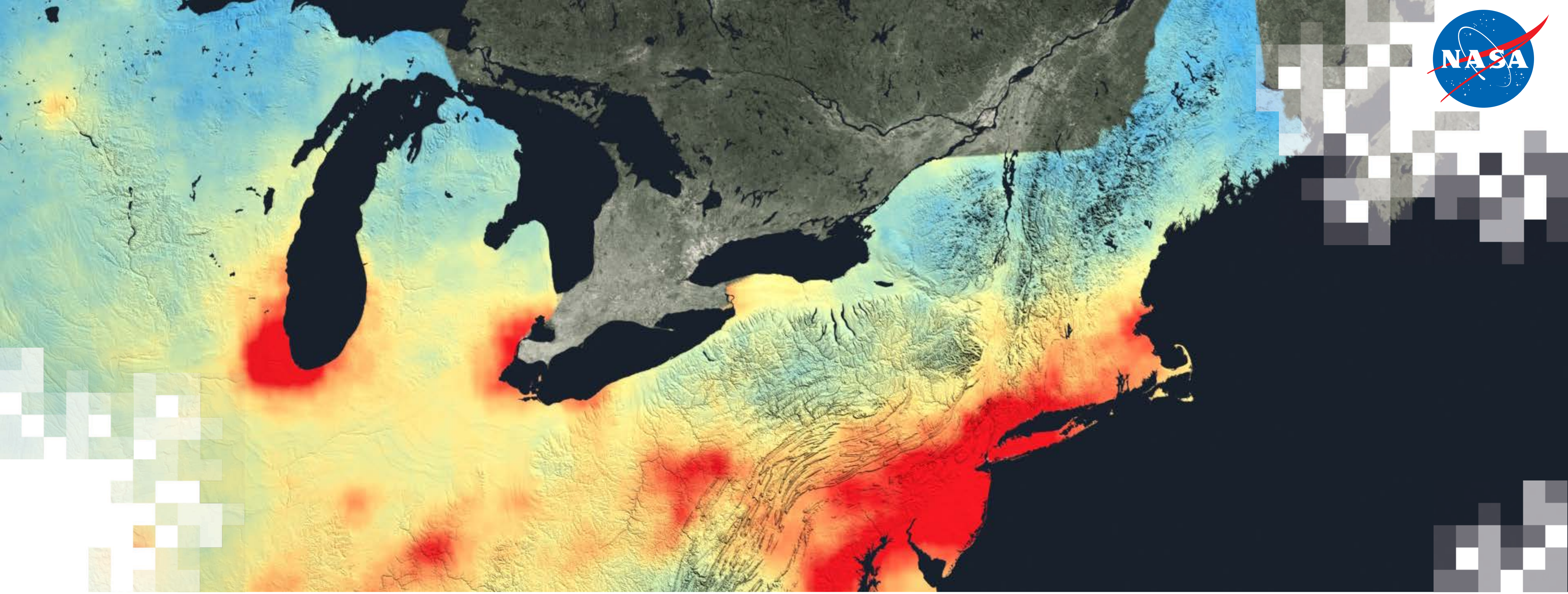


Remote Sensing of Trace Gases

Carl Malings, Melanie Follette-Cook, Pawan Gupta, Sarah Strode

NASA Air Quality Remote Sensing Training for EPA, March 21-23, 2023

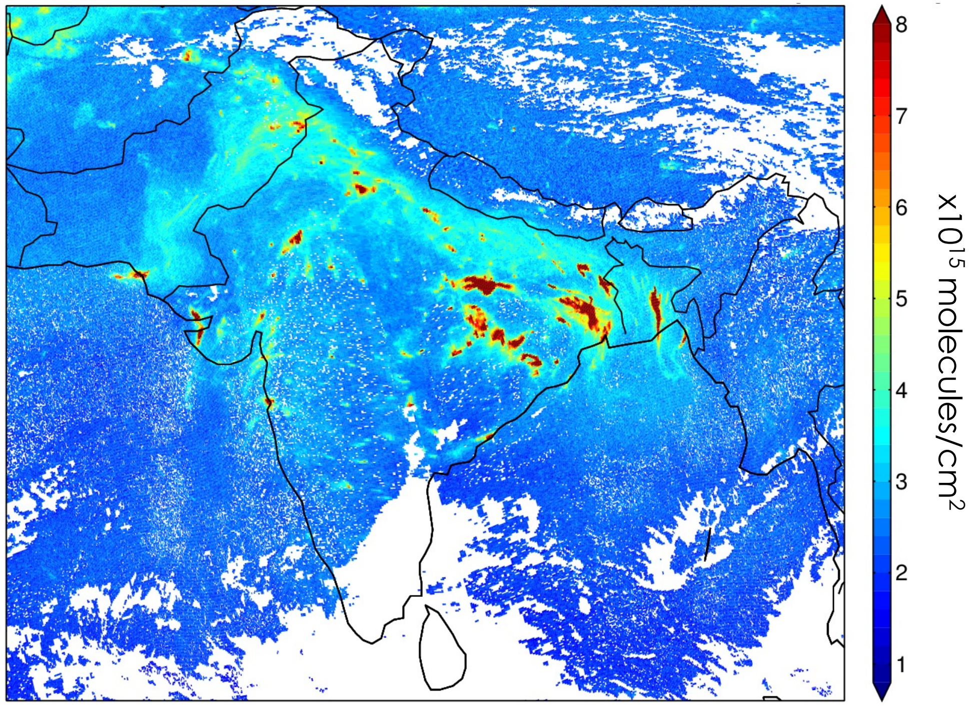
Satellite Remote Sensing of Trace Gases for Air Quality

Overview

- **This presentation will cover several trace gases relevant to air quality.**
  – O_3, NO_2, HCHO, SO_2, CO, and CH_4
- Some fundamentals of observing trace gases
- Information on specific data products
  – Limitations & strengths for air quality
- Specific examples of how data are used

November 28, 2017

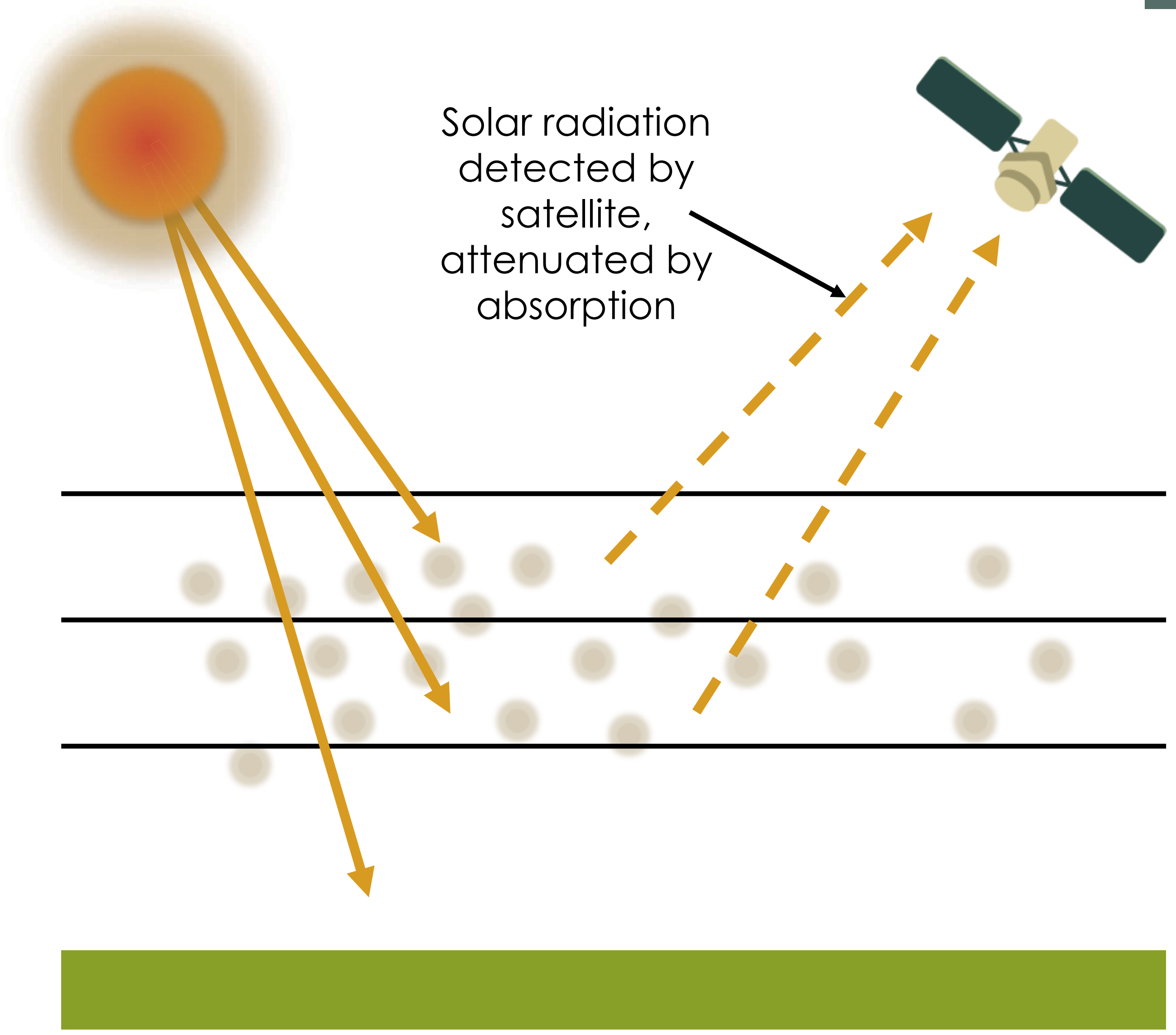
TROPOMI NO_2



Spatial Resolution = 5.5 x 7.0 km^2

Measuring Trace Gases from Space

- Satellites detect backscattered UV, visible, and/or emitted thermal radiation.
- We can determine a "spectral fingerprint" of each trace gas.
- Retrieval algorithms infer physical quantities such as number density, partial pressure, and column amount.
- Little information can be obtained on the vertical distribution of trace gases in the troposphere from a nadir view (limb view can help).



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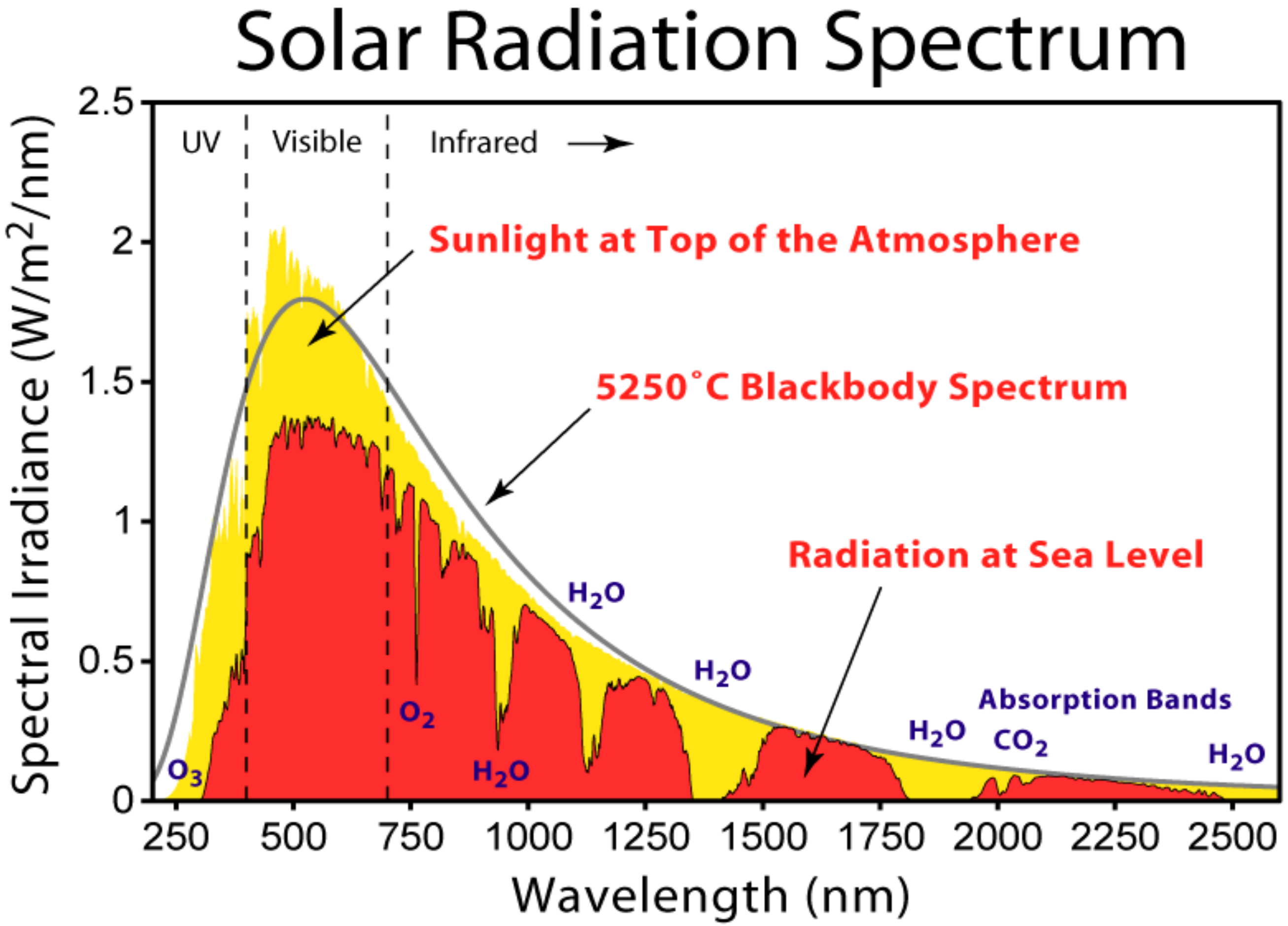


Image Credit: Wikipedia, Solar Spectrum

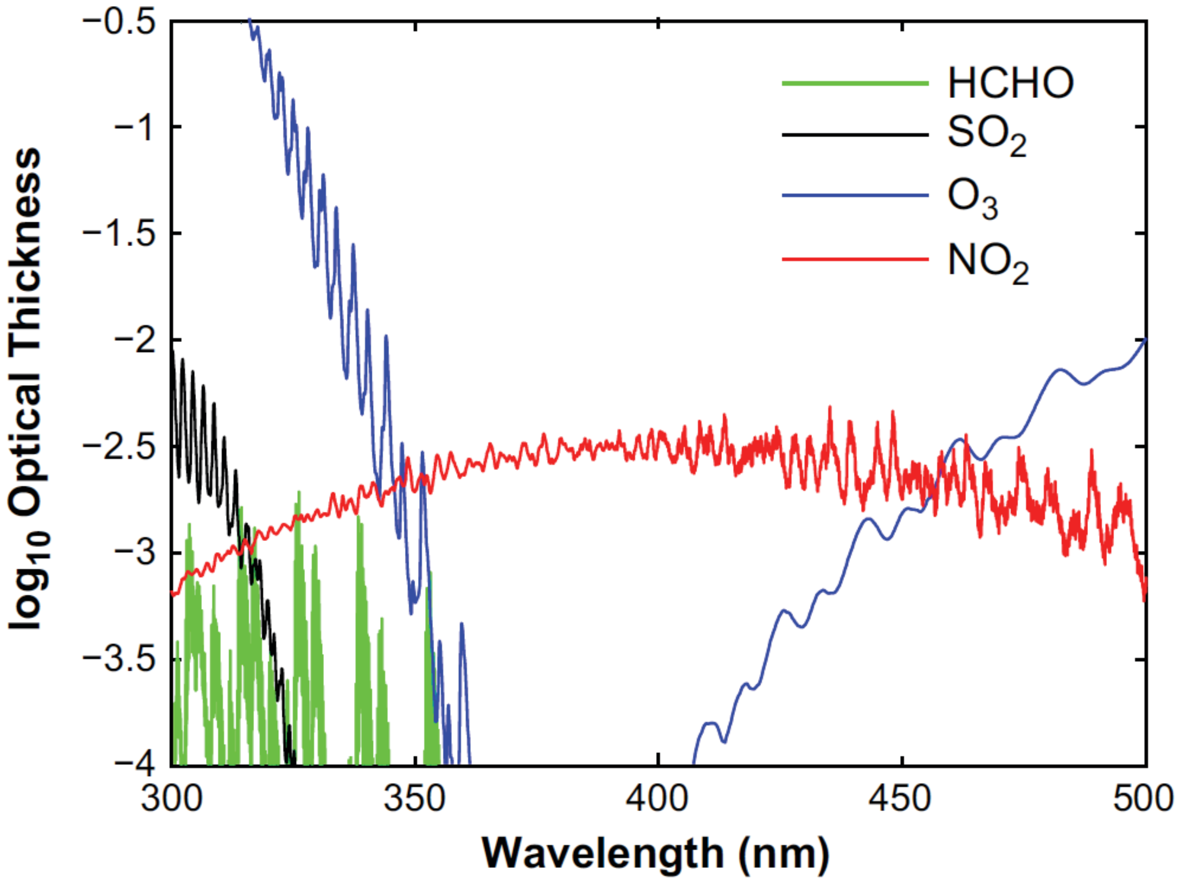
Optical Depth = Cross Section * Trace Gas Abundance

Optical depth or thickness (τ_λ) is a measure of the extinction of the solar beam by trace gases. In other words, trace gases in the atmosphere can block sunlight by absorbing or by scattering light.

$$\tau_\lambda = \sigma_\lambda \, \Omega$$

Where Ω is the trace gas abundance over the atmospheric path length, such as a vertical column.

Note: Optical depth is calculated in different ways for trace gases and aerosols.

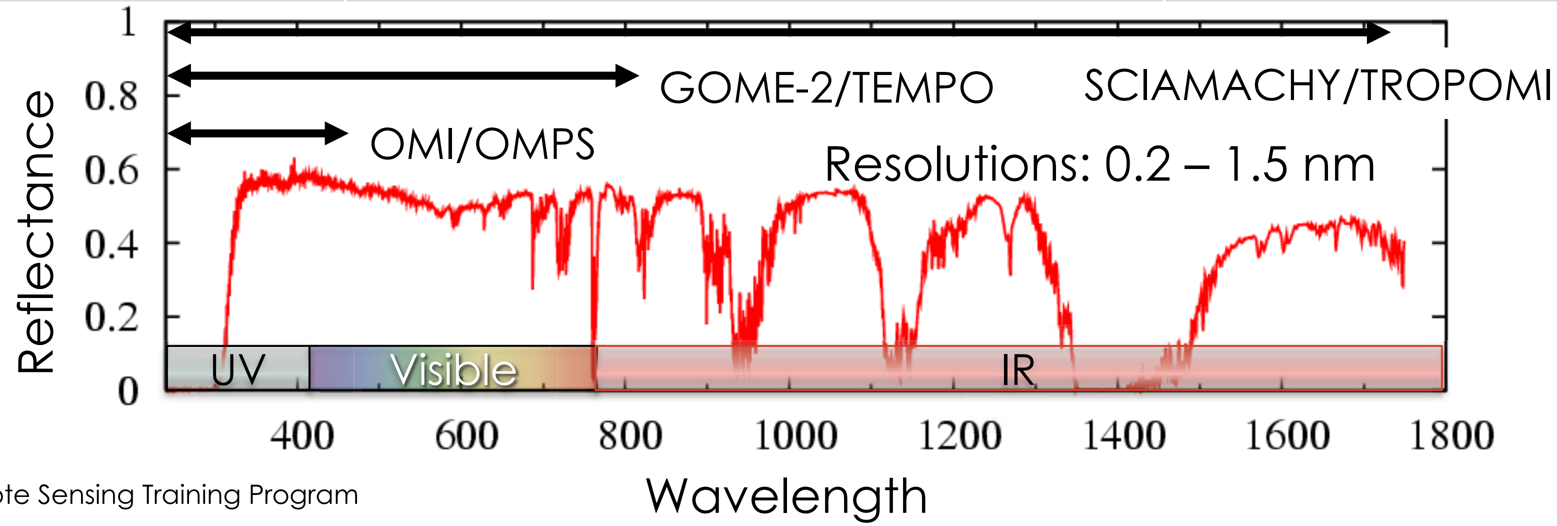


Martin, R.V., Satellite remote sensing of surface air quality, Atmos. Environ., 42, 7823-7843, 2008.

Hyperspectral Instruments

Current, Past, and Future Satellite UV-Visible-IR Spectrometers

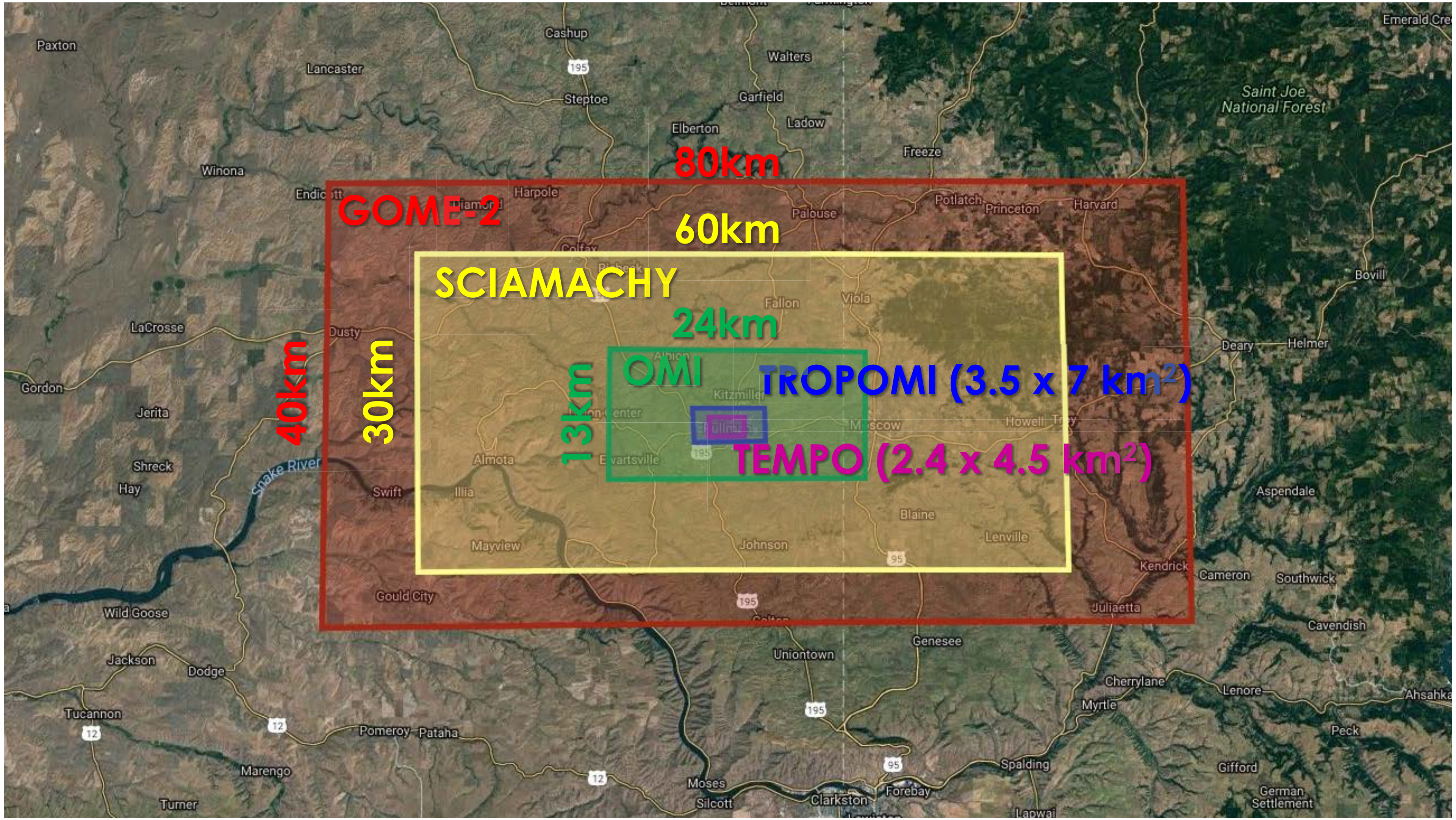
Instrument	Satellite	Wavelength
GOME (Defunct)	ERS-2	240 – 795 nm
SCIAMACHY (Defunct)	Envisat	240 – 2380 nm
OMI	EOS-Aura	270 – 500 nm
GOME-2	Metop-A, B, & C	240 – 790 nm
OMPS	Suomi-NPP, JPSS Series	250 – 380 nm
TROPOMI	Sentinel-5P	270 – 775 nm, 2305 – 2385 nm
TEMPO (Future)	Intelsat 40e (Geostationary)	290 – 490 nm, 540 – 740 nm



Trace Gases: Spatial Resolution

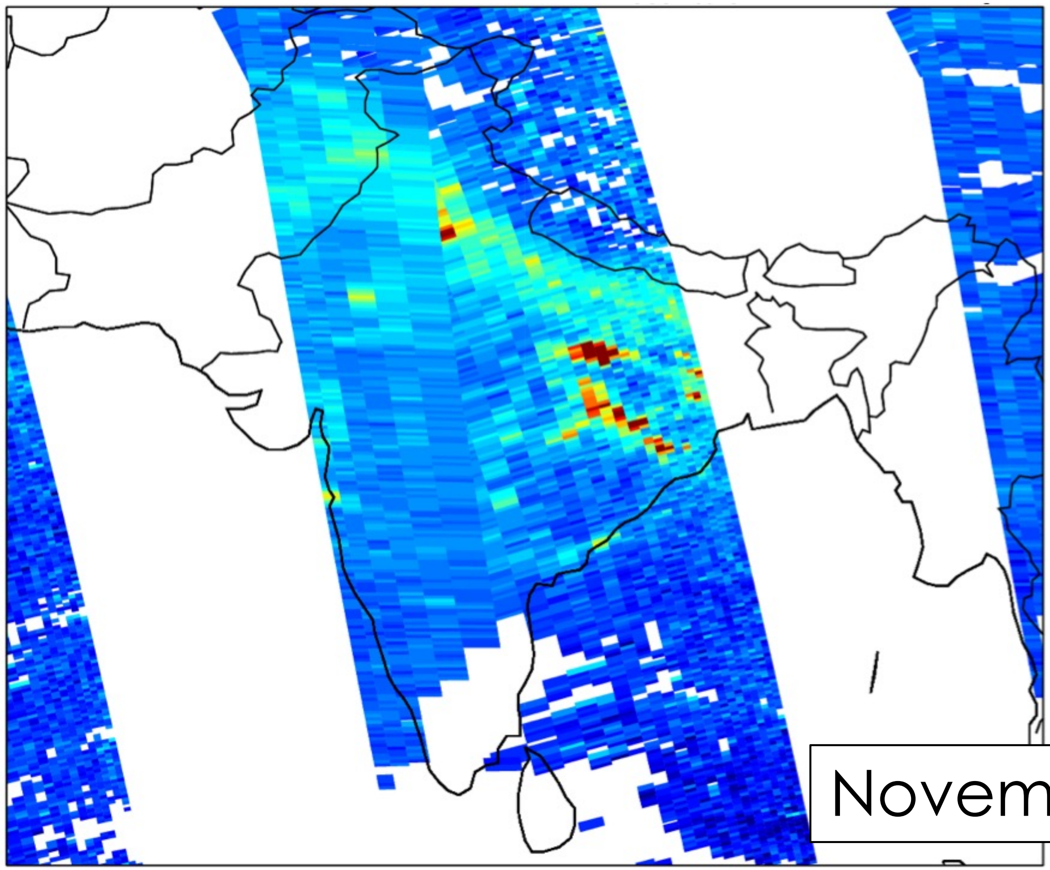
- Spatial resolution of current satellite instruments (~10 km diameter)
  - Good enough to map tropospheric concentration fields on local to regional scales
  - Fine enough to resolve individual power plants and large cities
- For species with short atmospheric lifetimes (e.g., NO_2), averaging over 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.

Evolution of Spatial Resolution



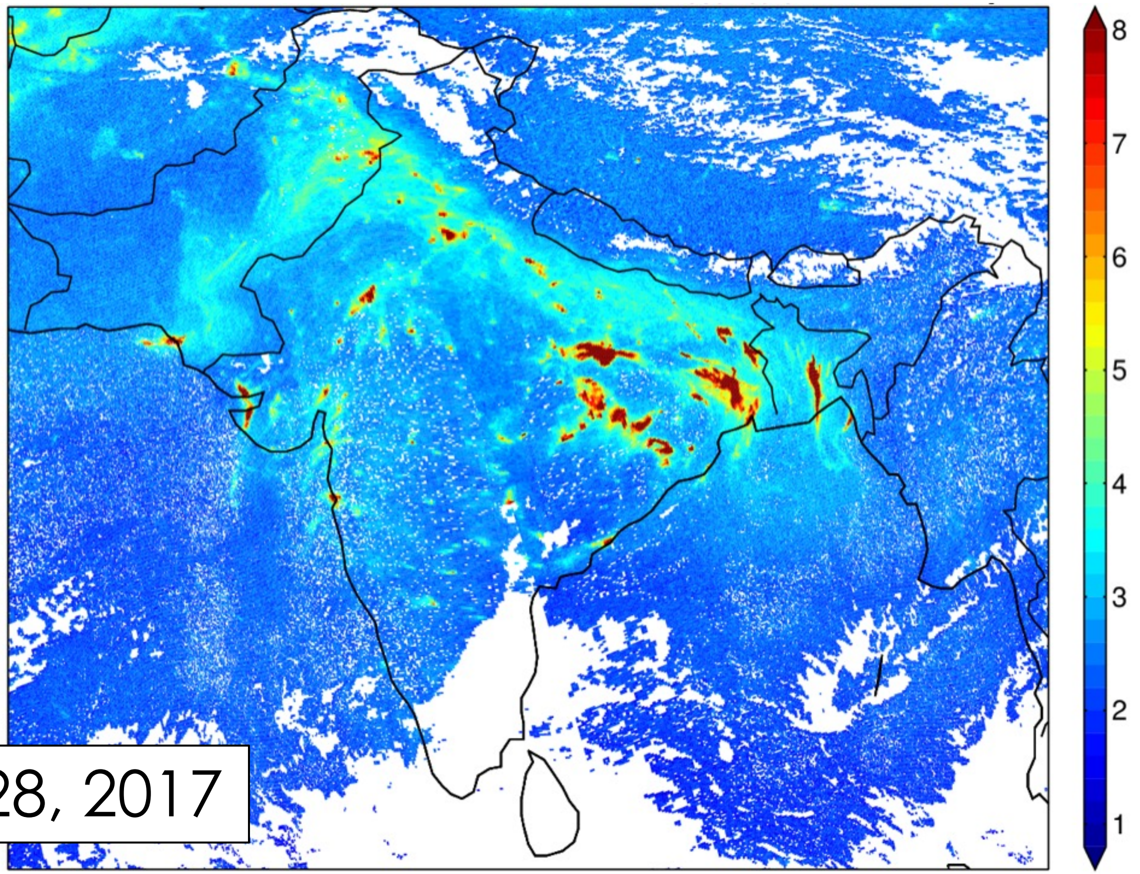
TROPOMI: Impact of Resolution

OMI NO_2



Spatial Resolution = 13 x 24 km^2

TROPOMI NO_2



Spatial Resolution = 5.5 x 7.0 km^2

November 28, 2017

Trace Gases: Temporal Resolution

- The current fleet of polar-orbiting satellites with hyperspectral instruments enables a revisit time on the order of **1 day**, with overpasses typically in the early afternoon.
  - Cannot provide any information about diurnal variations
- Future Geostationary satellites with hyperspectral instruments will enable **hourly** temporal resolution (during daylight hours) for normal operations and even higher temporal resolution (~10 minutes) during targeted special operations.
  - GEMS (East Asia)
    - Launched Feb. 19, 2020
  - TEMPO (North America)
    - Ready for Launch ~April 2023
  - Sentinel-4 (Europe)
    - Instrument fitting to host sat.

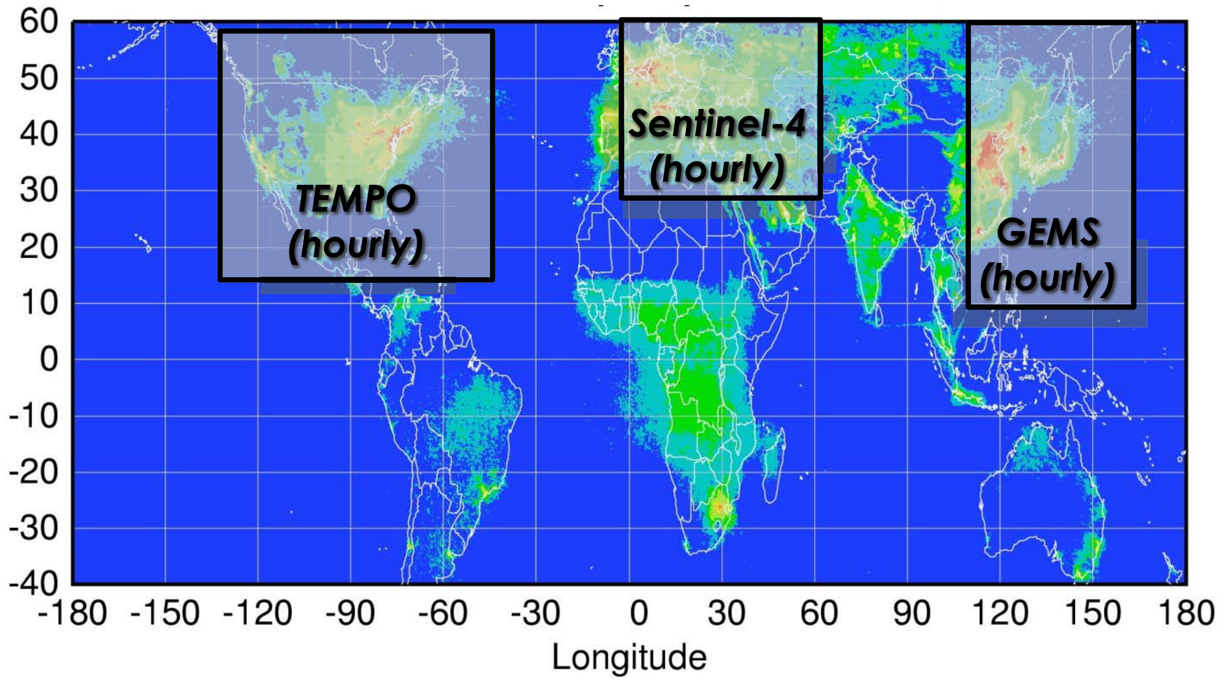
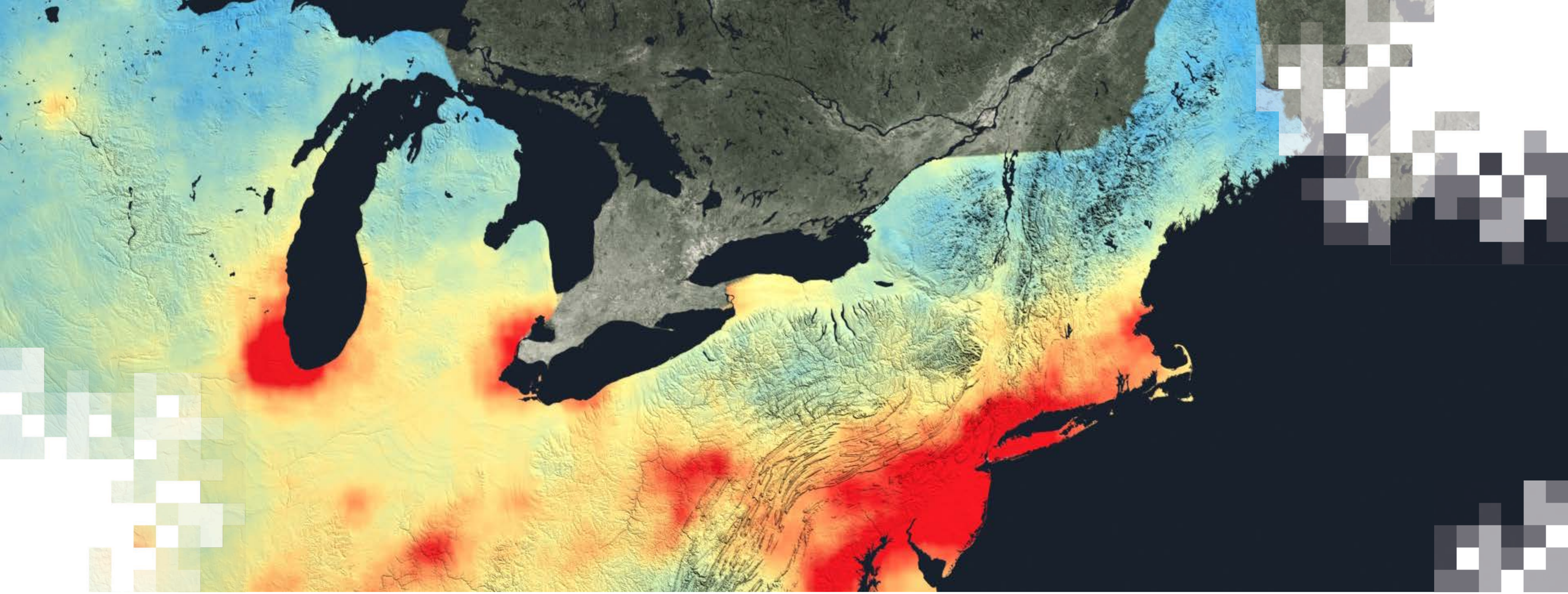


Image Credit: Courtesy Jhoon Kim, Andreas Richter

Trace Gases: Using Level 3 vs. Level 2 Data

- Advantages of Level 3 Data:
  – Uniform grid (usually lat/lon)
  – One file per time period (day, month, year, etc.)
  – Smaller sized files
  – Quality flags and filtering criteria have been applied
- Limitations of Level 3 Data:
  – Typically, at coarser resolution than L2
  – L2 observation typically at the same location as the L1 source data
  – Space & time averaging can obscure meaningful differences
  – Not all instruments have L3 products (e.g., TROPOMI)



OMI & TROPOMI

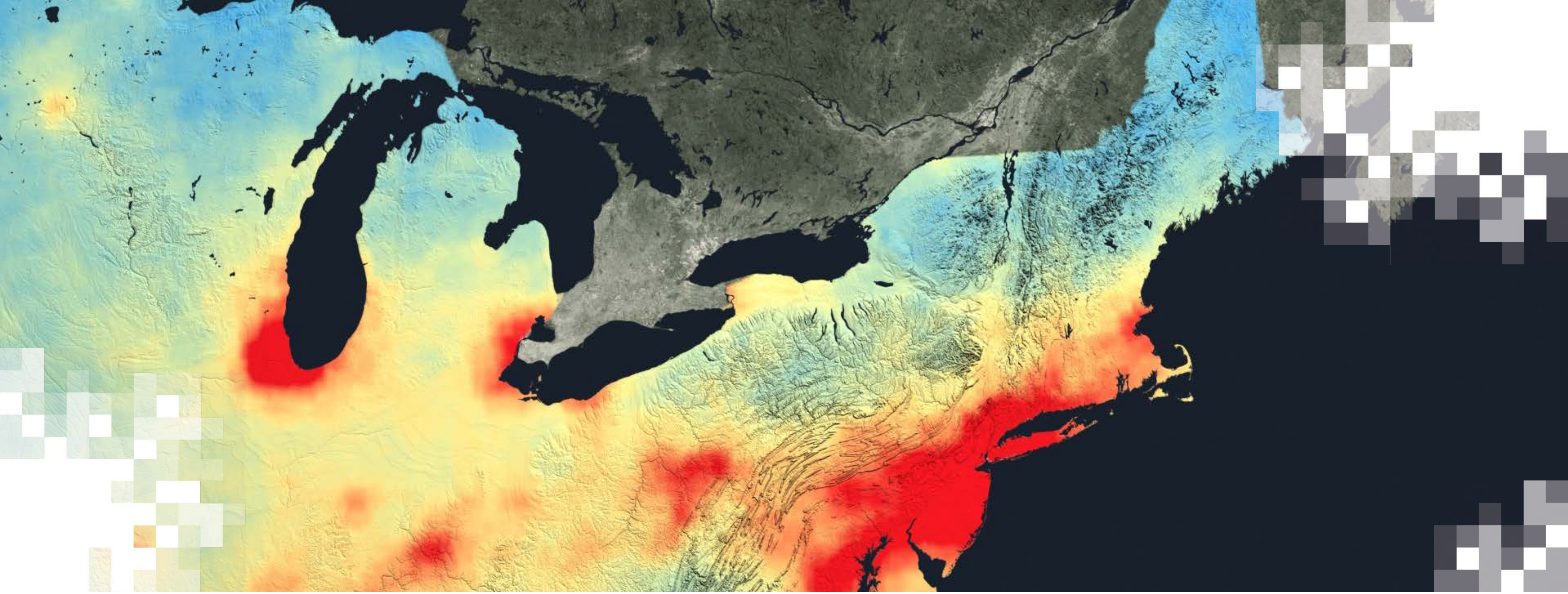
OMI vs TROPOMI

OMI		TROPOMI
Aura	*Satellite*	Sentinel-5P
July 2004	*Launched*	Oct 2017
Nadir-Viewing Imaging Spectrometer	*Instrument*	Nadir-Viewing Imaging Spectrometer
264 – 504 nm (UV/VIS)	*Spectral Range*	270 nm – 2.3 μm (UV/VIS/NIR/SWIR)
0.42 – 0.63 nm	*Spectral Resolution*	0.55 nm
13x24 km^2 at Nadir	*Spatial Resolution*	5.5 x 3.5 km^2 at Nadir 7 x 28 km^2 (UV1 Band) 7 x 7 km^2 (SWIR Bands)
Daily	*Global Coverage*	Daily
~ 13:45 LST	*Local Overpass Time*	~ 13:30 LST*

*synchronized within 5 minutes of SNPP

Products from OMI vs. TROPOMI

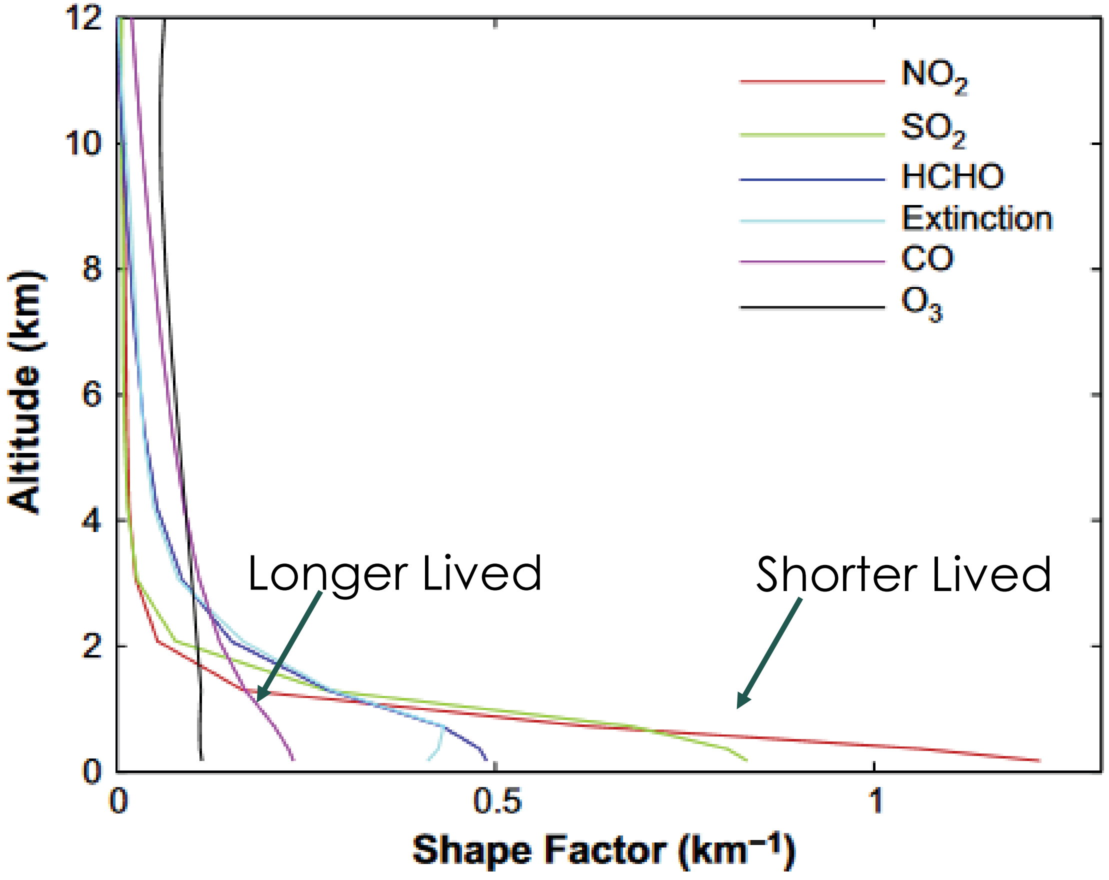
OMI		TROPOMI	
Tropospheric and Total Column NO_2	Swath, Gridded (0.25° and 0.1°)	Tropospheric and Total Column NO_2	Swath (5.5 km x 3.5km)
Total Column SO_2	Swath, Gridded (0.25°)	Total Column SO_2	Swath (5.5 x 3.5 km)
Aerosol Index	Swath	Aerosol Index	Swath (5.5 x 3.5 km)
Total Column HCHO	Swath, Gridded (0.1°)	Tropospheric Column HCHO	Swath (5.5 x 3.5 km)
Tropospheric and Total Column O_3	Gridded (0.25°)	Tropospheric, Total Column O_3, Profiles	Swath (5.5 x 3.5 km)
		Aerosol Layer Height	Swath (5.5 x 3.5 km)
		Carbon Monoxide (CO)	Swath (7 km x 5.5 km)
		Methane (CH_4)	Swath (7 km x 5.5 km)



O_3

Ozone in the Troposphere

- Why measure tropospheric ozone?
  - Negative health impacts for humans, crops, and ecosystems
  - Important to tropospheric chemistry
- Retrieval of boundary layer ozone from satellite remote sensing remains daunting.
  - Separation of total column into stratospheric and tropospheric contributions needed
  - Potential for significant free tropospheric contribution to the tropospheric column
- Tropospheric ozone products cannot be used for air quality monitoring



Martin, R.V., Satellite remote sensing of surface air quality, Atmos. Environ., 42, 7823-7843, 2008.

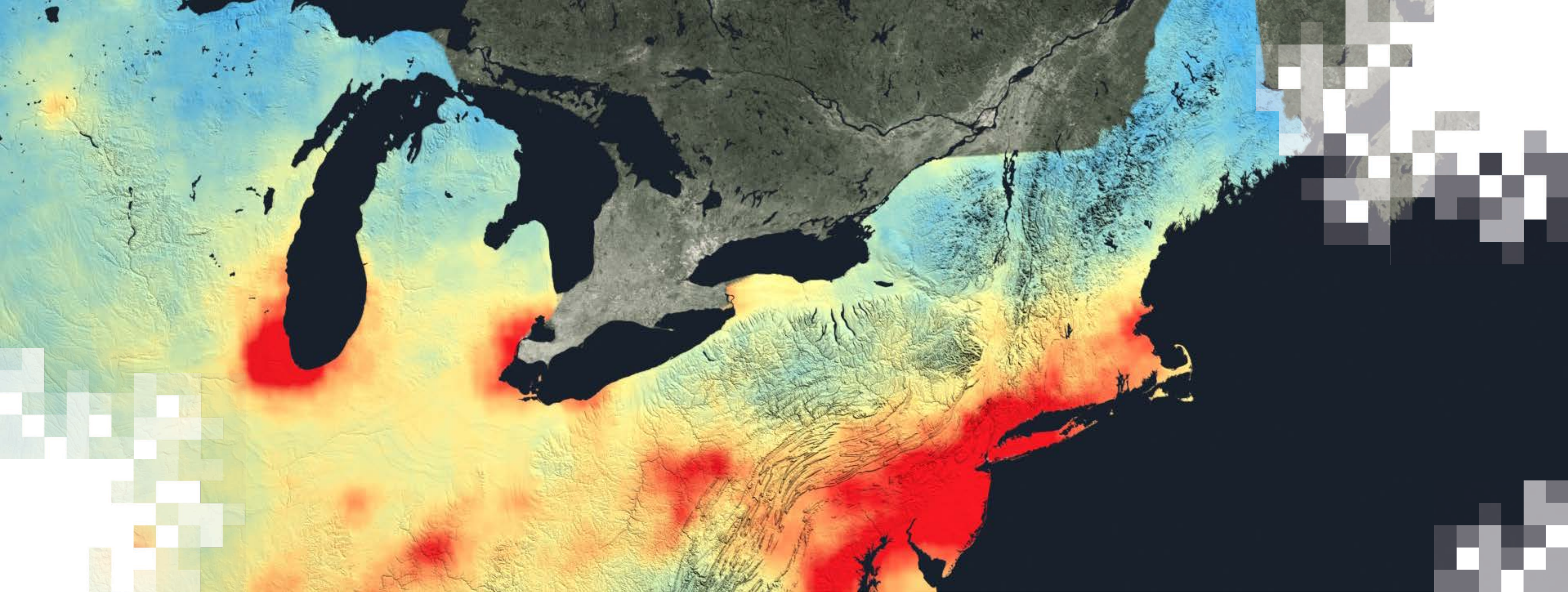
Ozone Products

OMI

- Available at https://disc.gsfc.nasa.gov/
- Total Column Ozone
  - OMTO3
- DOAS Total Column
  - OMDOAO3e
  - Level 3 (0.25° x 0.25° Daily)
- TOMS-Like Ozone
  - OMTO3e
  - Level 3 (0.25° x 0.25° Daily)

TROPOMI

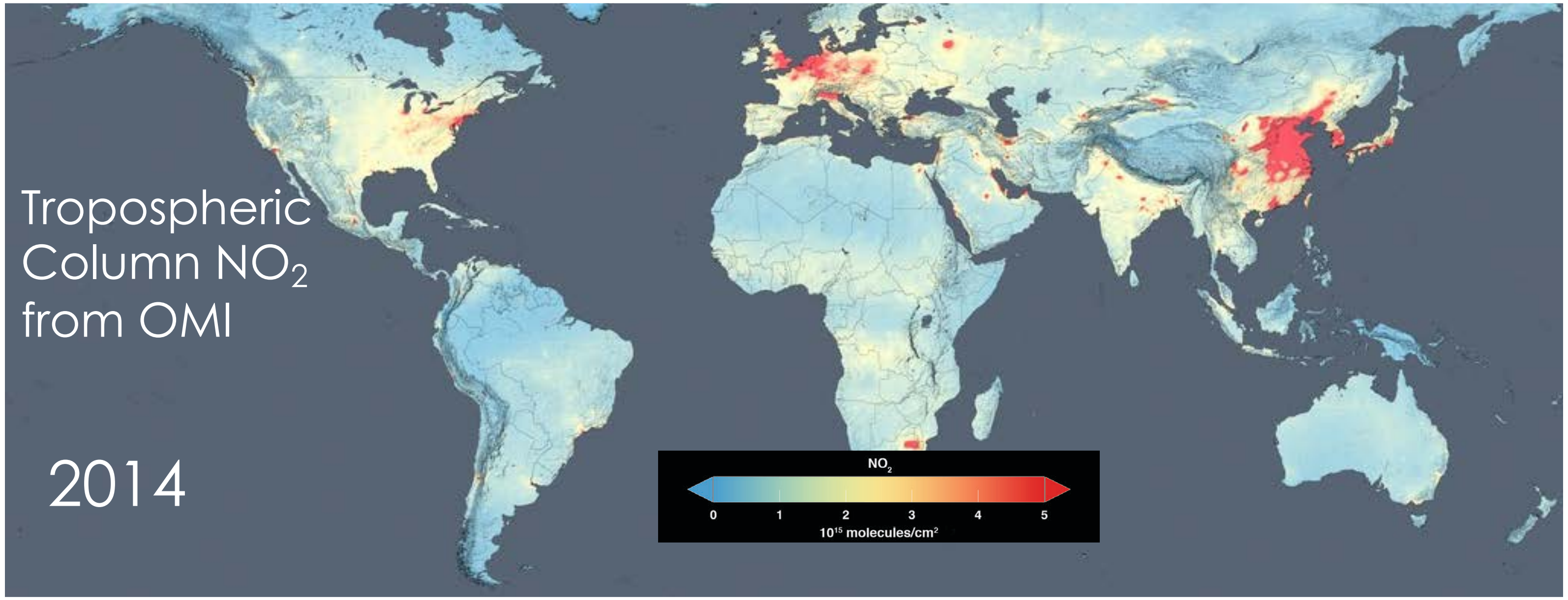
- Available at https://disc.gsfc.nasa.gov/
- Total Column Ozone
  - S5P_L2__O3_TOT, S5P_L2__O3_TOT_HiR
- Tropospheric Column Ozone
  - S5P_L2__O3_TCL
  - Gridded Product: 0.5° x 1.0° Resolution
  - Only Available 20°S to 20°N
- Ozone Vertical Profiles
  - S5P_L2__O3__PR_HiR
  - Vertical Resolution: 6 km
  - Horizontal Resolution: 30 x 30 km^2



Tropospheric Column NO_2

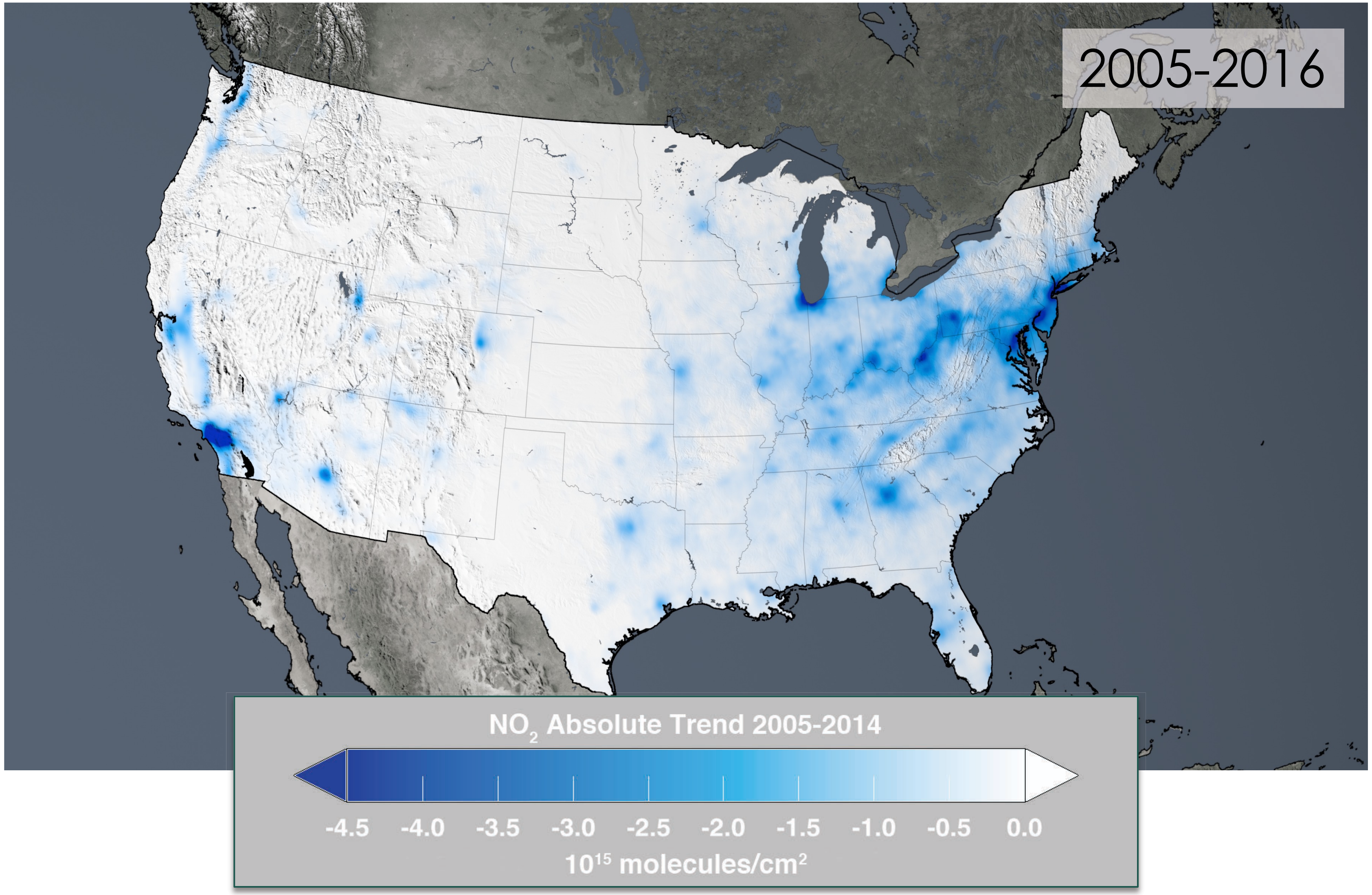
Nitrogen Dioxide (NO_2)

- Why measure NO_2?
  - NO_2 is an ozone precursor and health irritant.
  - Surface 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)



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

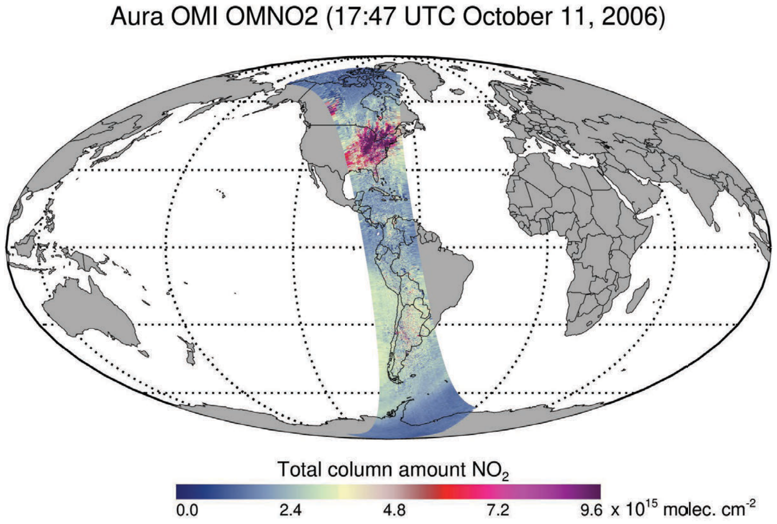
OMI Detects NO_2 Changes in Pollution Over Time



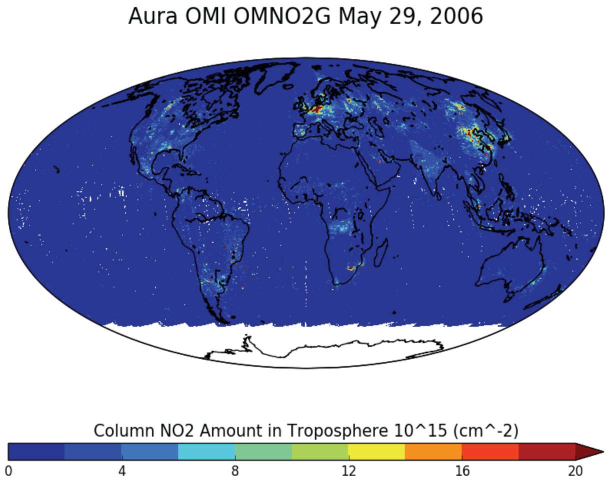
OMI NO_2 Products

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

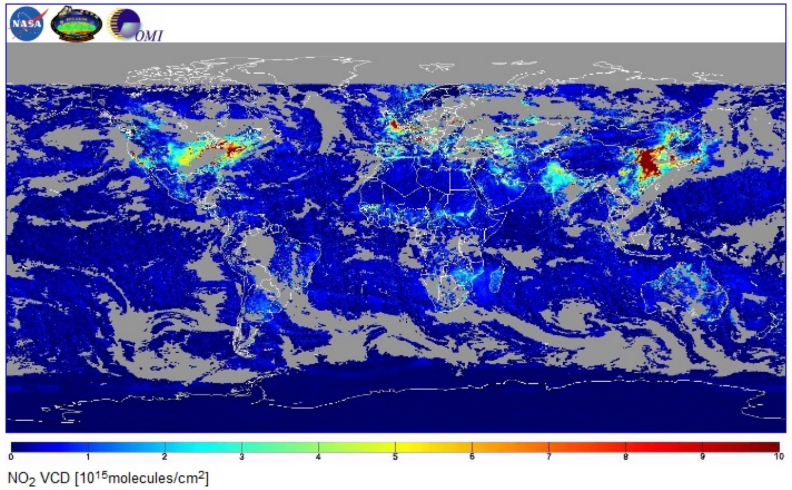
OMNO2 Level 2
Native Resolution



OMNO2g Level 2 Gridded
(0.25° x 0.25°)
no pixel averaging



OMNO2d Level 3 Gridded
(0.25° x 0.25°)
pixel averaging



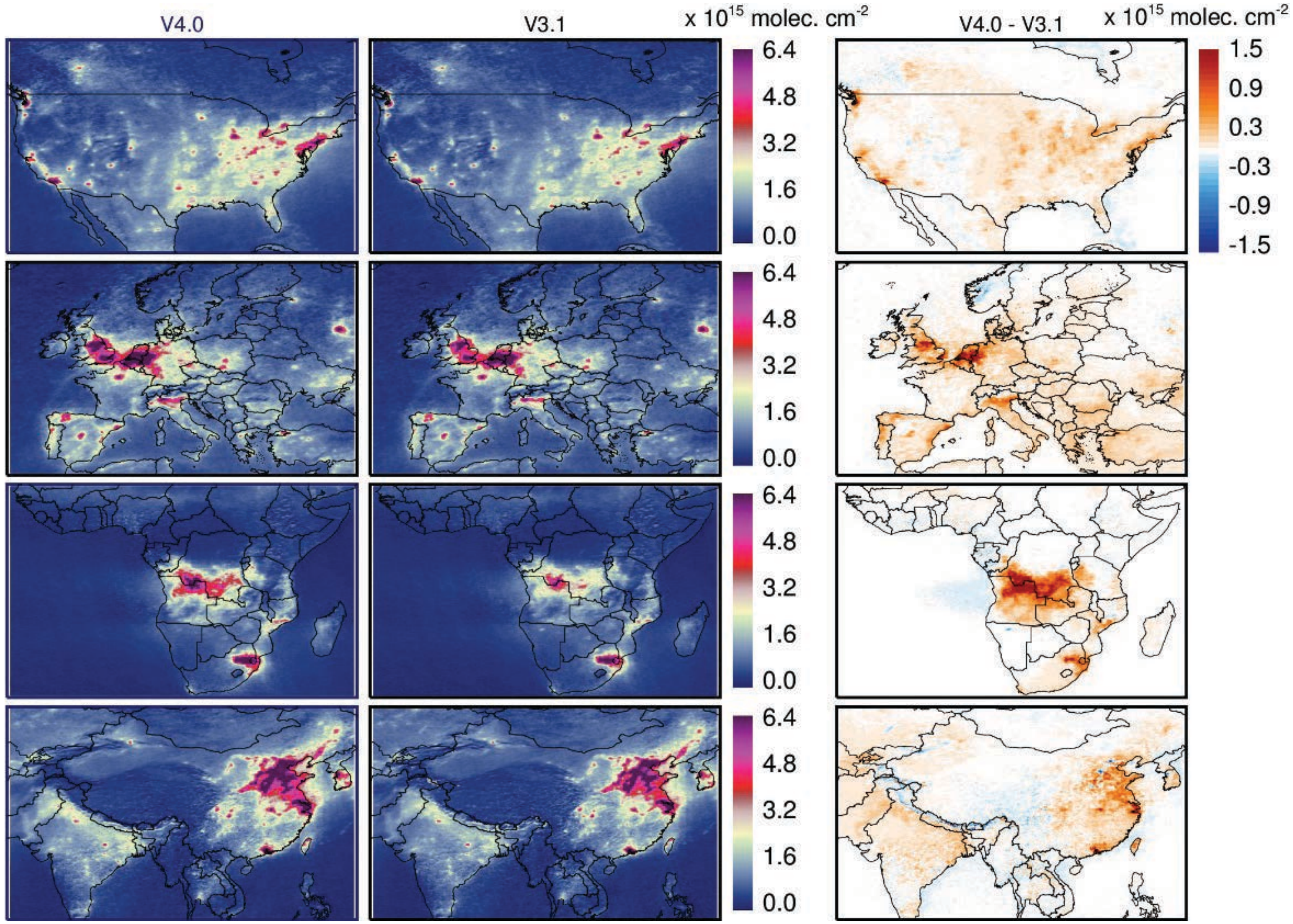
New OMI NO_2 V4

- V4 OMI NO2 Standard Product (OMNO2) with updated AMF [Lamsal et al., 2021]
  - https://amt.copernicus.org/articles/14/455/2021/
  - New geometry-dependent surface reflectivity (GLER)
  - New (GSFC) O_2-O_2 cloud products with GLER (OMCDO2N)
  - Improved Field-Of-View (FOV) specific terrain pressure
  - Improved ice/snow treatment using retrieved scene LER/pressure
  - Internal consistency between NO_2 and cloud retrievals
- Other features kept same as in V3.1 (released 2018) [Krotkov et al., 2017]
  - https://www.atmos-meas-tech.net/10/3133/2017/
  - New algorithm for slant column retrievals
  - Use of higher-resolution (1° x 1.25°) GMI monthly a priori NO_2 profiles with year specific emissions

Source: Lok Lamsal

OMI V4 Tropospheric NO_2 Columns Higher than V3.1 Over Polluted Regions

June-July-August 2005



Source: Lok Lamsal

OMI NO_2 Parameter Information (OMNO2)

SDS Name	Description	Unit	Notes
ColumnAmountNO2Trop	Tropospheric Column NO_2	Molec / cm^2	• Use only scenes with: radiative cloud fraction < 0.5-0.7 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: ($-2.^{100} \approx -1.26765\times10^{30}$)
- All row anomaly pixels have fill values
- Preserve small negative pixel values when computing statistics (e.g., averages)

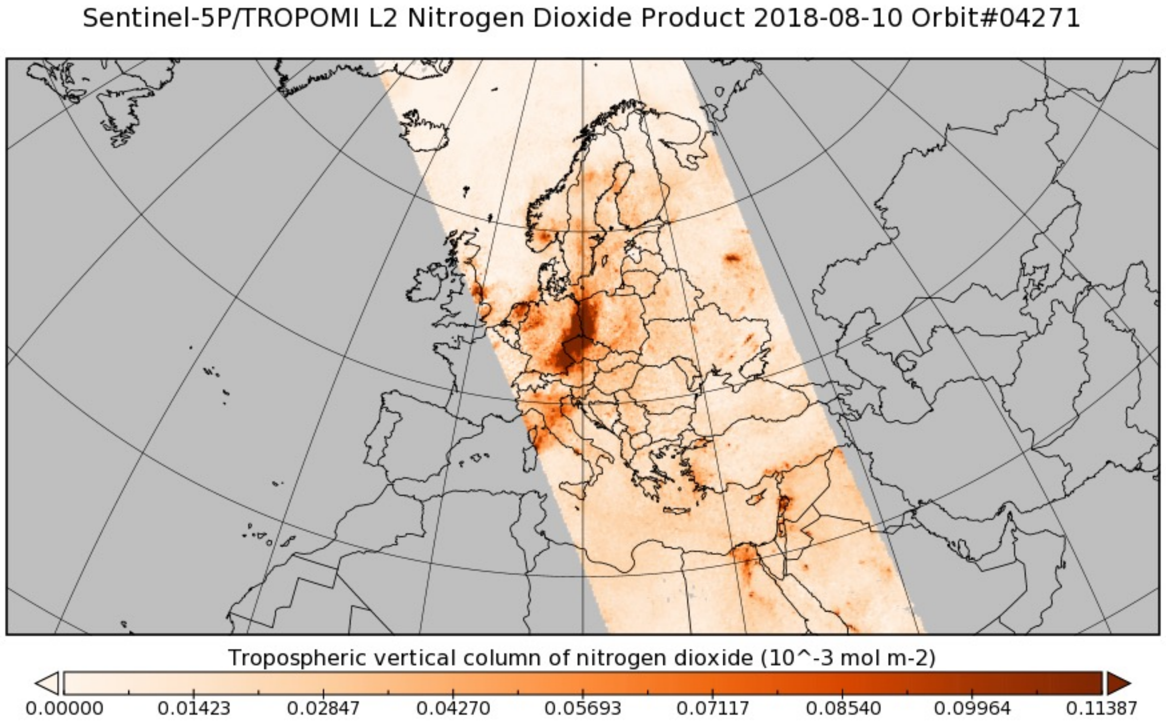
OMNO2_HR Gridded High Resolution OMI NO_2 (0.1° x 0.1°)

- 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), NetCDF format, and TIF images

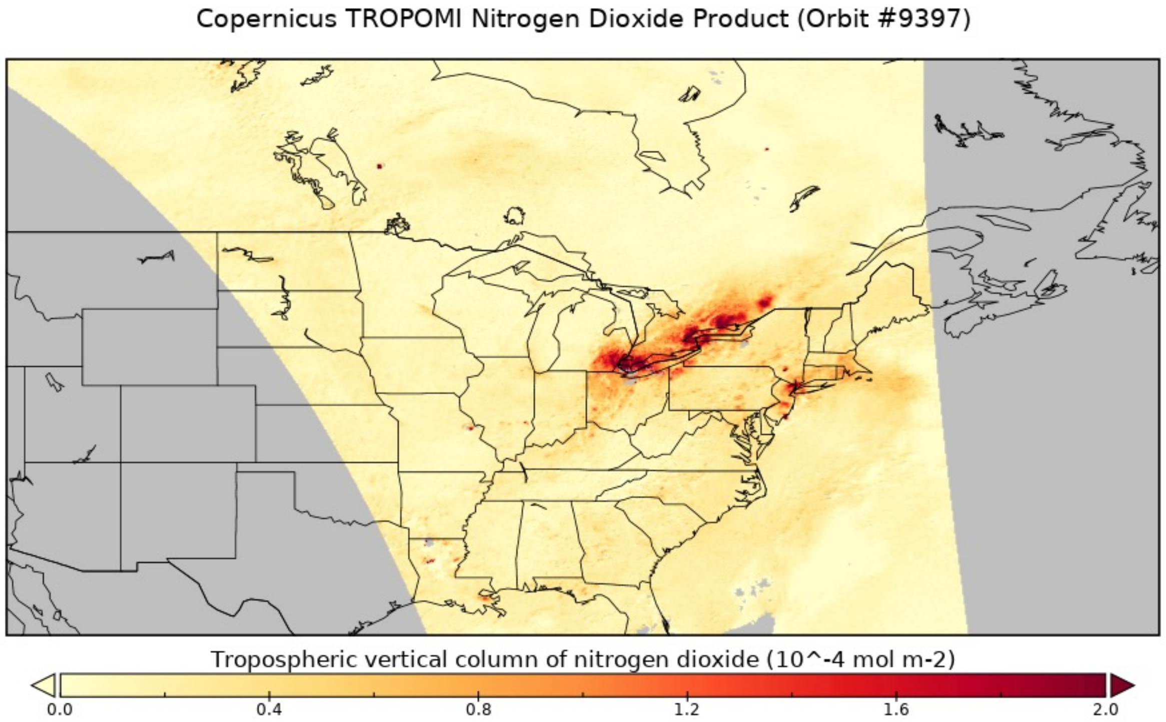
TROPOMI NO_2 Products

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

S5P_L2__NO2____ – Level 2 – 7km x 3.5km
(4/30/2018 – 8/6/2019)



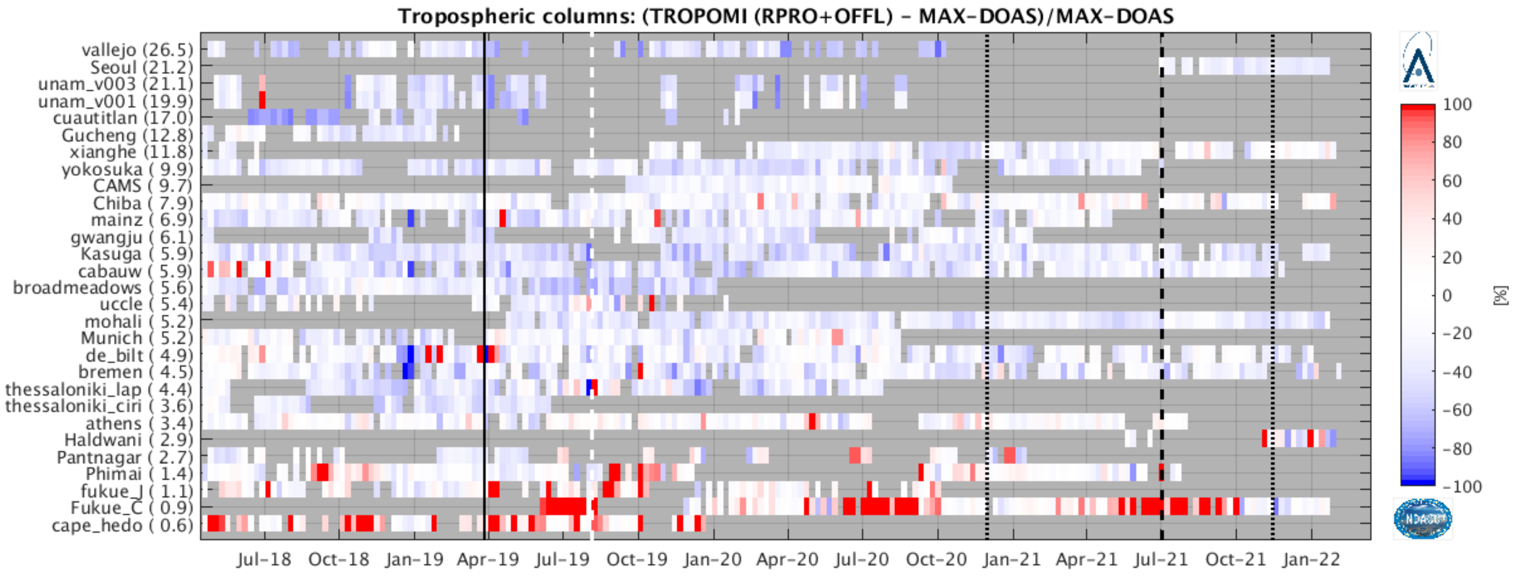
S5P_L2__NO2____HiR – Level 2 – 5.5km x 3.5km
(v1: 8/6/2019 – 7/1/2021; v2: 7/1/2021 onwards)



TROPOMI NO_2 Validation

http://mpc-vdaf.tropomi.eu/

Validation against PANDORA and MAX-DOAS surface remote sensing networks



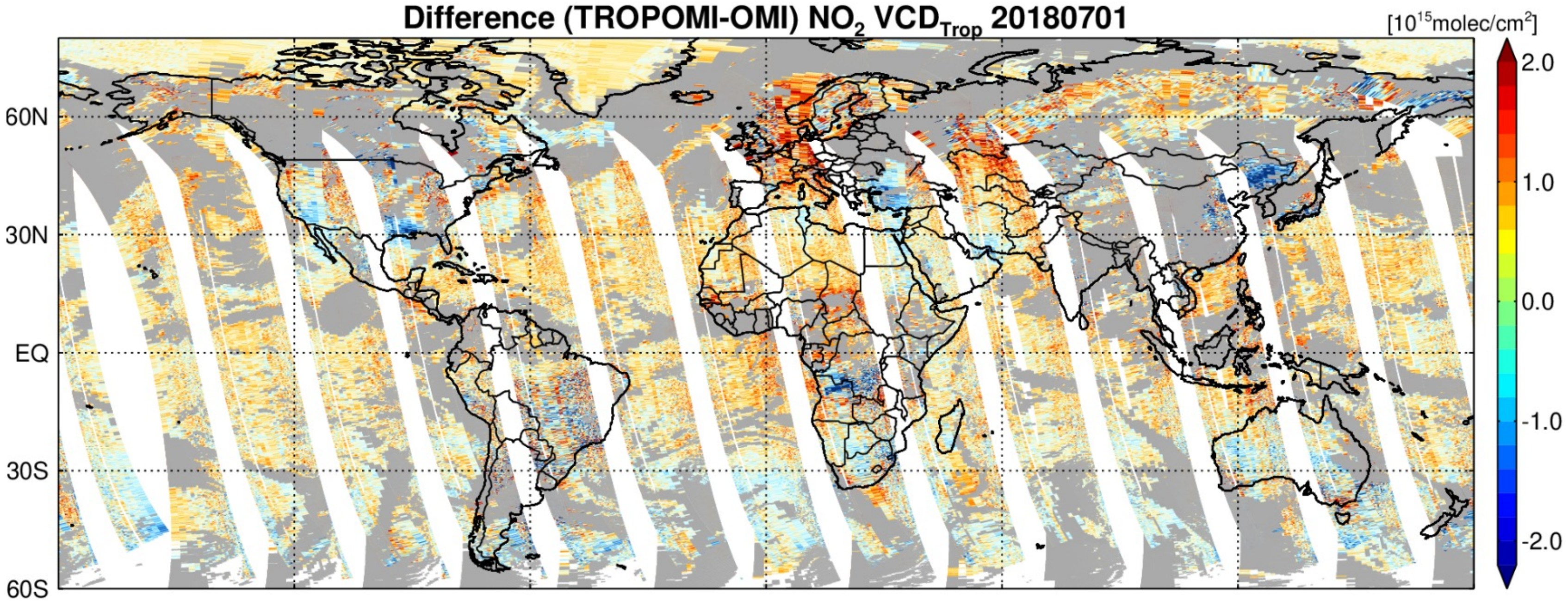
Update of Verhoelst et al., AMT v14, p481, 2021, produced by BIRA–IASB for the S5p MPC VDAF on 01–Mar–2022 using NDACC reference data

Product ID	Stream	Product	Bias	Dispersion	Special features
L2_NO2	NRTI	NO_2 troposphere	-37%	2.6 Pmolec/cm^2	Total NO_2 bias varies with column amount: positive bias over low pollution, negative bias over high pollution, with 7 Pmolec/cm^2 as a threshold.
		NO_2 stratosphere	-5%	0.3 Pmolec/cm^2	
		NO_2 total	0±50%	-	
	OFFL RPRO	NO_2 troposphere	-34%	2.6 Pmolec/cm^2	
		NO_2 stratosphere	-6%	0.3 Pmolec/cm^2	
		NO_2 total,low	+4%	0.9 Pmolec/cm^2	
		NO_2 total,high	-21%	2 Pmolec/cm^2	

Content Source: TROPOMI Nitrogen Dioxide Validation Summary Website: https://mpc-vdaf.tropomi.eu/index.php/nitrogen-dioxide

How does TROPOMI compare with OMI?

- Operational TROPOMI tropospheric NO_2 columns are lower than OMI in polluted areas; the difference is due to the use of the new GLER-cloud in the OMNO2 V4 product (communication: Lok Lamsal).
- Striping issue could impact long term trend
- Reasonable agreement with Pandora

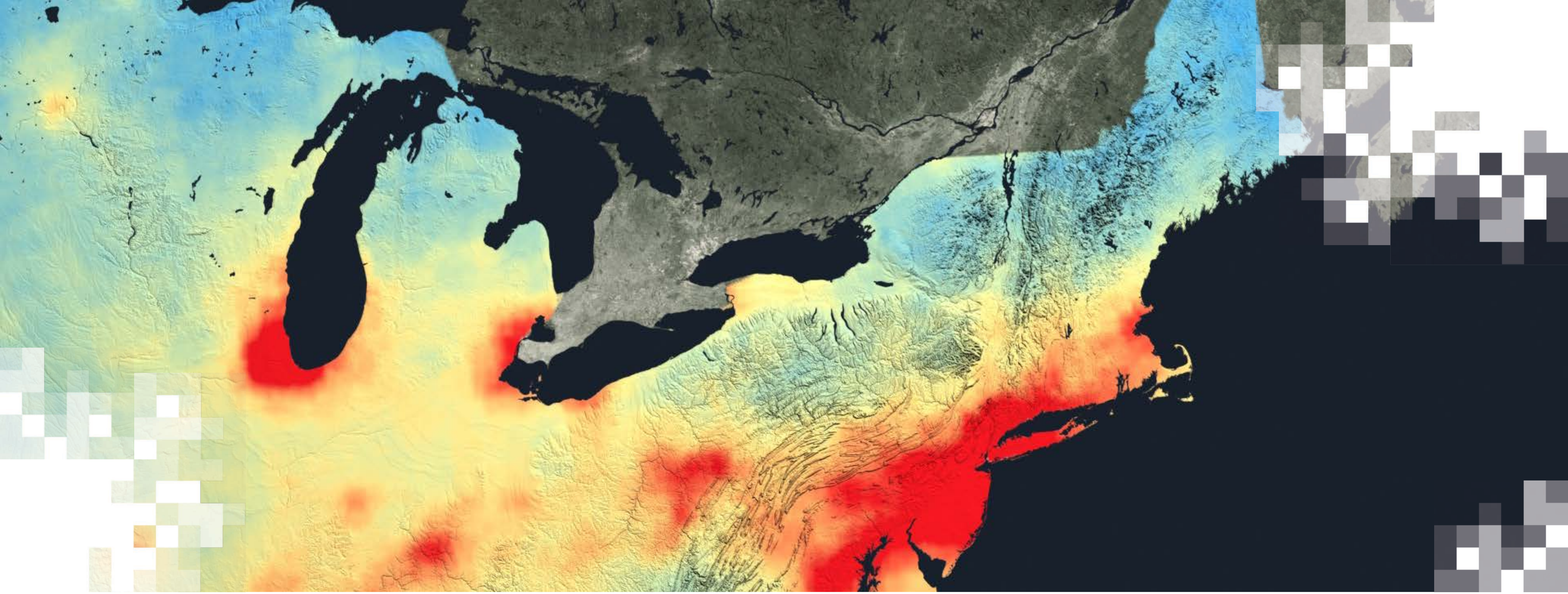


Source: Lok Lamsal

TROPOMI NO_2 Parameter (SDS) Information

SDS name	Description	Unit	Notes
nitrogendioxide_tropospheric_column	Tropospheric Column NO_2	mol/m^2	Estimated accuracy provided in nitrogendioxide_tropospheric_column_precision
nitrogendioxide_total_column	Total Column NO_2	mol/m^2	Estimated accuracy provided in nitrogendioxide_total_column_precision
qa_value	Data Quality Value	Unitless	Range 0 (worst) to 1 (best)

- Recommended to use qa_value > 0.75, use of qa_value > 0.5 is acceptable



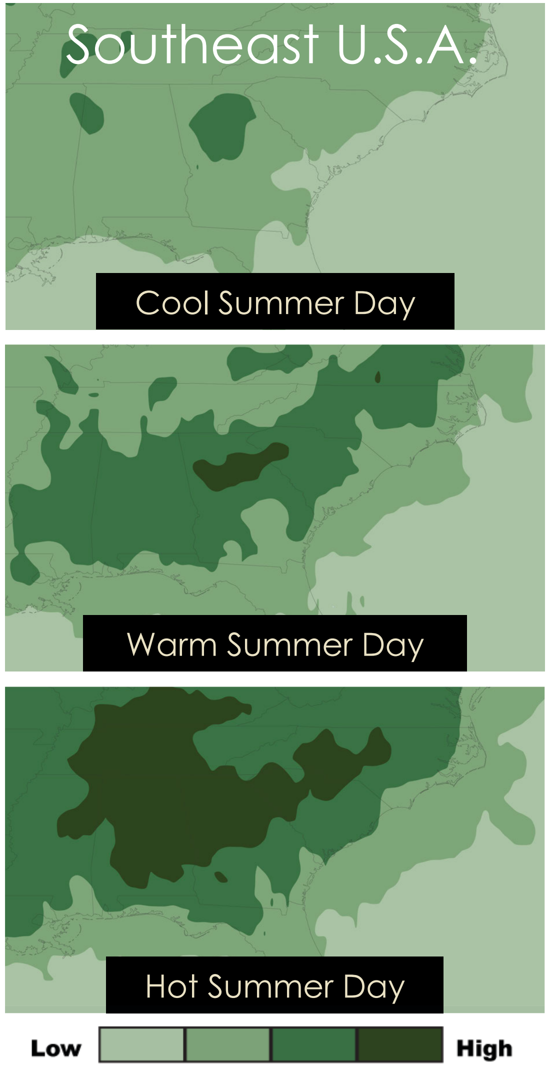
HCHO

Formaldehyde (HCHO)

- Why measure formaldehyde?
  - It is an ozone precursor and can serve as a proxy for total VOC chemical reactivity and isoprene emissions.

- Caution when using these data for quantitative analyses

- OMI and TROPOMI
  - Biased high for small HCHO levels
  - Biased low for high HCHO levels
  - Likely require spatial and/or temporal averaging to cancel random noise



Source: Bryan Duncan (NASA)

Where to get HCHO Data

OMI – NASA/Smithsonian Retrieval

- Level 2G Data (0.25° x 0.25°): https://disc.gsfc.nasa.gov/datasets/OMHCHOG_V003/summary
- Level 3 Data (0.1° x 0.1°): https://disc.gsfc.nasa.gov/datasets/OMHCHOd_003/summary
- Readme Document: https://www.cfa.harvard.edu/atmosphere/Instruments/OMI/PGEReleases/READMEs/OMHCHO_README_v3.0.pdf

OMI – BIRA Retrieval

- Level 3 daily files, monthly, and annual averages: http://h2co.aeronomie.be/

TROPOMI

- Level 2 (5.5 km x 3.5 km): https://disc.gsfc.nasa.gov/datasets/S5P_L2__HCHO___HiR_2/summary

Using HCHO/NO_2 Ratios

- Ozone formation chemistry is sensitive to relative NO_X and VOC concentrations in different regimes.
- NO_2 can be a remotely sensed proxy for all NO_X.
- HCHO can be a remotely sensed proxy for all VOCs.
- Regime Distinctions (Rough Estimates)
    - HCHO/NO_2 < 1: VOC-Limited
    - HCHO/NO_2 > 2-4: NO_X-Limited

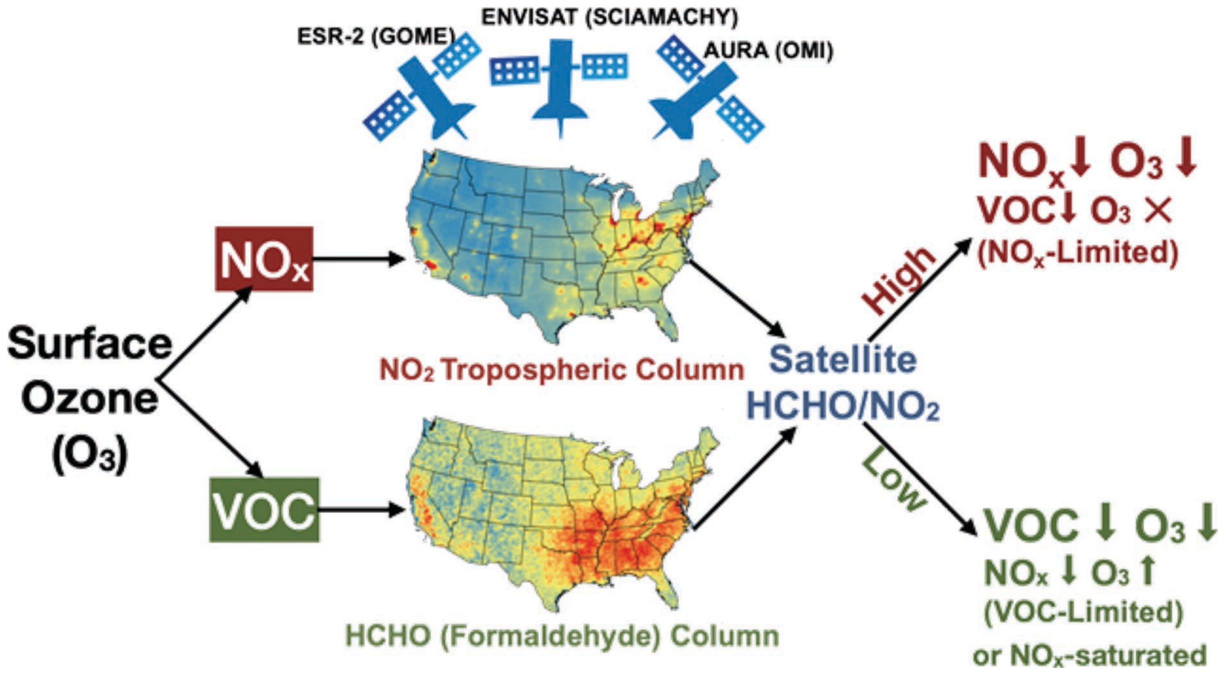


Image Credit: Jin et al. 2021, Inferring changes in summertime surface ozone-NOx-VOC chemistry over U.S. urban areas from two decades of satellite and ground-based observations. https://doi.org/10.1021/acs.est.9b07785.

Using HCHO/NO_2 Ratios

- Relative Errors
  - OMI-derived ratio error estimated at ~35% (Duncan et al. 2010)
  - TROPOMI-derived ratio errors <50% for urban areas (Souri et al. 2023)
- Higher Spatial Resolution preferred to distinguish regimes in urban and suburban areas
- Best Practices (Jin et al. 2018)
  - Recommend using weekly or monthly averages (based on OMI)
  - Recommend ignoring areas of low NO_2 (tropospheric column below 2.5×10^{15} molecules cm^{-2})

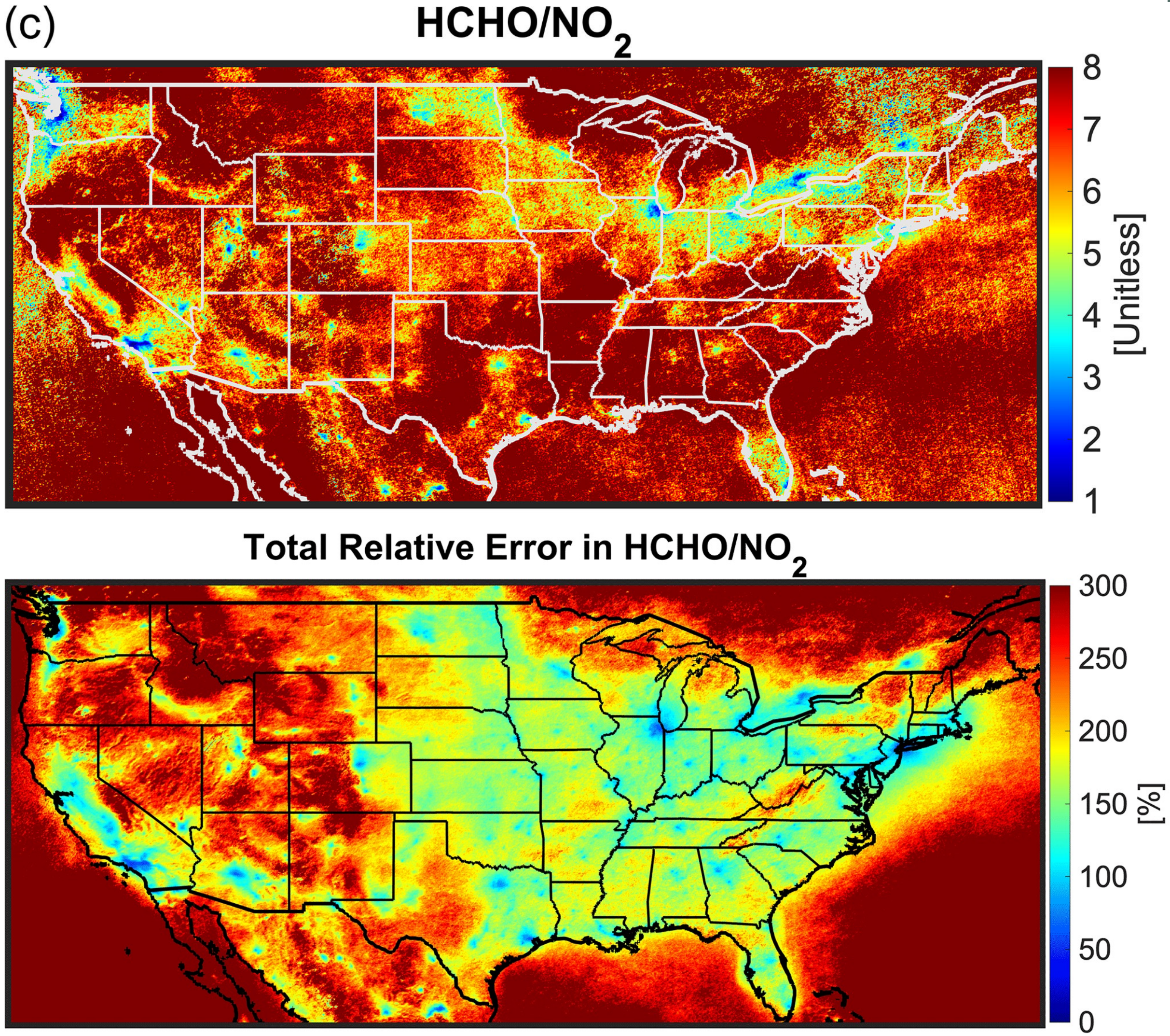
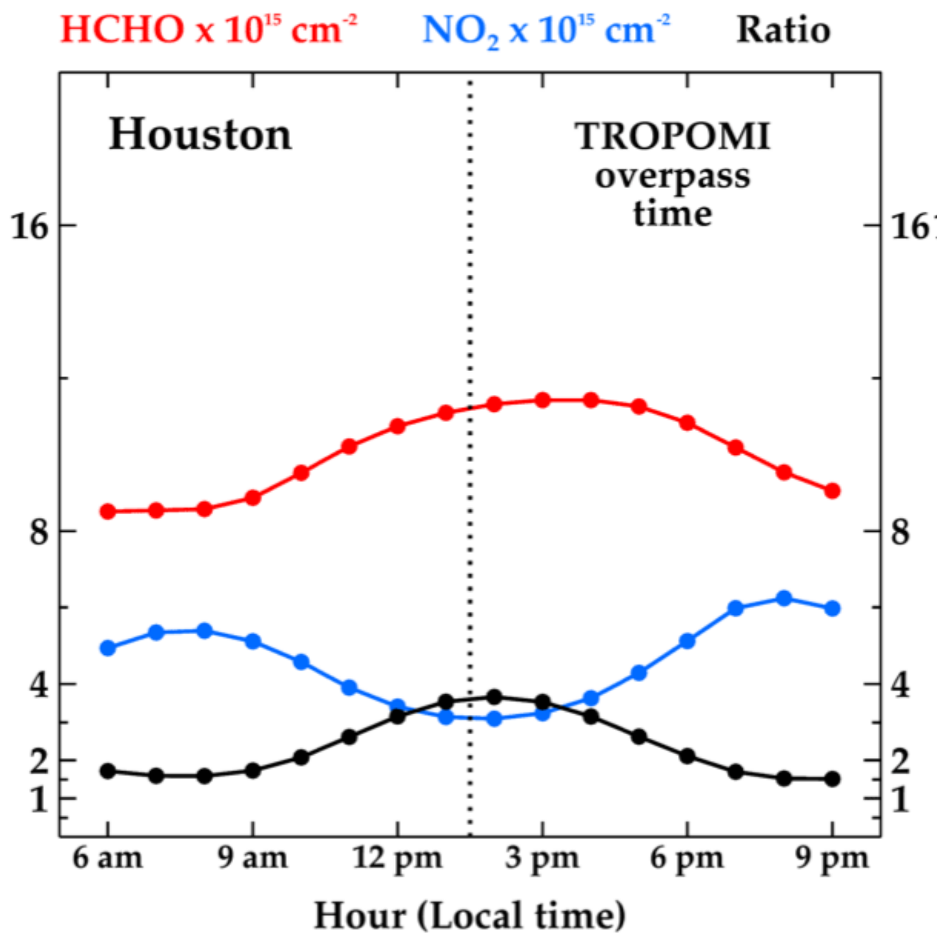


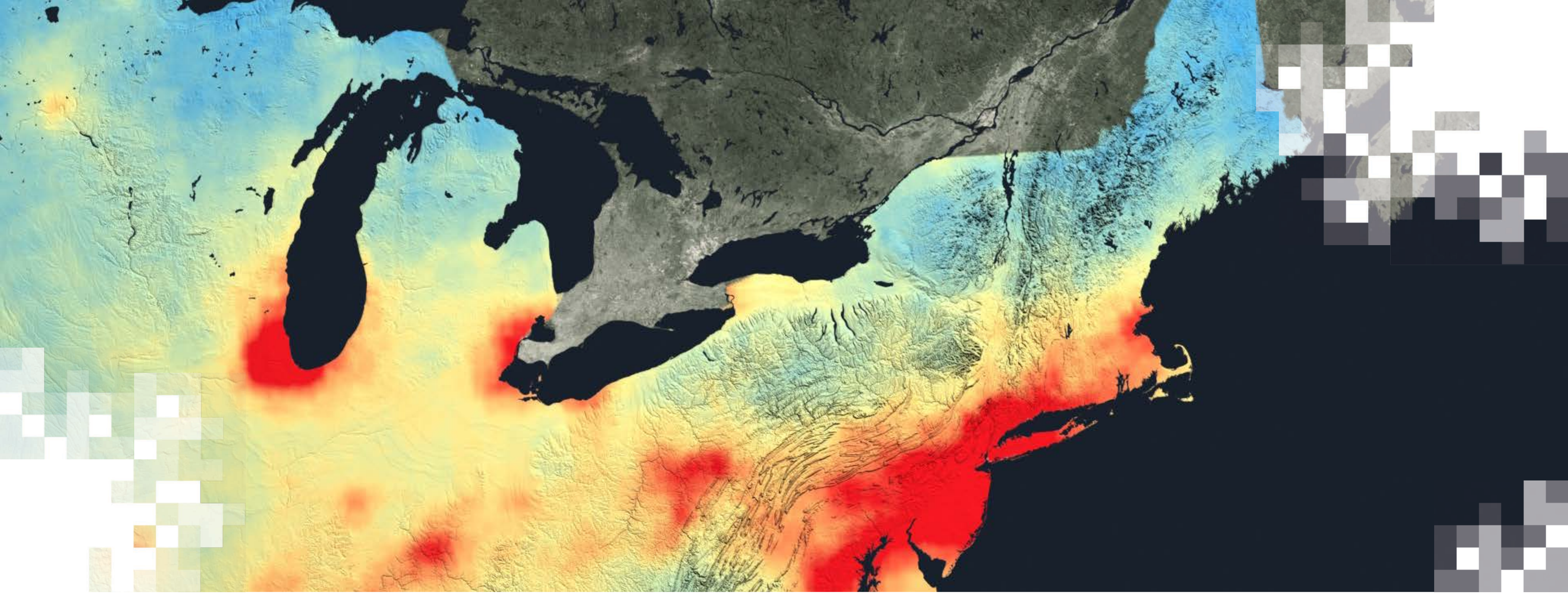
Image Credit: Souri et al. 2023, Characterization of errors in satellite-based HCHO/NO2 tropospheric column ratios with respect to chemistry, column-to-PBL translation, spatial representation, and retrieval uncertainties. https://doi.org/10.5194/acp-23-1963-2023. Figures 7c, 13

Using $HCHO/NO_2$ Ratios

- Ratios vary throughout the diurnal cycle; late afternoon satellite overpass time biases estimates towards NO_x sensitivity.
  - Highlight benefits of geostationary observations (e.g., TEMPO)
- Ratio confounded by Isoprene emissions, especially in Southeastern USA (Duncan et al. 2010)
- Correcting for HCHO bias and recalculating NO_2 retrievals based on higher resolution air mass factors from regional models improves ability to represent observed ozone formation regimes (Goldberg et al. 2022)



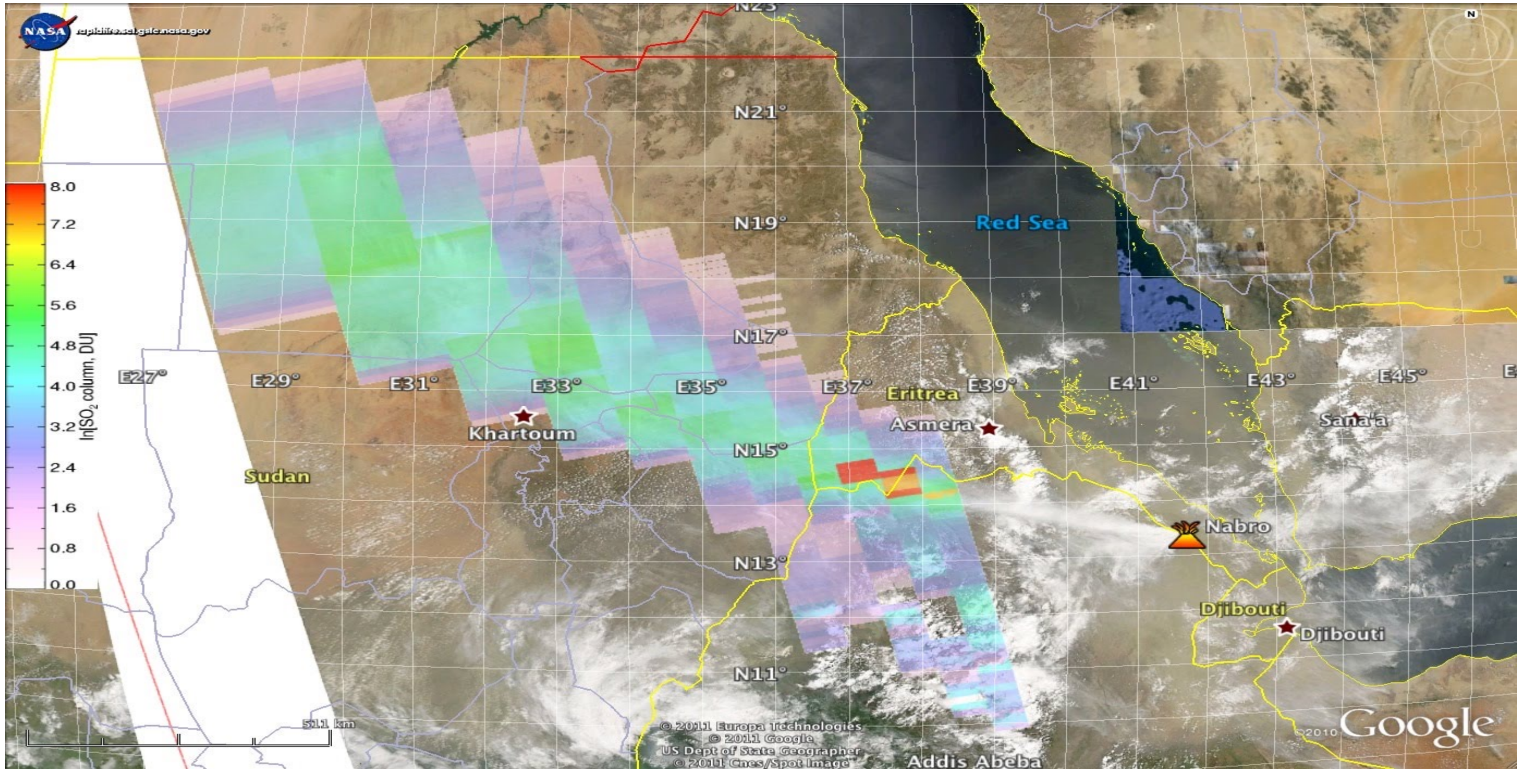
Credit: Goldberg et al. 2022, Evaluating NOx emissions and their effect on O3 production in Texas using TROPOMI NO2 and HCHO. https://doi.org/10.5194/acp-22-10875-2022. Figure 11.



Anthropogenic & Volcanic SO_2

SO_2 in the Boundary Layer

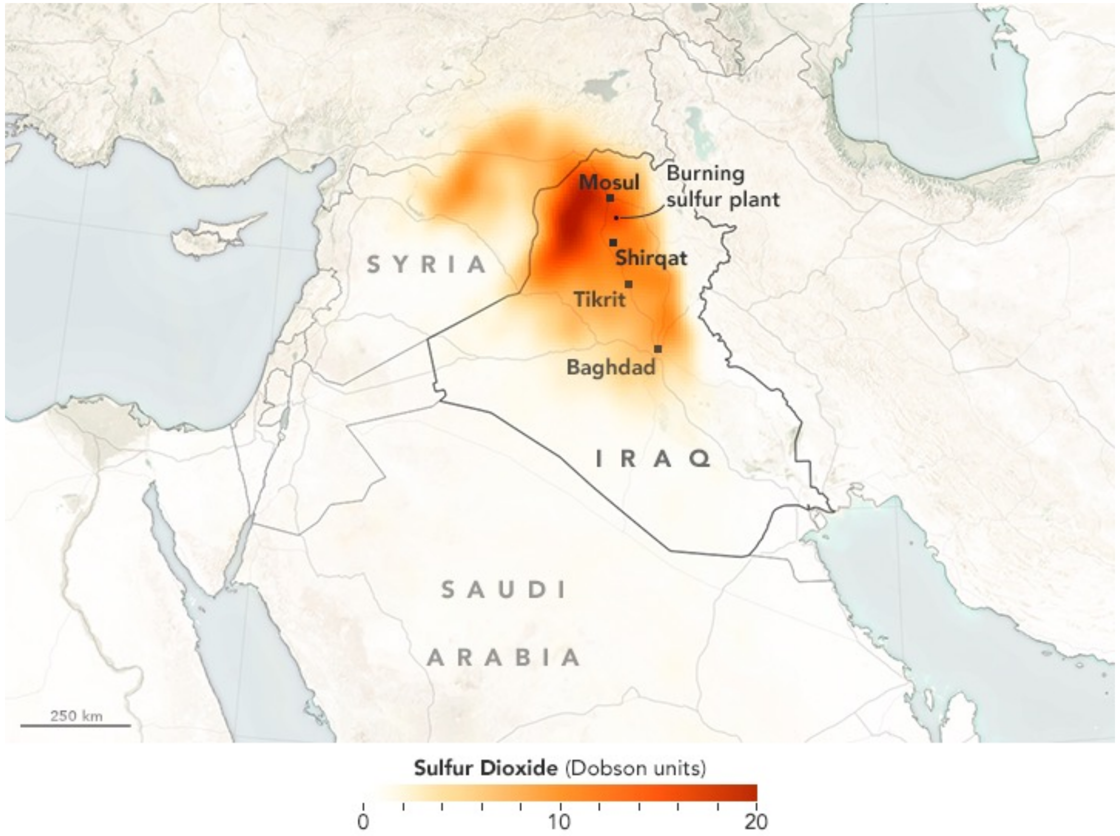
- Why measure SO_2?
  - SO_2 has also been linked to adverse respiratory effects.
  - Contributes to acid deposition
  - Sources: Volcanoes, coal, and oil burning



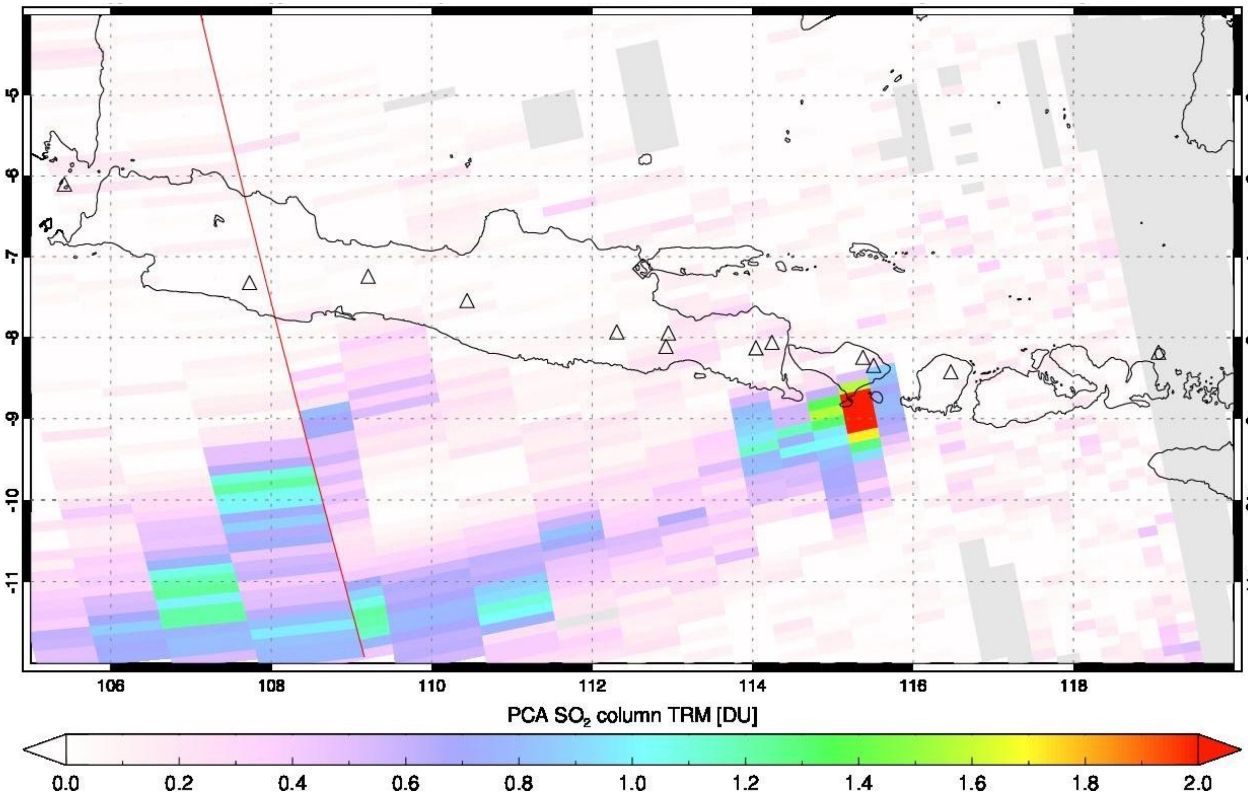
Aqua MODIS visible image of the Nabro (Eritrea) eruption on June 13, 2011, with the SO2 plume overlaid.

Perspective: What is Considered High SO_2?

OMI SO_2 from Sulfur Mine Fire
October 24, 2016



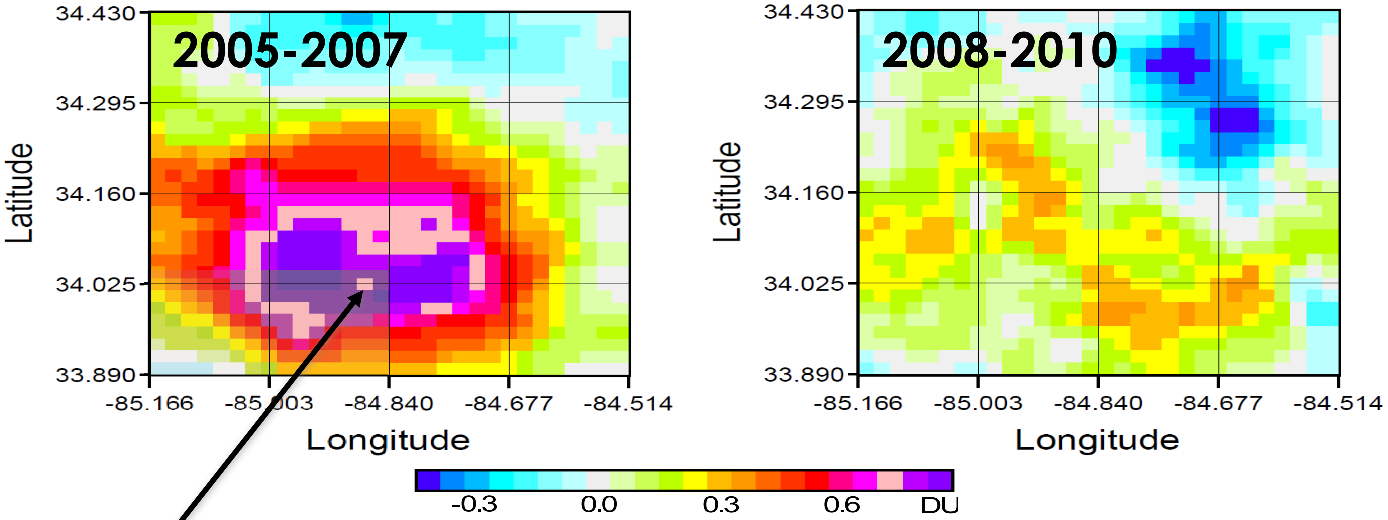
OMI SO_2 from Agung Volcano
November 29, 2017

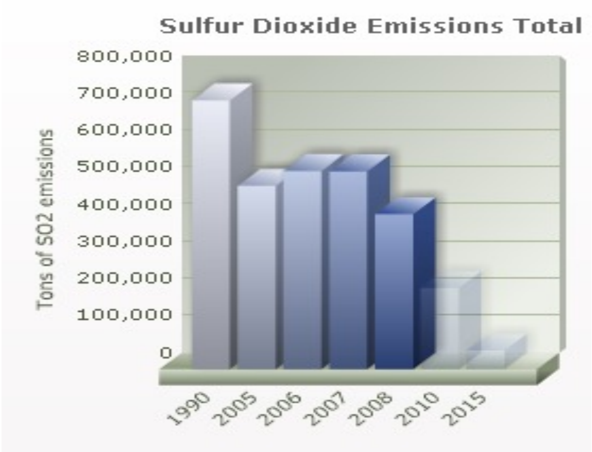


Left: https://earthobservatory.nasa.gov/IOTD/view.php?id=88994;
Right: https://so2.gsfc.nasa.gov/

Perspective: What is Considered High SO_2?

#1 U.S. Source: Bowen Coal Power Plant, Georgia (3500 MW),
SO_2 Emissions: 170 kT in 2006





"In **2008**, the mammoth construction program yielded the first scrubbers, sophisticated equipment that will reduce our overall systems emissions by as much as 90 percent."

Georgia Power Website

Source: V. Fioletov, et al., 2011

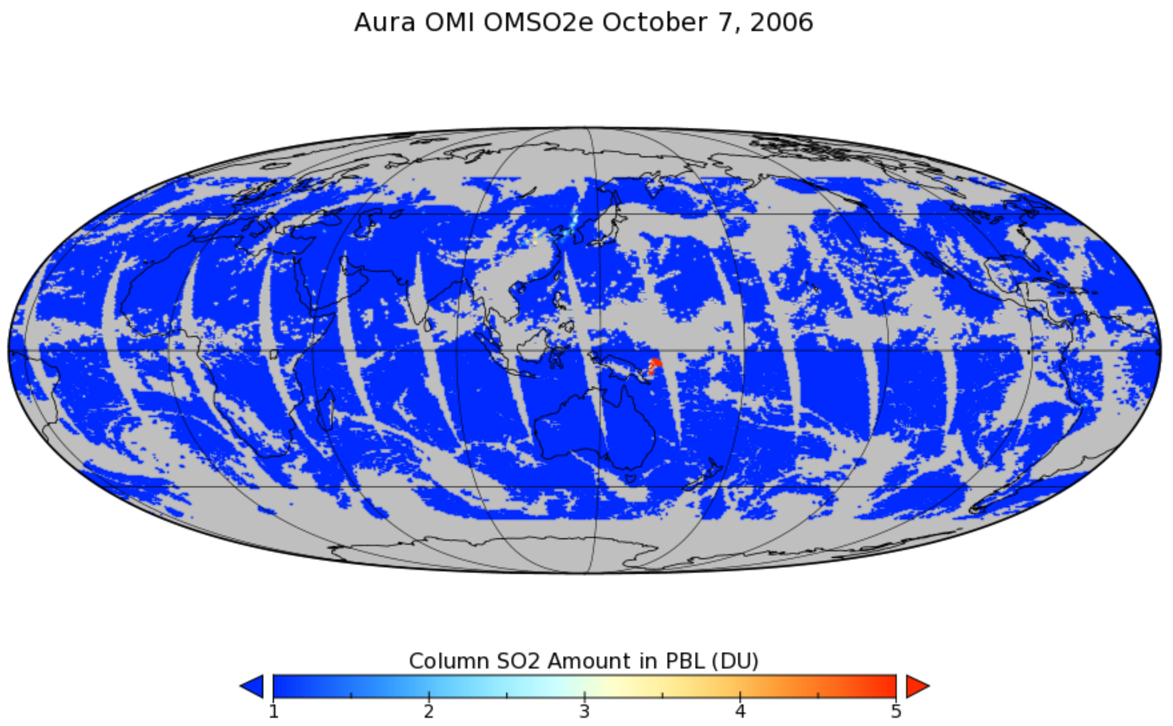
OMI SO_2 Parameter (SDS) Information (OMSO2)

SDS name	Description	Unit	Notes
ColumnAmountSO2_PBL	Total Column SO_2	DU	• Assumes SO_2 well mixed <1 km • Use for most applications (including AQ) • Use only rows 4-54 (where first row = 0) • Use only scenes with radiative cloud fraction < 0.3 solar zenith angle < 70°
ColumnAmountSO2_TRL /TRM/TRU/STL	Total Column SO_2	DU	• Assumes SO_2 plume at 3/8/13/18 km • Use for volcanic outgassing & eruptions • All rows can be used • Use scenes with solar zenith angle < 70°
RadiativeCloudFraction		Unitless	No scale factor
SolarZenithAngle		Deg	In geolocation fields

- As of the latest version (v1.3), the OMSO2 documentation does not recommend using the included data quality flags for screening.
- All fill values are high negative numbers $(-2.^{100} \approx -1.26765\times10^{30})$.

OMI Gridded PBL SO_2

- PBL Dataset Short Name = OMSO2e
  - Product Level: 3
  - Daily, beginning October 1, 2004
  - Resolution: 0.25° x 0.25°
  - File Size (approx): 5 mb
  - Screened for data quality (e.g., OMI row anomaly, clouds, etc.)
  - PBL emissions assumption
  - "Best" pixel selected
  - https://disc.gsfc.nasa.gov/datasets/OMSO2e_003/summary

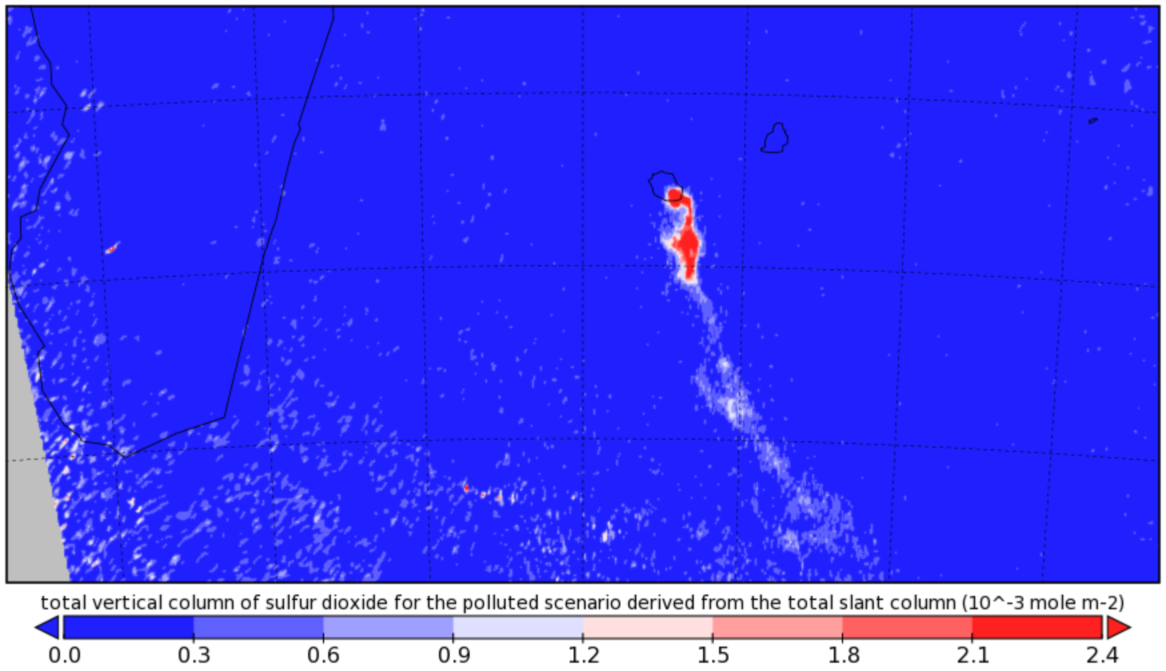


TROPOMI SO_2 Products

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

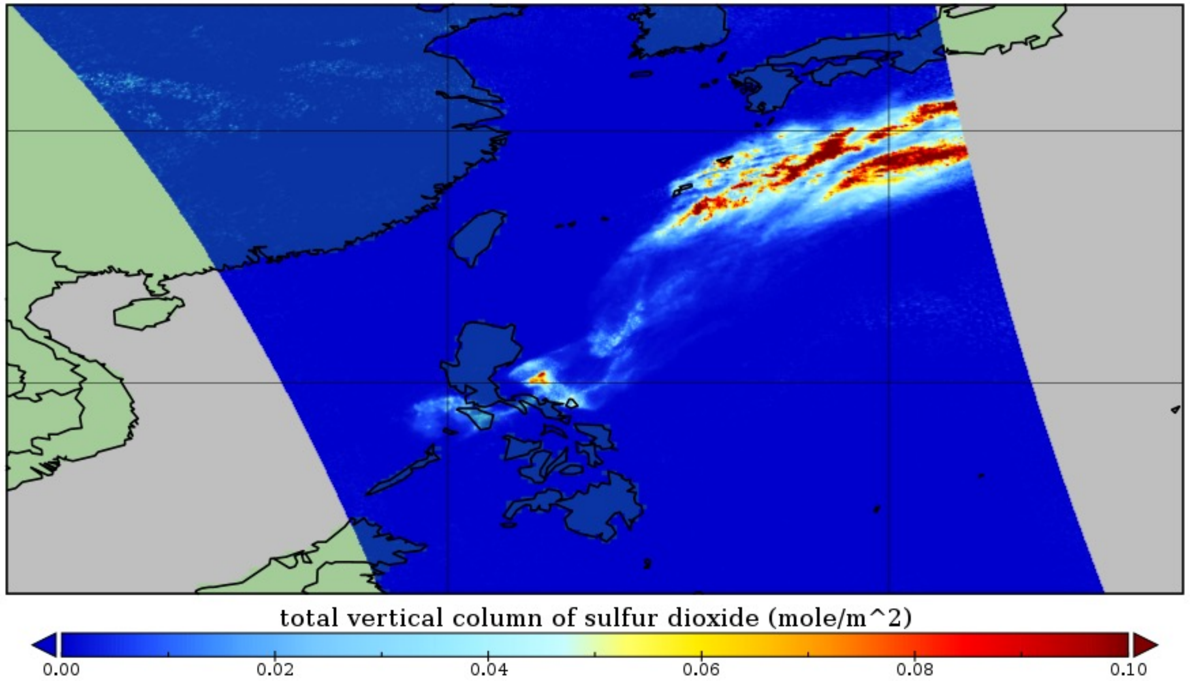
S5P_L2__SO2____ – Level 2 – 7km x 3.5km
(5/6/2018 – 8/6/2019)

Copernicus Sentinel-5P/TROPOMI Sulfur Dioxide Product (Orbit#7037)



S5P_L2__SO2____HiR – Level 2 – 5.5km x 3.5km
(v1:8/6/2019 – 7/13/2020; v2:7/13/2020 onwards)

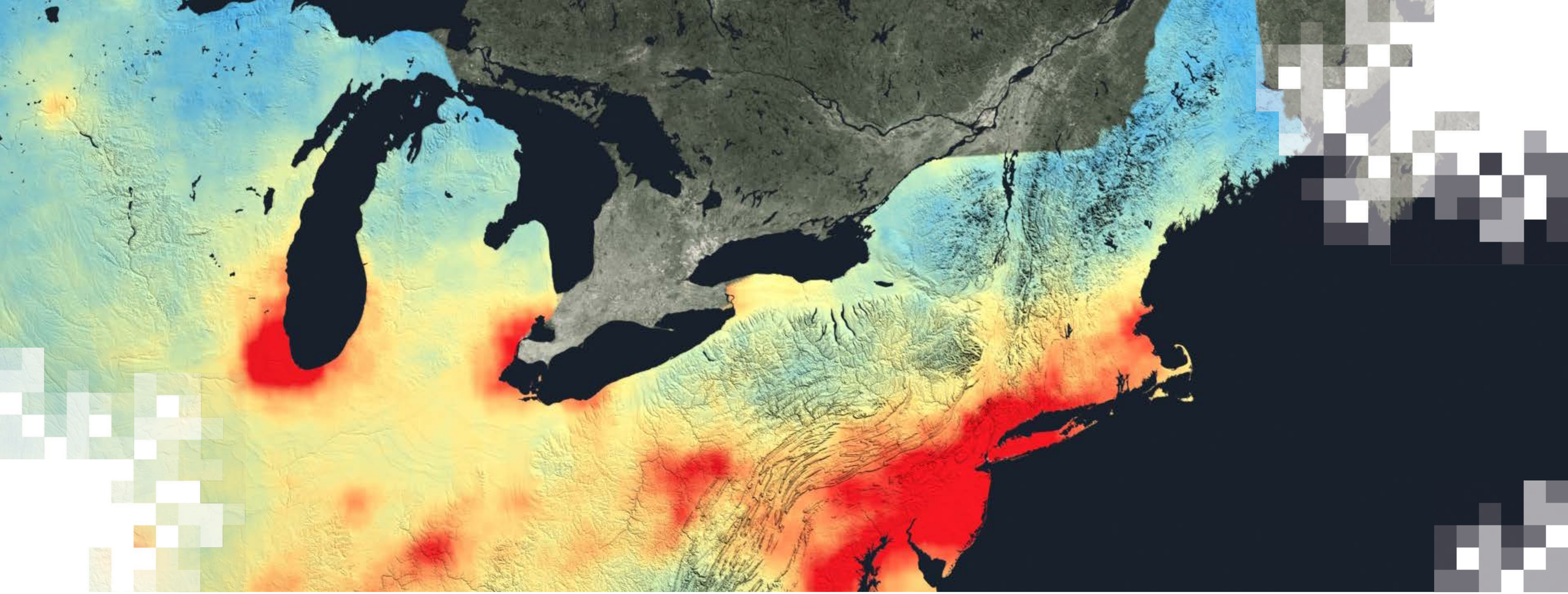
Copernicus Sentinel-5P TROPOMI Sulfur Dioxide Product (January 13th, 2020)



TROPOMI SO_2 Parameter (SDS) Information

SDS Name	Description	Unit	Notes
sulfurdioxide_total_ vertical_column	Total Column SO_2	mol/m^2	Total column from the surface to the top of the atmosphere, assuming all SO2 is in the PBL *Not realistic for less polluted or remote areas
sulfurdioxide_total_ vertical_column_1km/ _7km/_15km	Total Column SO_2	mol/m^2	Total SO_2 columns assuming 1 km thick box profile at ground level, centered at 7 km, and centered at 15 km above sea level
qa_value	Data Quality Value	Unitless	Only applies to total column

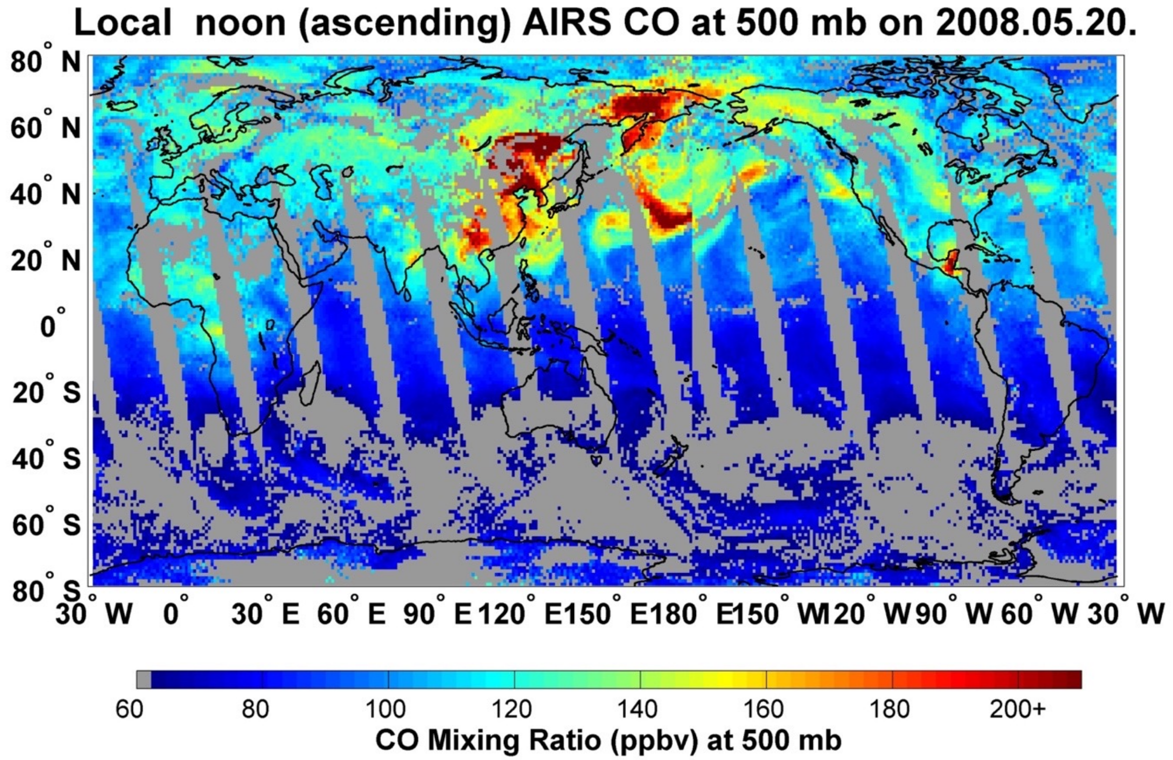
- Currently, should only use qa_value > 0.5



CO

Carbon Monoxide

- Why measure CO?
  - Major global precursor for O_3, and dominant sink for OH
  - Relatively long lifetime (~1-2 months) makes it a useful tracer of transport
- Typically measured as a column density
- Instruments (e.g., MOPITT, AIRS) tend to have good sensitivity to CO in the mid-troposphere (~500 mb)
- Current Sensors: AIRS, MOPITT, IASI, TROPOMI



Measurements of Pollution in The Troposphere (MOPITT)

https://www2.acom.ucar.edu/mopitt

- Operational since 2000
- Global coverage every 3 days
- Nadir, Pixel Size:
  - 22 km^2 at nadir
- Swath Width: 640 km
- Equator Crossing Times:
  - 10:30 (descending)
- Three Retrievals:
  - TIR: Highest temporal stability
  - NIR: Daytime, column only
  - TIR/NIR (Joint): Greatest sensitivity to lower troposphere, but larger errors

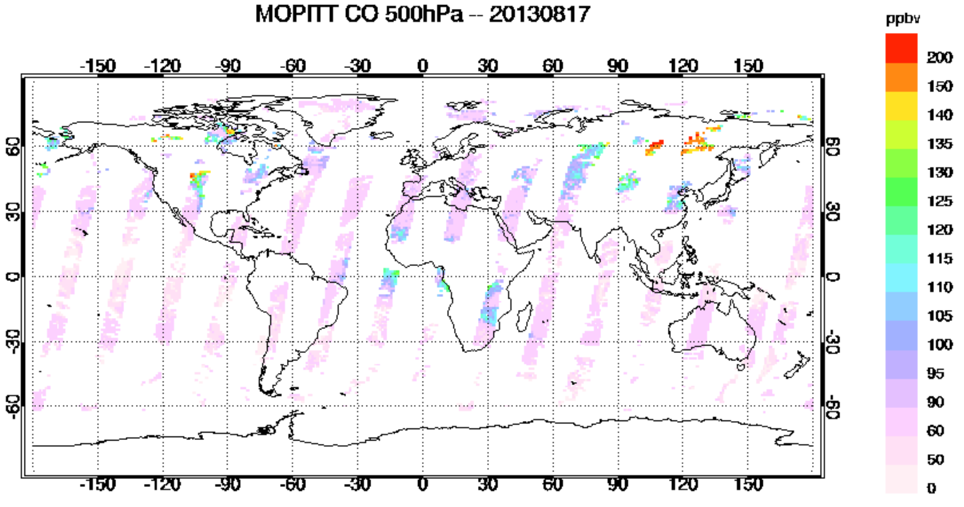


Image Source: NCAR UCAR

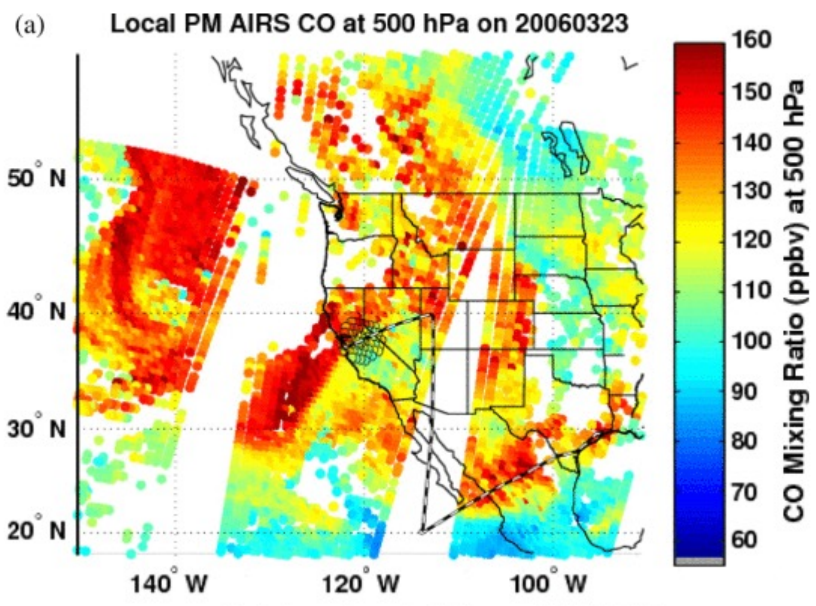
- Profile Measurements:
  - 10 Pressure Levels: Surface – 100 hPa
- Data Source:
  - Level 2 pixel https://subset.larc.nasa.gov/mopitt/
  - Level 3 gridded 1° x 1° resolution https://giovanni.gsfc.nasa.gov/giovanni/

Atmospheric Infrared Sounder (AIRS)

http://airs.jpl.nasa.gov/

- Operational since Sep 2002
- Daily coverage
- Nadir, Pixel Size:
  - 14 km at nadir
  - 41x21 km edges
- Swath Width: 1,650 km
- Equator Crossing Times:
  - 13:30 (ascending)
  - 1:30 (descending)

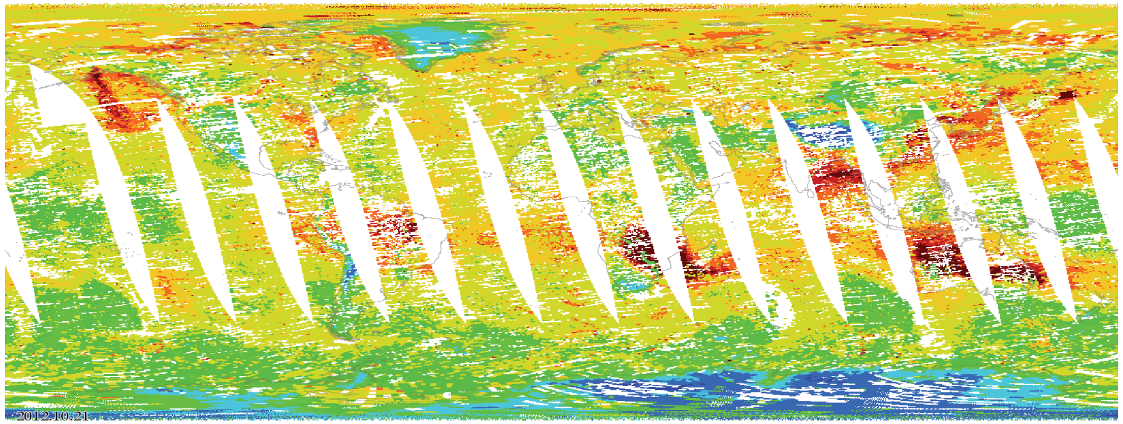
- Profile Measurements:
  - 9 vertical layers
  - 901.866 hPa – 0.16 hPa
- Data:
  - https://disc.gsfc.nasa.gov
  - Level 2 pixel
  - Level 3 gridded 1° x 1° resolution



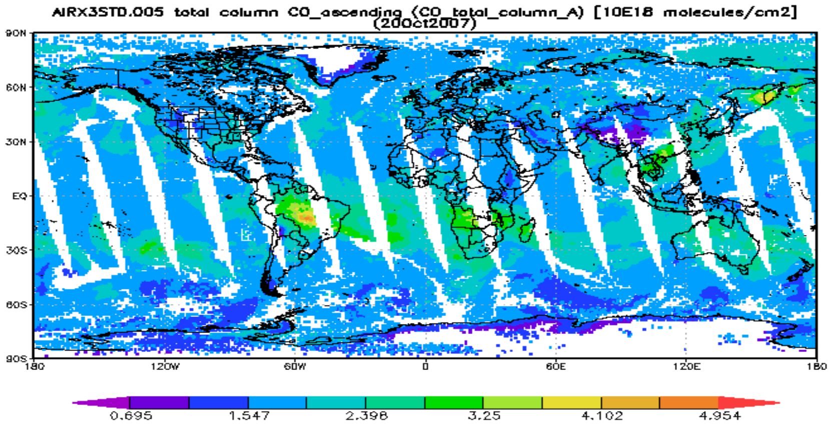
Source: Figure 6a from McMillan et al. (2011)

AIRS vs. MOPPITT CO – Daily Coverage

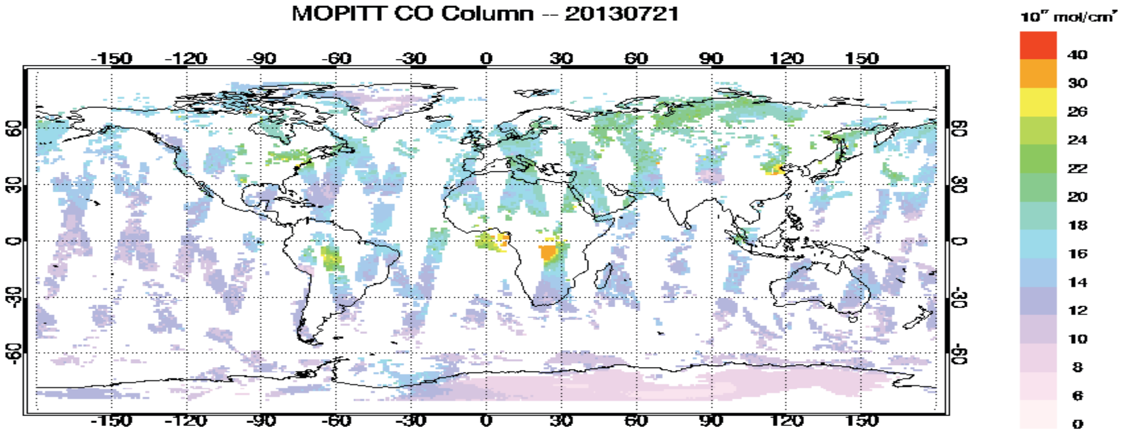
AIRS Level 2 from NRT Website



AIRS Level 3, 1°x1° from Giovanni



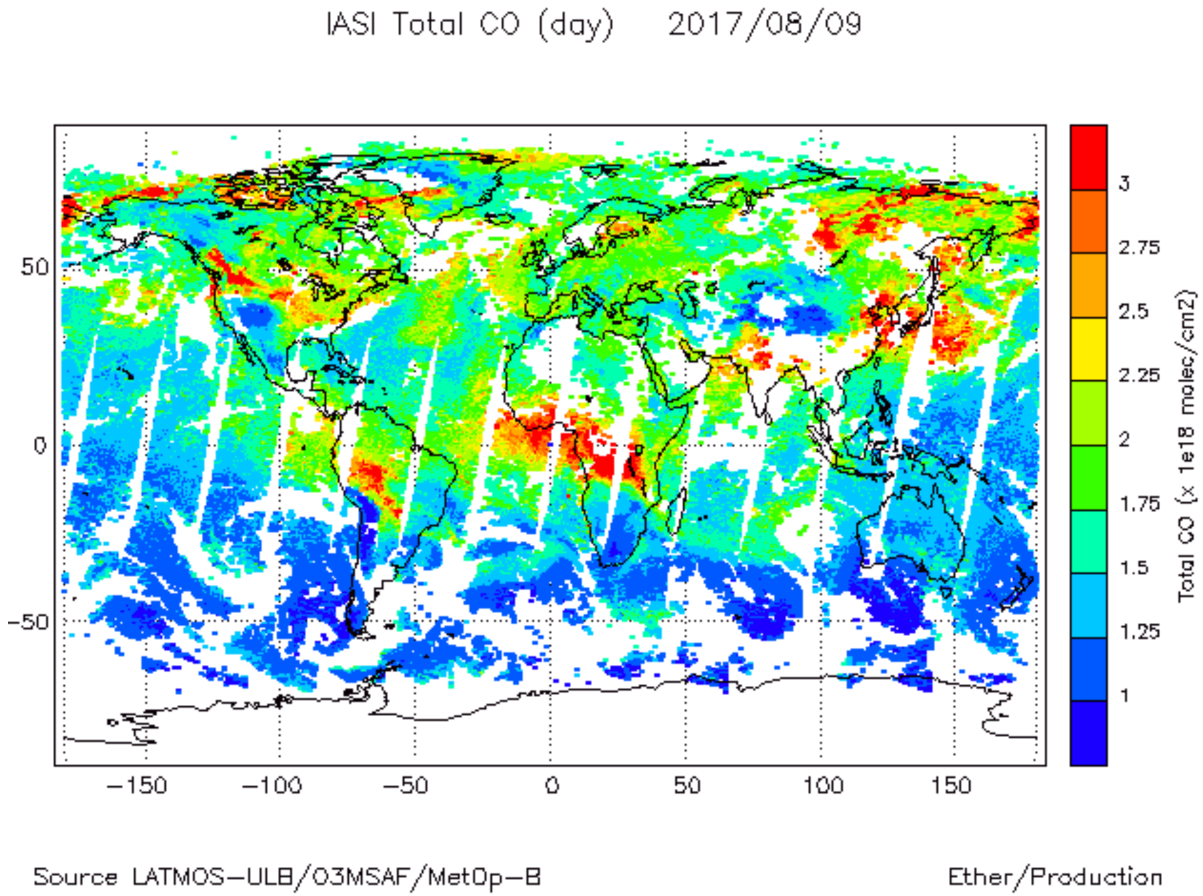
MOPPITT Level 3, 1°x1°



Infrared Atmospheric Sounding Interferometer (IASI)

http://bit.ly/ESA-IASI

- Operational since 2006
- Daily coverage
- Nadir, Pixel Size
  - 12 km^2 at nadir
- Swath Width: 2,200 km
- Equator Crossing Times:
  - 9:30 (descending)
  - 21:30 (ascending)
- CO Columns Available in NRT
  - Within three hours of observation
- 18 1km layers, plus total above 18km
- Data:
  - https://iasi.aeris-data.fr/co/
  - Level 2 pixel, daily
  - Level 3 gridded, monthly 1° x 1° resolution

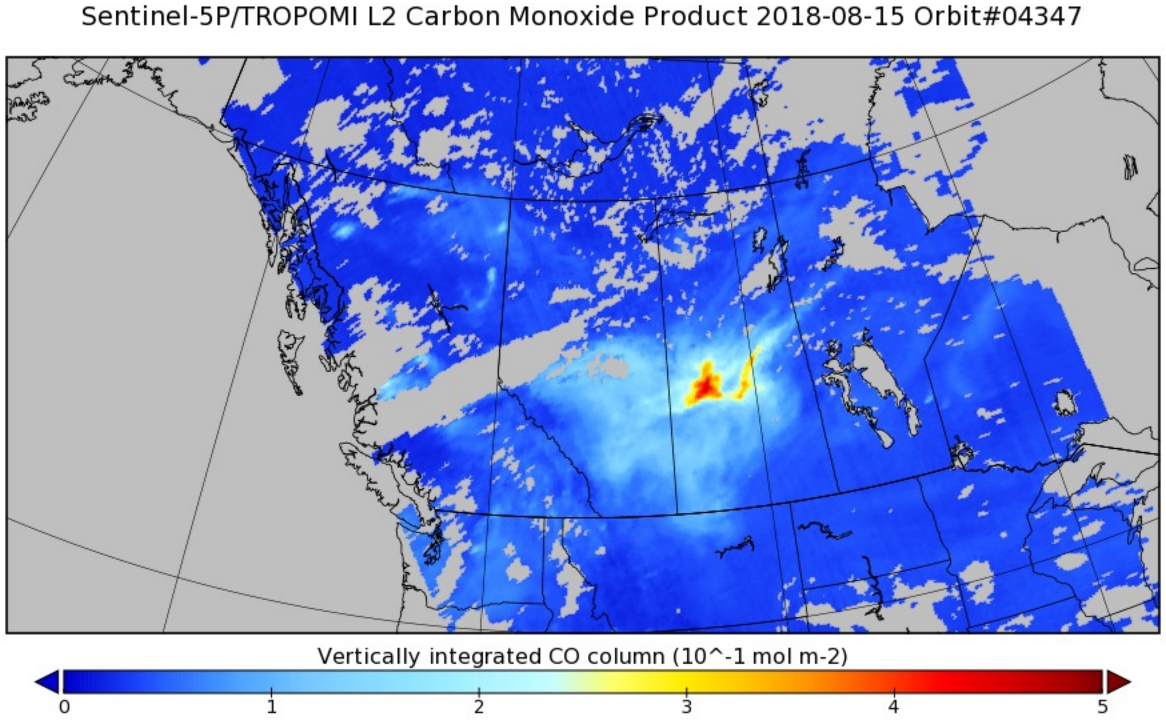


TROPOMI CO Products

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

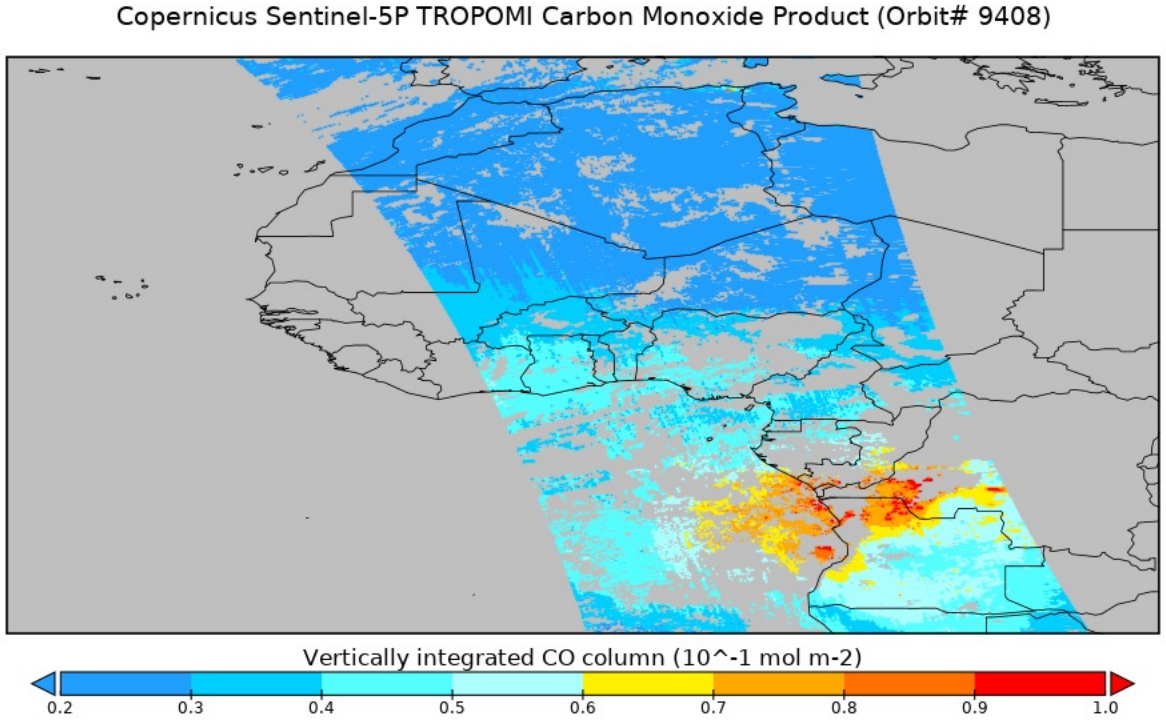
S5P_L2__CO____1 – Level 2 – 7km x 7km

(4/30/2018 – 8/6/2019)



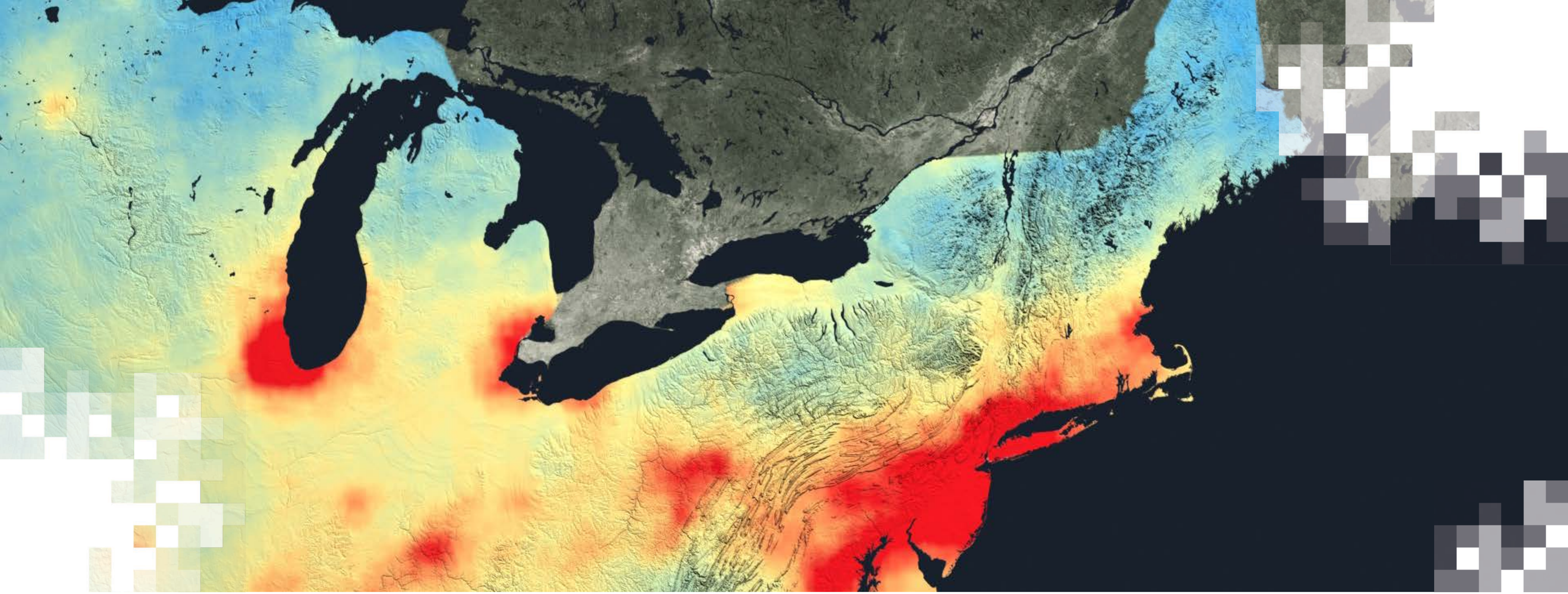
S5P_L2__CO____HiR – Level 2 – 7km x 5.5km

(4/30/2018 onwards)



Comparison Chart - CO

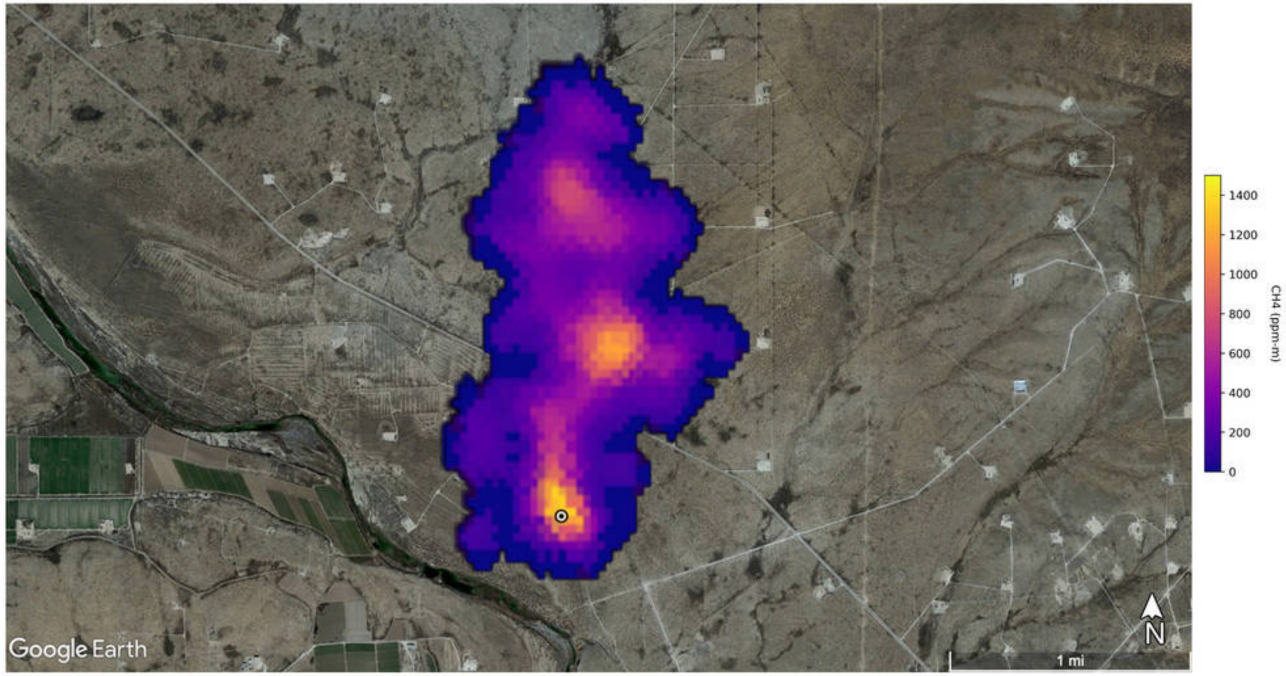
	MOPITT	TROPOMI	AIRS	IASI
Product/Pixel size	22 x 22 km^2	7 x 5.5 km^2	14 x 14 km^2	12 x 12 km^2
Swath Width	650 km	2600 km	1,650 km	2,200 km
Global Coverage	3 days	daily	2x per day	2x per day
Overpass Time (Local Time)	10:30	13:30	1:30, 13:30	9:30, 21:30
L3 Product Resolution	L3: 1° Grid	*NO L3 Product*	L3: 1° Grid	L3: 1° Grid
Products Available	L2 Swath L3 Daily, Monthly	L2 Swath	L2 Granule L3 Daily, Monthly	L2 Daily L3 Monthly
Vertical Sensitivity	Column: Mid & Lower Troposphere	Column: Mid & Lower Troposphere	Mid Troposphere	Mid Troposphere



CH_4

Methane

- Why measure CH_4?
  - Methane is a potent greenhouse gas (80x more absorbing than CO_2, but with a shorter atmospheric lifetime).
- Major releases due to leaks in natural gas infrastructure
  - "Super-emitters" can be found (& fixed?) quickly with satellite data.
- Distributed sources (agriculture, wetlands) more difficult to quantify with bottom-up emission inventories.
- Extreme high resolution from EMIT, GHGSat
- TROPOMI has column CH_4 products.



3-km-long methane plume from ONG facility leak detected southeast of Carlsbad, New Mexico by NASA EMIT instrument on ISS.

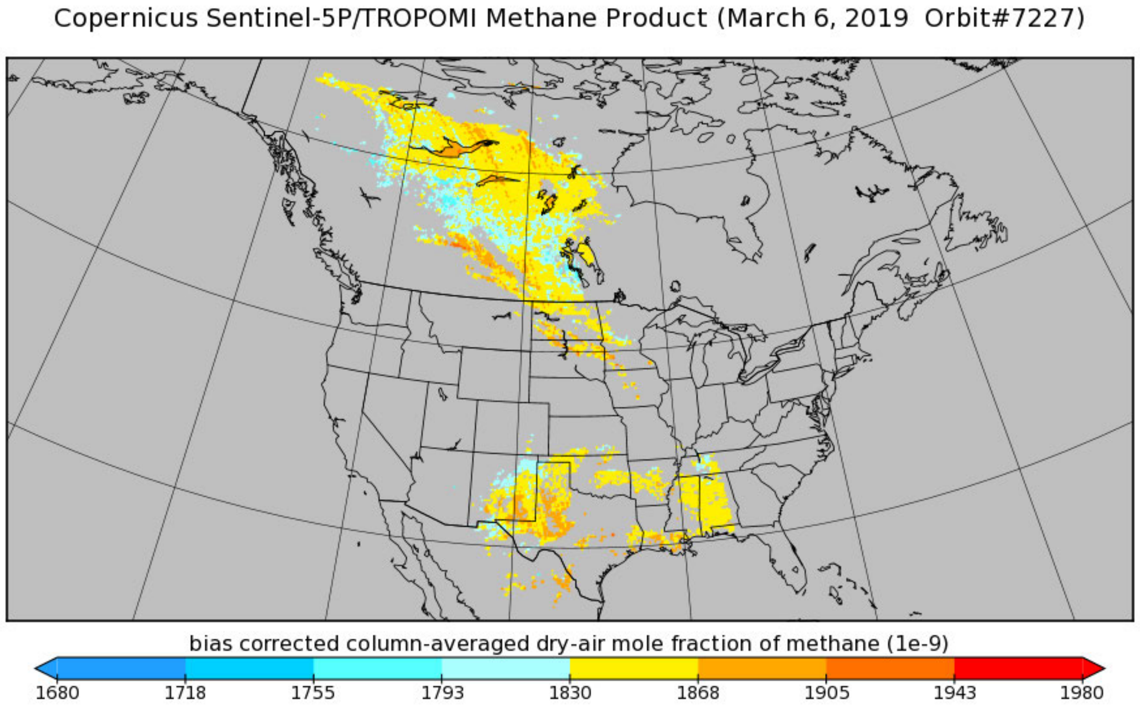
Image Credit: NASA/JPL-Caltech

Credit: NASA JPL, https://www.nasa.gov/feature/jpl/methane-super-emitters-mapped-by-nasa-s-new-earth-space-mission

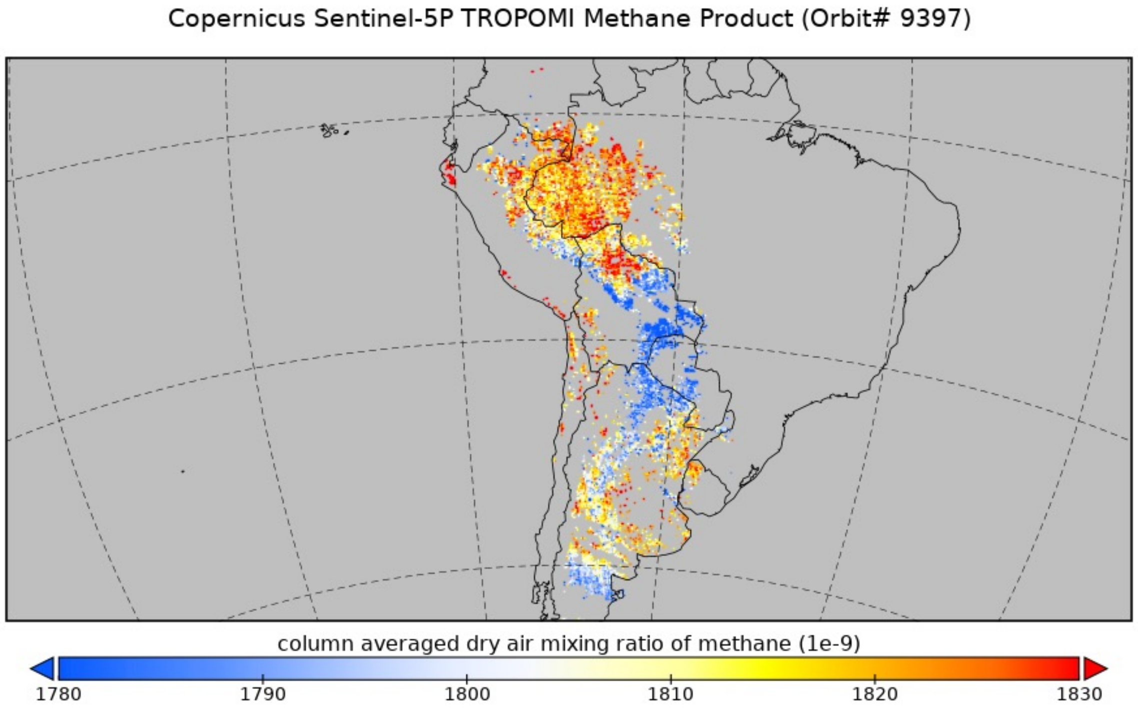
TROPOMI CH_4 Products

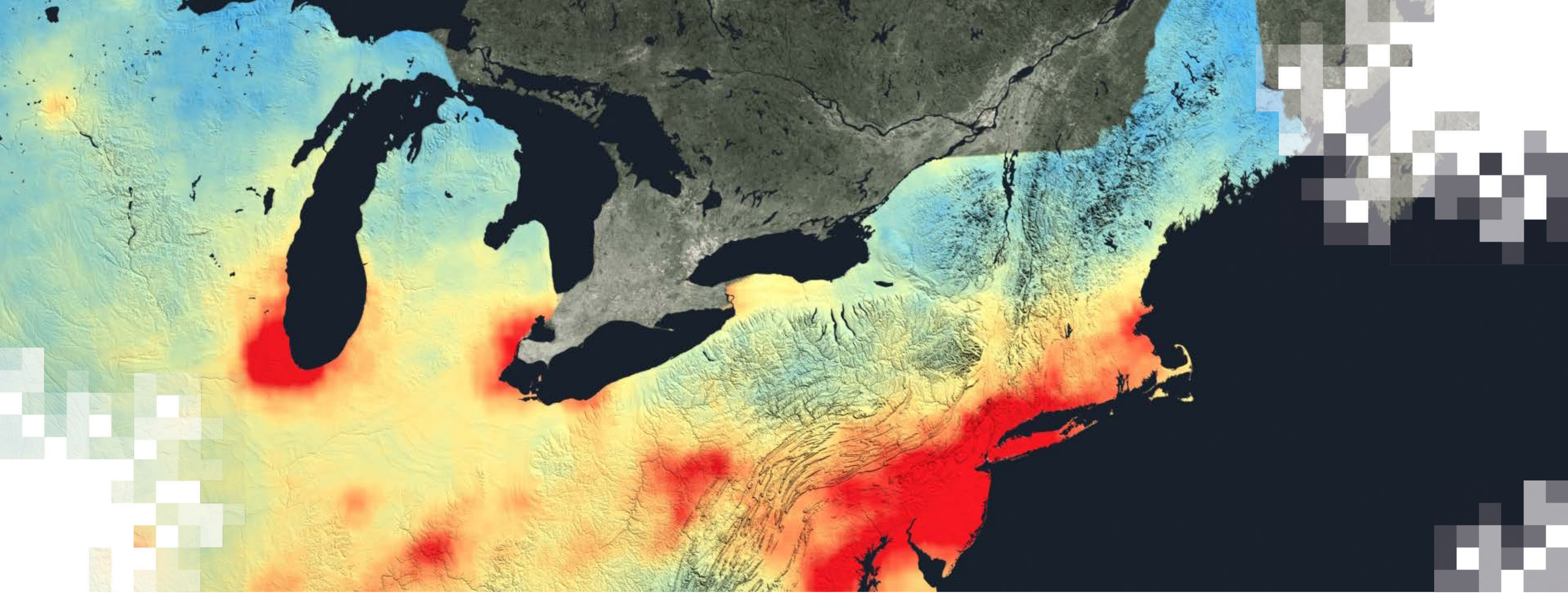
Available at https://disc.gsfc.nasa.gov/

S5P_L2__CH4____ – Level 2 – 7km x 7km
(4/30/2018 – 8/6/2019)



S5P_L2__CH4____HiR – Level 2 – 7km x 5.5km
(v1: 8/6/2019 – 7/1/2021; v2: 7/1/2020 onwards)





Questions?