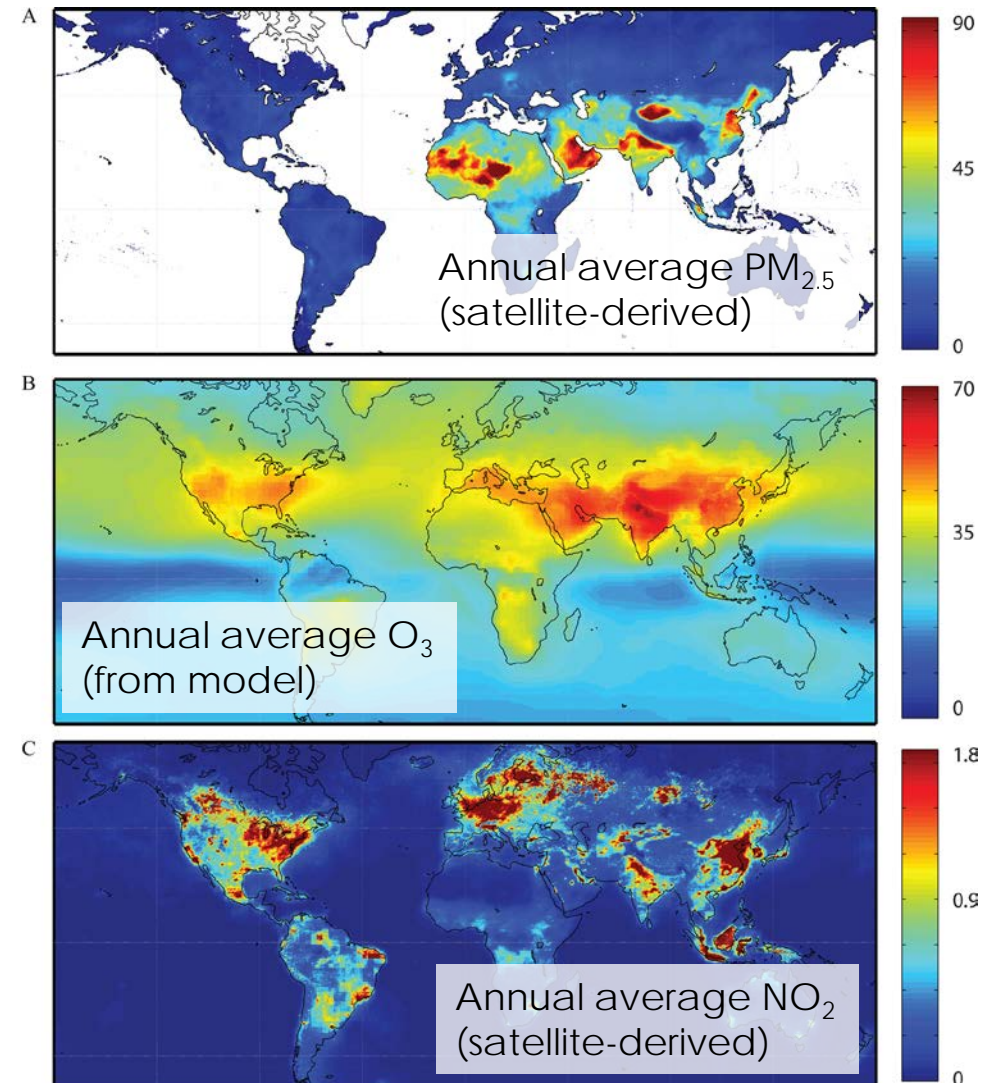
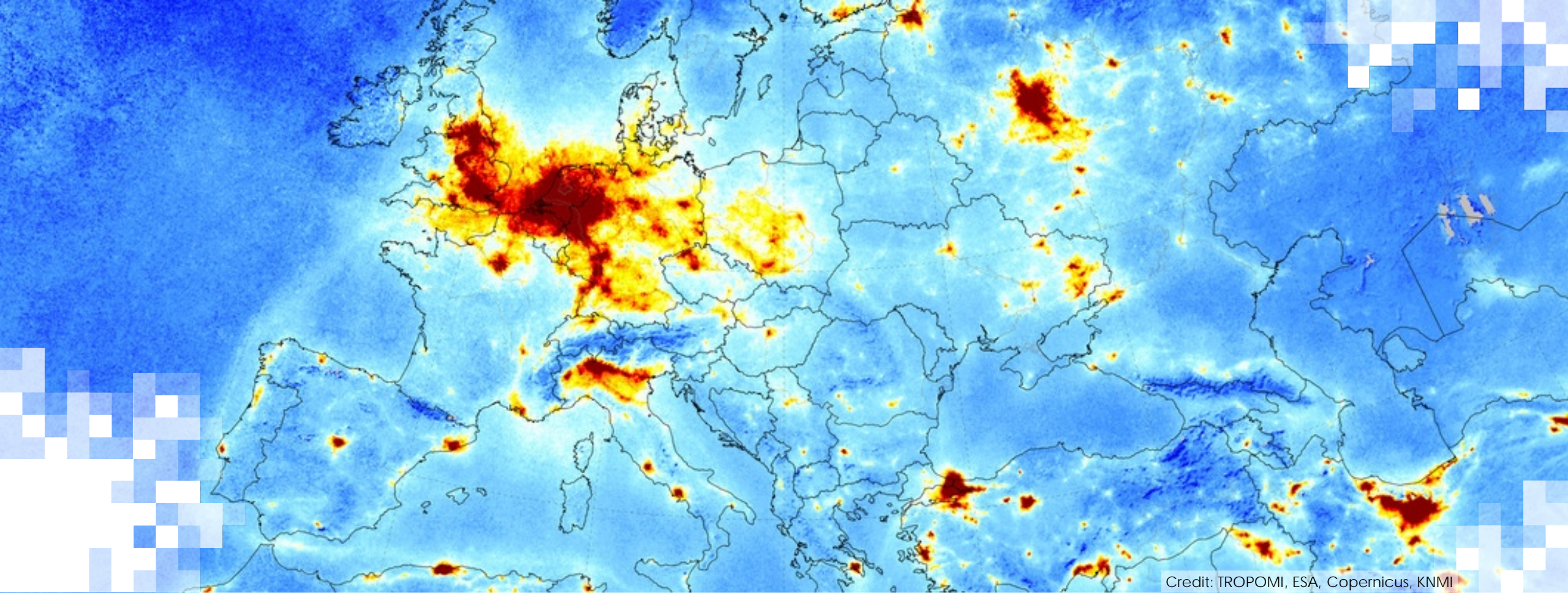


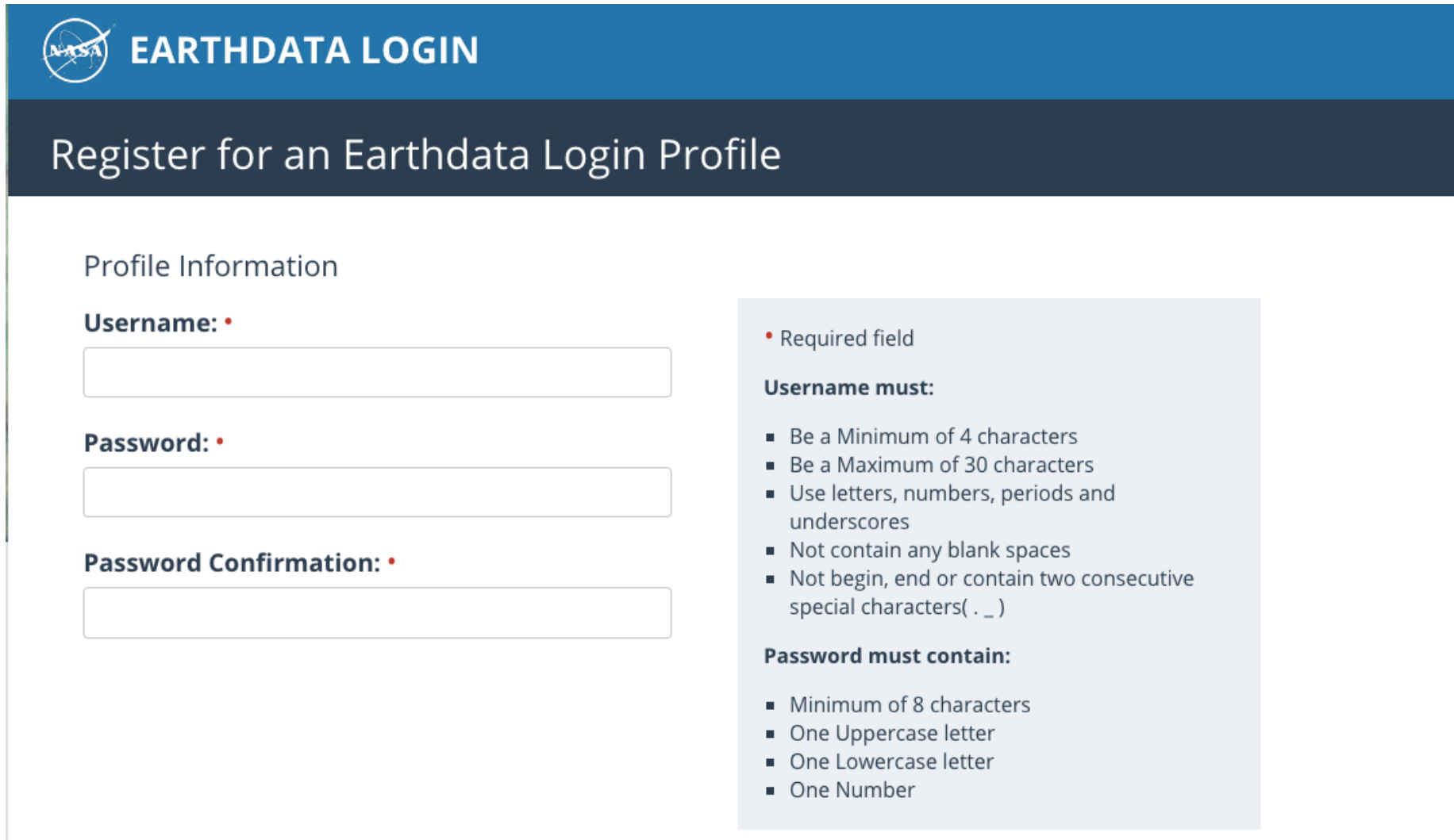
Image credit: Anenberg et al. 2018

[NASA's Applied Remote Sensing Training Program](#)



Data Access

Step 1: Visit <https://urs.earthdata.nasa.gov/users/new>



The screenshot shows the Earthdata Login registration page. At the top, there is a blue header with the NASA logo and the text "EARTHDATA LOGIN". Below this is a dark blue banner with the text "Register for an Earthdata Login Profile". The main content area is white and contains a registration form. The form has three input fields: "Username:", "Password:", and "Password Confirmation:". To the right of the form is a light blue box containing a list of requirements for the username and password. The requirements for the username are: it is a required field, it must be a minimum of 4 characters, a maximum of 30 characters, use letters, numbers, periods, and underscores, and not contain any blank spaces. The requirements for the password are: it must contain a minimum of 8 characters, one uppercase letter, one lowercase letter, and one number.

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.

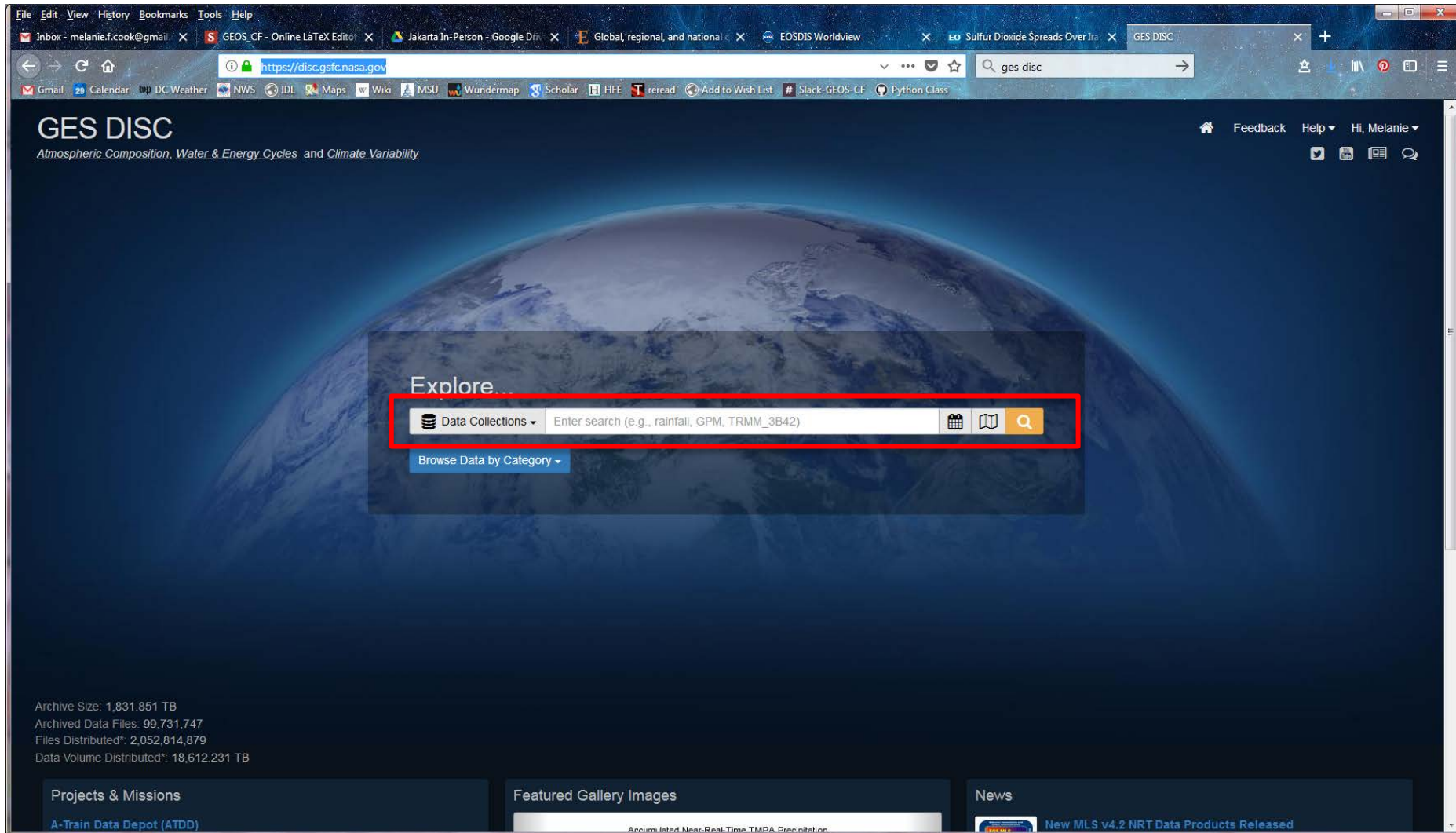
Earthdata Feedback Module	?
Earthdata Website	?
Earthdata Code Collaborative	?
Metadata Management Tool	?
Earthdata Wiki	✎ ✕
SEDAC Website	✎ ✕
Earthdata Search	✎ ✕
LAADS Web	✎ 👤 ✕
Toolsets for Airborne Data (TAD)	✎ ✕
Earthdata Search Prod (new)	✎ ✕
NASA GESDISC DATA ARCHIVE	✎ ✕

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

The screenshot shows the NASA GES DISC website interface. The top left corner displays the text "GES DISC" and the subtitle "Atmospheric Composition, Water & Energy Cycles and Climate Variability". The top right corner features a navigation bar with a home icon, "Feedback", "Help", and a user profile dropdown menu that is open, showing "Hi, Melanie" with a downward arrow. Below the navigation bar are social media icons for Twitter, YouTube, and Facebook. The main content area is a dark blue background with a satellite image of Earth. A central "Explore..." panel contains a "Data Collections" dropdown menu, a search input field with the placeholder text "Enter search (e.g., rainfall, GPM, TRMM_3B42)", and a "Browse Data by Category" button. To the right of the search field are icons for a calendar, a book, and a magnifying glass.



Step 4: Enter Search Keywords (e.g. OMNO₂ or OMSO₂)



The screenshot shows the NASA GES DISC website interface. The browser's address bar displays the URL <https://disc.gsfc.nasa.gov>. The page title is "GES DISC" with the subtitle "Atmospheric Composition, Water & Energy Cycles and Climate Variability". A search bar is prominently displayed in the center, containing the placeholder text "Enter search (e.g., rainfall, GPM, TRMM_3B42)". The search bar is highlighted with a red rectangular box. To the left of the search bar is a "Data Collections" dropdown menu, and to the right are icons for a calendar, a book, and a search magnifying glass. Below the search bar is a "Browse Data by Category" button. The background of the page features a large image of Earth from space. At the bottom left, statistics are provided: "Archive Size: 1,831.851 TB", "Archived Data Files: 99,731,747", "Files Distributed*: 2,052,814,879", and "Data Volume Distributed*: 18,612.231 TB". The footer includes sections for "Projects & Missions" (with a link to "A-Train Data Depot (ATDD)"), "Featured Gallery Images" (with a link to "Accumulated Near-Real-Time TMPA Precipitation"), and "News" (with a link to "New MLS v4.2 NRT Data Products Released").

Step 5: Make a Product Selection

The screenshot shows the NASA GES DISC website interface. The browser address bar displays the URL: <https://disc.gsfc.nasa.gov/datasets?page=1&keywords=OMSO2>. The page title is "GES DISC" with the subtitle "Atmospheric Composition, Water & Energy Cycles and Climate Variability". The main content area is titled "Data Collections" and shows "Showing 1 - 3 of 3 datasets associated with OMSO2".

On the left side, there is a "Refine By" section with several filters:

- Subject:** Atmospheric Chemistry (3)
- Measurement:** Sulfur Dioxide (3)
- Source:** Aura OMI (3)
- Processing Level:** 2 (2), 3 (1)
- Project:** ATDD (1), Aura (2)
- Temporal Resolution:** 98 minutes (1), 98.8 minutes (1), 1 day (1)
- Spatial Resolution:** 13 km x 24 km (2), 0.25 ° x 0.25 ° (1)

The main table lists the datasets:

Image	Dataset	Source	Temporal Resolution	Spatial Resolution	Process Level	Begin Date	End Date
	OMI/Aura Level 2 Sulphur Dioxide (SO2) Trace Gas Column Data 1-Orbit subset Swath along CloudSat track 1-Orbit Swath 13x24 km (OMSO2_CPR.003) - Atmospheric Chemistry	Aura OMI	98.8 minutes	13 km x 24 km	2	2006-06-01	2018-01-17
	OMI/Aura Sulphur Dioxide (SO2) Total Column 1-orbit L2 Swath 13x24 km V003 (OMSO2.003) - Atmospheric Chemistry	Aura OMI	98 minutes	13 km x 24 km	2	2004-10-01	2018-01-17
	OMI/Aura Sulfur Dioxide (SO2) Total Column L3 1 day Best Pixel in 0.25 degree x 0.25 degree V3 (OMSO2e.003) - Atmospheric Chemistry	Aura OMI	1 day	0.25 ° x 0.25 °	3	2004-10-01	2018-01-17

The second row, representing the "OMI/Aura Sulphur Dioxide (SO2) Total Column 1-orbit L2 Swath 13x24 km V003 (OMSO2.003)" dataset, is highlighted with a red rectangular box. A mouse cursor is pointing at the "Get Data" link for this dataset.

At the bottom of the page, there is a footer with links for "NASA Official: Long Pham", "Science Focus Areas", "Tools", "Resources", and "About Us".



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

GES DISC
Atmospheric Composition, Water & Energy Cycles and Climate Variability

Go to Search Results

OMSO2: OMI/Aura Sulphur Dioxide (SO₂) Total Column 1-orbit L2 Swath 13x24 km V003

The Aura Ozone Monitoring Instrument (OMI) Sulfur Dioxide Product 'OMSO2' Version 3 is now available to the public from the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC). The OMSO2 product contains three values of SO₂ Vertical column corresponding to three a-priori vertical profiles used in the retrieval algorithm. It also contains quality flags, geolocation and other ancillary information. The lead scientist for the OMSO2 product is Nickolay Kroktov. The shortname for this Level-2 OMI total column SO₂ product is OMSO2.

The OMSO2 files are stored in the version 5 EOS Hierarchical Data Format (HDF-EOS5). Each file contains data from the day lit portion of an orbit (~53 minutes). There are approximately 14 orbits per day. The maximum file size for the OMSO2 data product is approximately 21 MB.

Product Summary | [Data Citation](#) | [Documentation](#)

Shortname:	OMSO2
Longname:	OMI/Aura Sulphur Dioxide (SO ₂) Total Column 1-orbit L2 Swath 13x24 km V003
DOI:	10.5067/Aura/OMI/DATA2022
Version:	003
Format:	HDF5
Spatial Coverage:	-180.0,-90.0,180.0,90.0
Temporal Coverage:	2004-10-01 to present
File Size:	26 MB per file
Data Resolution	
Spatial:	13 km x 24 km
Vertical:	80 km
Temporal:	98 minutes

1:1 History

Step 7: Select Product

The screenshot displays the NASA Earthdata Search interface. At the top, the search bar contains the query 'OMSO2_003'. Below the search bar, a map of the Middle East and surrounding regions is visible. On the left side, there is a sidebar with navigation options: 'Browse Collections', 'Features' (with sub-options for Map Imagery, Near Real Time, and Subsetting Services), 'Keywords', 'Platforms', 'Instruments', 'Organizations', 'Projects', and 'Processing levels'. Below the map, a section titled '2 Matching Collections' lists search results. The first result is highlighted with a red box and includes a thumbnail, the title 'OMI/Aura Sulphur Dioxide (SO2) Total Column 1-orbit L2 Swath 13x24 km V003 (OMSO2) at GES DISC', and a description: '67736 Granules • 2004-10-01 ongoing • The Aura Ozone Monitoring Instrument (OMI) Sulfur Dioxide Product 'OMSO2' Version 3 is now available to the public from the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC). The OMSO2 product contains three values of SO2 vertical column corresponding to...'. The second result is titled 'OMI/Aura Sulphur Dioxide (SO2) Total Column 1-orbit L2 Swath 13x24 km V003 NRT' and has a 'No image available' thumbnail. The interface also includes a 'Report a metadata problem' button and a 'Learn More' link.

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)

Granule ID	START	END
OMI-Aura_L2-OMSO2_2018m0118t0800-o71867_v003-2018m0118t142500.he5	2018-01-18 08:00:41	2018-01-18 09:39:35
OMI-Aura_L2-OMSO2_2018m0118t0621-o71866_v003-2018m0118t141452.he5	2018-01-18 06:21:48	2018-01-18 08:00:41
OMI-Aura_L2-OMSO2_2018m0118t0442-o71865_v003-2018m0118t123448.he5	2018-01-18 04:42:55	2018-01-18 06:21:48
OMI-Aura_L2-OMSO2_2018m0118t0304-o71864_v003-2018m0118t092759.he5	2018-01-18 03:04:01	2018-01-18 04:42:55
OMI-Aura_L2-OMSO2_2018m0118t0125-o71863_v003-2018m0118t073427.he5	2018-01-18 01:25:08	2018-01-18 03:04:01
OMI-Aura_L2-OMSO2_2018m0117t2346-o71862_v003-2018m0118t055001.he5	2018-01-17 23:46:15	2018-01-18 01:25:08
OMI-Aura_L2-OMSO2_2018m0117t2207-o71861_v003-2018m0118t041541.he5		
OMI-Aura_L2-OMSO2_2018m0117t2028-o71860_v003-2018m0118t041510.he5		
OMI-Aura_L2-OMSO2_2018m0117t1849-o71859_v003-2018m0118t021312.he5		
OMI-Aura_L2-OMSO2_2018m0117t1710-o71858_v003-2018m0117t231809.he5		
OMI-Aura_L2-OMSO2_2018m0117t1531-o71857_v003-2018m0117t211323.he5		
OMI-Aura_L2-OMSO2_2018m0117t200605.he5		



Step 9: Select Swath

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

OMSI/Aura Sulphur Dioxide (SO₂) Total Column 1-orbit L2 Swath 13x24 km V003 (OMSO2) at GES DISC

Showing 15 of 15 matching granules for the selected day. (Show All) Sort by: Start Date, Newest first Granule Search: Search Single or Multiple Granule IDs... Search Time: 0.2s Report a metadata problem

Granule ID	START	END
OMI-Aura_L2-OMSO2_2016m1024t1228-o65302_v003-2016m1024t222720.he5	2016-10-24 12:28:14	2016-10-24 14:07:06
OMI-Aura_L2-OMSO2_2016m1024t1049-o65301_v003-2016m1024t224733.he5	2016-10-24 10:49:21	2016-10-24 12:28:14
OMI-Aura_L2-OMSO2_2016m1024t0910-o65300_v003-2016m1024t174753.he5	2016-10-24 09:10:29	2016-10-24 10:49:21
OMI-Aura_L2-OMSO2_2016m1024t0731-o65299_v003-2016m1024t163627.he5	2016-10-24 07:31:36	2016-10-24 09:10:29
OMI-Aura_L2-OMSO2_2016m1024t0552-o65298_v003-2016m1024t163822.he5	2016-10-24 05:52:43	2016-10-24 07:31:36
OMI-Aura_L2-OMSO2_2016m1024t0413-o65297_v003-2016m1024t114026.he5	2016-10-24 04:13:51	2016-10-24 05:52:43

DAY: 01 Oct 2016 to 31

Step 10: Download Single Granule by Clicking Gear Icon

The screenshot shows the Earthdata search interface. At the top, there's a search bar with 'OMSO2_003' and a 'Find a DAAC' dropdown. Below the search bar is a map of the Atlantic Ocean with green lines indicating the swath of the satellite. A tooltip shows the dates '2016-10-24 09:10:29' and '2016-10-24 10:49:21'. Below the map, there's a 'Back to Collections' button and a 'Download Data' button. The main content area shows a table of 15 granules for the selected day. The table has columns for granule ID, start time, and end time. A red box highlights the gear icon for the granule with ID 'OMI-Aura_L2-OMSO2_2016m1024t0910-o65300_v003-2016m1024t174753.he5'. Below the table is a timeline showing the day of October 2016, with the 24th highlighted in green.

OMI/Aura Sulphur Dioxide (SO₂) Total Column 1-orbit L2 Swath 13x24 km V003 (OMSO2) at GES DISC

Showing 15 of 15 matching granules for the selected day. (Show All) Sort by: Start Date, Newest first Granule Search: Search Single or Multiple Granule IDs... Search Time: 0.2s Report a metadata problem

Granule ID	START	END
OMI-Aura_L2-OMSO2_2016m1024t1228-o65302_v003-2016m1024t222720.he5	2016-10-24 12:28:14	2016-10-24 14:07:06
OMI-Aura_L2-OMSO2_2016m1024t1049-o65301_v003-2016m1024t224733.he5	2016-10-24 10:49:21	2016-10-24 12:28:14
OMI-Aura_L2-OMSO2_2016m1024t0910-o65300_v003-2016m1024t174753.he5	2016-10-24 09:10:29	2016-10-24 10:49:21
OMI-Aura_L2-OMSO2_2016m1024t0731-o65299_v003-2016m1024t163627.he5	2016-10-24 07:31:36	2016-10-24 09:10:29
OMI-Aura_L2-OMSO2_2016m1024t0552-o65298_v003-2016m1024t163822.he5	2016-10-24 05:52:43	2016-10-24 07:31:36
OMI-Aura_L2-OMSO2_2016m1024t0413-o65297_v003-2016m1024t114026.he5	2016-10-24 04:13:51	2016-10-24 05:52:43

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

Data Access
Review and select service options for your data prior to download

1 OMI/Aura Sulphur Dioxide (SO₂) Total Column 1-orbit L2 Swath 13x24 km V003 (OMSO2) at GES DISC

Review & Select Service Options

Review

1 Granule
26.2 Megabytes

Granule List

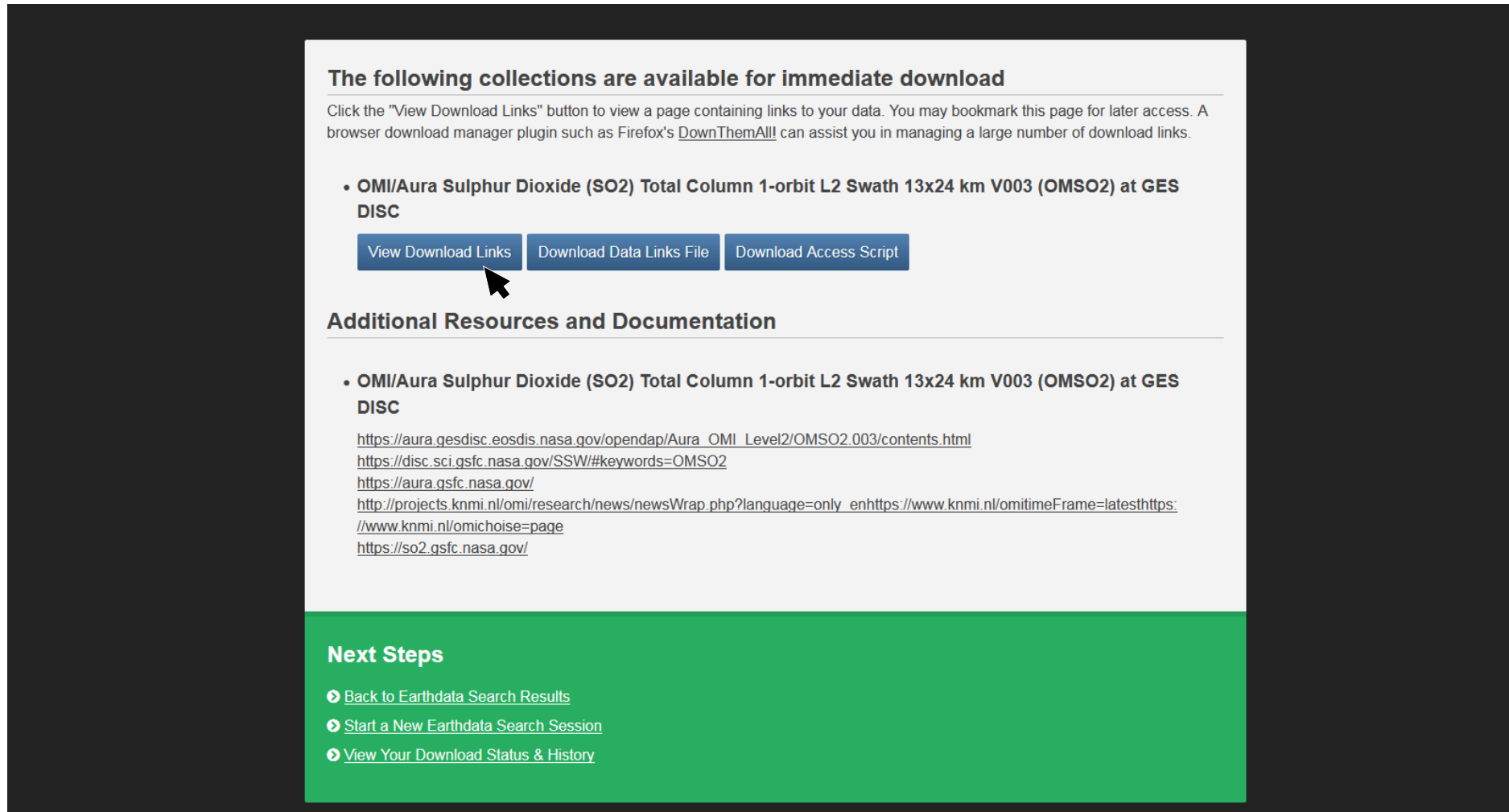
Expand List

Select Data Access Method

Direct Download
Download data **as-is** now from your browser or access script.

Submit

Step 12: Click "View Download Link" to Download



The following collections are available for immediate download

Click the "View Download Links" button to view a page containing links to your data. You may bookmark this page for later access. A browser download manager plugin such as Firefox's [DownThemAll!](#) can assist you in managing a large number of download links.

- **OMI/Aura Sulphur Dioxide (SO2) Total Column 1-orbit L2 Swath 13x24 km V003 (OMSO2) at GES DISC**
[View Download Links](#) [Download Data Links File](#) [Download Access Script](#)

Additional Resources and Documentation

- **OMI/Aura Sulphur Dioxide (SO2) Total Column 1-orbit L2 Swath 13x24 km V003 (OMSO2) at GES DISC**
https://aura.gesdisc.eosdis.nasa.gov/opendap/Aura_OMI_Level2/OMSO2.003/contents.html
<https://disc.sci.gsfc.nasa.gov/SSW/#keywords=OMSO2>
<https://aura.gsfc.nasa.gov/>
http://projects.knmi.nl/omi/research/news/newsWrap.php?language=only_enhttps://www.knmi.nl/omitimeFrame=latesthttps://www.knmi.nl/omichoise=page
<https://so2.gsfc.nasa.gov/>

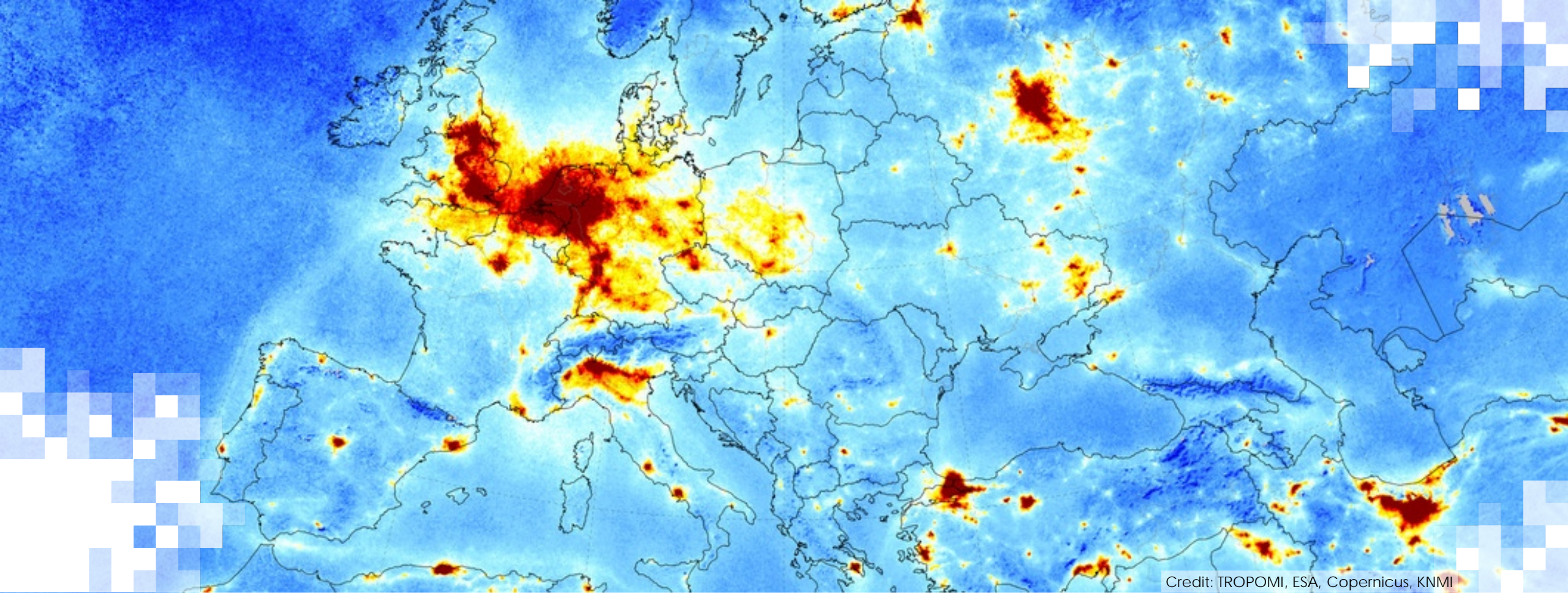
Next Steps

- [Back to Earthdata Search Results](#)
- [Start a New Earthdata Search Session](#)
- [View Your Download Status & History](#)

Step 13: Download the Data

- http://aura.gesdisc.eosdis.nasa.gov/data/Aura_OMI_Level2/OMS02.003/2016/298/OMI-Aura_L2-OMS02_2016m1024t0910-o65300_v003-2016m1024t174753.he5

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



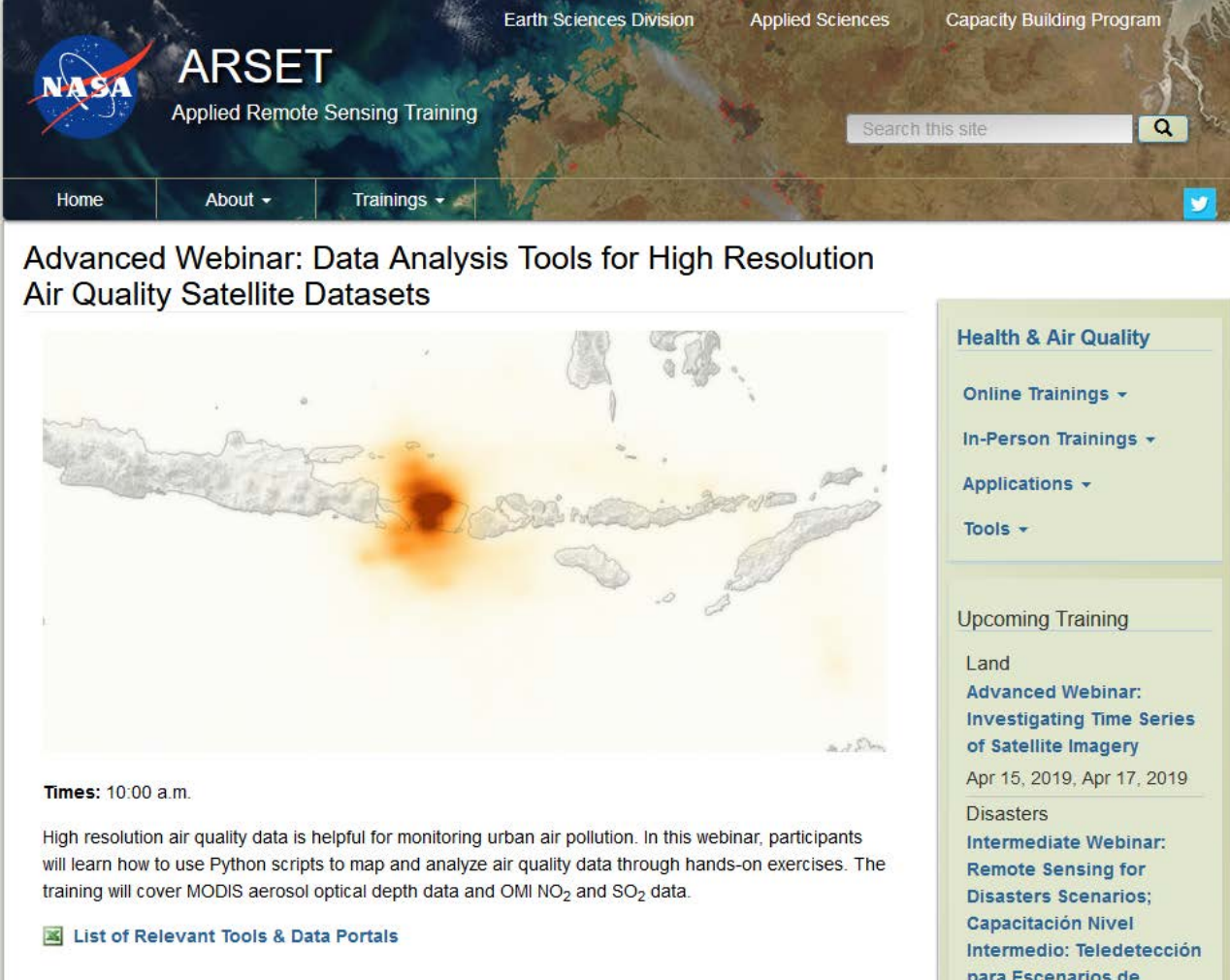
Credit: TROPOMI, ESA, Copernicus, KNMI

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 NO₂ and SO₂ and MODIS)
 - Modifying available scripts for future use
- All past webinar recordings, presentations, and Q&A transcripts are available for download

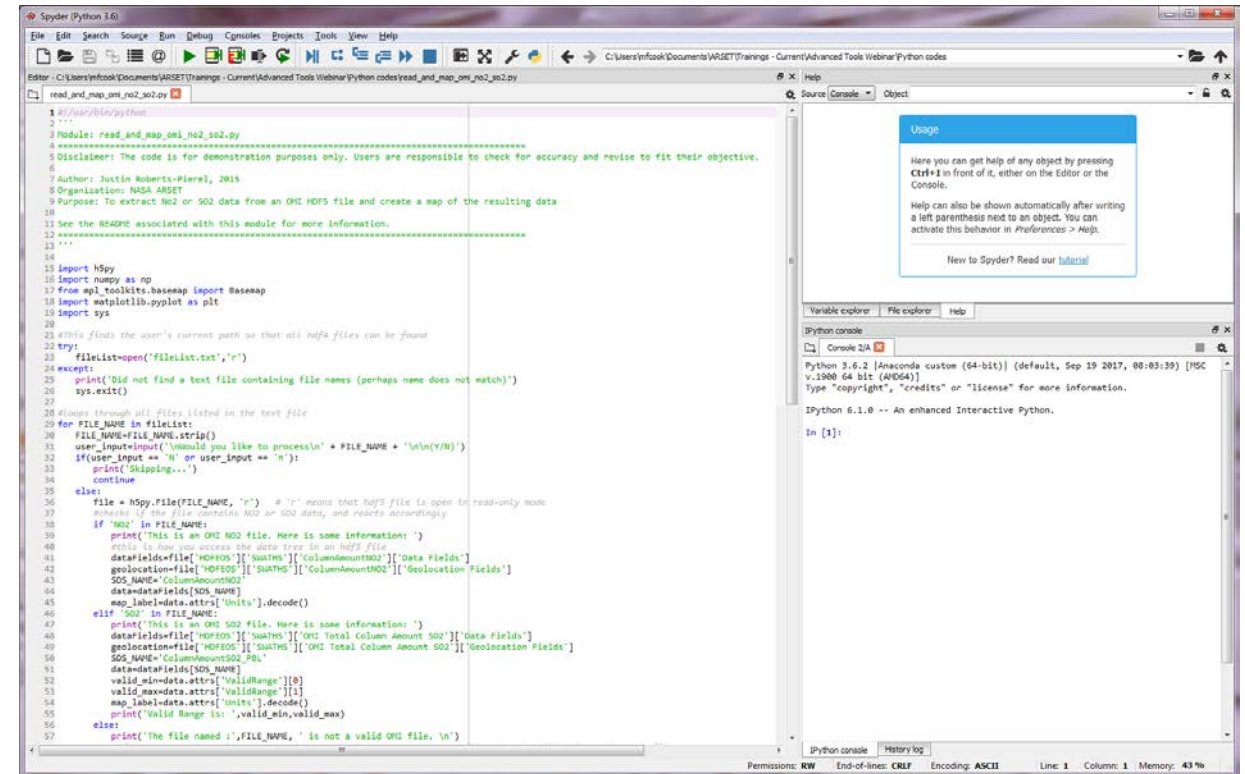


The screenshot shows the ARSET (Applied Remote Sensing Training) website. The header includes the NASA logo, the text 'ARSET Applied Remote Sensing Training', and navigation links for 'Earth Sciences Division', 'Applied Sciences', and 'Capacity Building Program'. A search bar is present on the right. Below the header is a navigation menu with 'Home', 'About', and 'Trainings'. The main content area features the title 'Advanced Webinar: Data Analysis Tools for High Resolution Air Quality Satellite Datasets' and a map of Indonesia with a prominent orange and red air quality anomaly over the island of Sumatra. Below the map, the text indicates the webinar is at 10:00 a.m. and describes the content: 'High resolution air quality data is helpful for monitoring urban air pollution. In this webinar, participants will learn how to use Python scripts to map and analyze air quality data through hands-on exercises. The training will cover MODIS aerosol optical depth data and OMI NO₂ and SO₂ data.' A link for 'List of Relevant Tools & Data Portals' is provided. On the right side, there is a sidebar with a 'Health & Air Quality' section containing links for 'Online Trainings', 'In-Person Trainings', 'Applications', and 'Tools'. Below this is an 'Upcoming Training' section listing 'Land' and 'Disasters' with specific webinar titles and dates.

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



```
1 #!/usr/bin/python
2 ...
3 Module: read_and_map_ohf_no2_so2.py
4 .....
5 Disclaimer: The code is for demonstration purposes only. Users are responsible to check for accuracy and revise to fit their objective.
6
7 Author: Justin Roberts-Piers1, 2015
8 Organization: NASA ARSET
9 Purpose: To extract NO2 or SO2 data from an OHF HDF5 file and create a map of the resulting data
10
11 See the README associated with this module for more information.
12 .....
13
14
15 import h5py
16 import numpy as np
17 from mpl_toolkits.basemap import Basemap
18 import matplotlib.pyplot as plt
19 import sys
20
21 #this finds the user's current path so that all hdf5 files can be found
22 try:
23     filelist=open('filelist.txt','r')
24 except:
25     print('Did not find a text file containing file names (perhaps name does not match)')
26     sys.exit()
27
28 #loops through all files listed in the text file
29 for FILE_NAME in filelist:
30     FILE_NAME=FILE_NAME.strip()
31     user_input=input('Would you like to process\n' + FILE_NAME + '\n\n(Y/N)')
32     if(user_input == 'n' or user_input == 'N'):
33         print('skipping...')
34         continue
35     else:
36         file = h5py.File(FILE_NAME, 'r') # 'r' means that h5py file is open in read-only mode
37         #this is the file contains NO2 or SO2 data, and prints accordingly
38         if 'NO2' in FILE_NAME:
39             print('This is an OHF NO2 file. Here is some information: ')
40             #this is how you access the data tree in an h5py file
41             datafields=file['HDFEOS']['SWATHS']['ColumnAmountNO2']['Data Fields']
42             geolocation=file['HDFEOS']['SWATHS']['ColumnAmountNO2']['Geolocation Fields']
43             SDS_NAME='ColumnAmountNO2'
44             data=datafields[SDS_NAME]
45             map_label=data.attrs['Units'].decode()
46         elif 'SO2' in FILE_NAME:
47             print('This is an OHF SO2 file. Here is some information: ')
48             datafields=file['HDFEOS']['SWATHS']['OHF Total Column Amount SO2']['Data Fields']
49             geolocation=file['HDFEOS']['SWATHS']['OHF Total Column Amount SO2']['Geolocation Fields']
50             SDS_NAME='ColumnAmountSO2_P8'
51             data=datafields[SDS_NAME]
52             valid_min=data.attrs['ValidRange'][0]
53             valid_max=data.attrs['ValidRange'][1]
54             map_label=data.attrs['Units'].decode()
55             print('Valid Range is: ',valid_min,valid_max)
56         else:
57             print('The file named ',FILE_NAME, ' is not a valid OHF file. \n')
```

References

Anenberg, S., et al. (2018), Estimates of the Global Burden of Ambient PM_{2.5}, Ozone, and NO₂ on Asthma Incidence and Emergency Room Visits, *Environ. Health Perspec.*, doi: <https://doi.org/10.1289/EHP3766>.

Duncan, B., et al., (2016), A space-based, high-resolution view of notable changes in urban NO_x pollution around the world (2005–2014), *J. Geophys. Res.*, doi:10.1002/2015JD024121.

Geddes, J. A., et al. (2015), Long-term trends worldwide in ambient NO₂ concentrations inferred from satellite observations for exposure assessment, *Environ. Health Perspec.*, doi:10.1289/ehp.1409567.

Lamsal, L.N., et al. (2008), Ground-level nitrogen dioxide concentrations inferred from the satellite-borne Ozone Monitoring Instrument (OMI), *J. Geophys. Res.*, doi:10.1029/2007JD009235.

Lamsal, L.N., et al. (2010), Indirect validation of tropospheric nitrogen dioxide retrieved from the OMI satellite instrument: Insight into the seasonal variation of nitrogen oxides at northern midlatitudes, *J. Geophys. Res.*, doi:10.1029/2009JD013351.

References

Lamsal, L., et al. (2015), U.S. NO₂ trends (2005–2013): EPA Air Quality System (AQS) data versus improved observations from the Ozone Monitoring Instrument (OMI), *Atmos. Environ.*, <https://doi.org/10.1016/j.atmosenv.2015.03.055>.

Streets et al., (2013), Emissions estimation from satellite retrievals: A review of current capability, *Atmos. Environ.*, doi: <https://doi.org/10.1016/j.atmosenv.2013.05.051>.

Van der A. et al., (2008), Trends, seasonal variability and dominant NO_x source derived from a ten year record of NO₂ measured from space, *J. Geophys. Res.*, doi:10.1029/2007JD009021.

OMI NO₂ V3 paper:

Krotkov, N. A., et al. (2017), The version 3 OMI NO₂ standard product, *Atmos. Meas. Tech.*, 10, 3133-3149, <https://doi.org/10.5194/amt-10-3133-2017>.