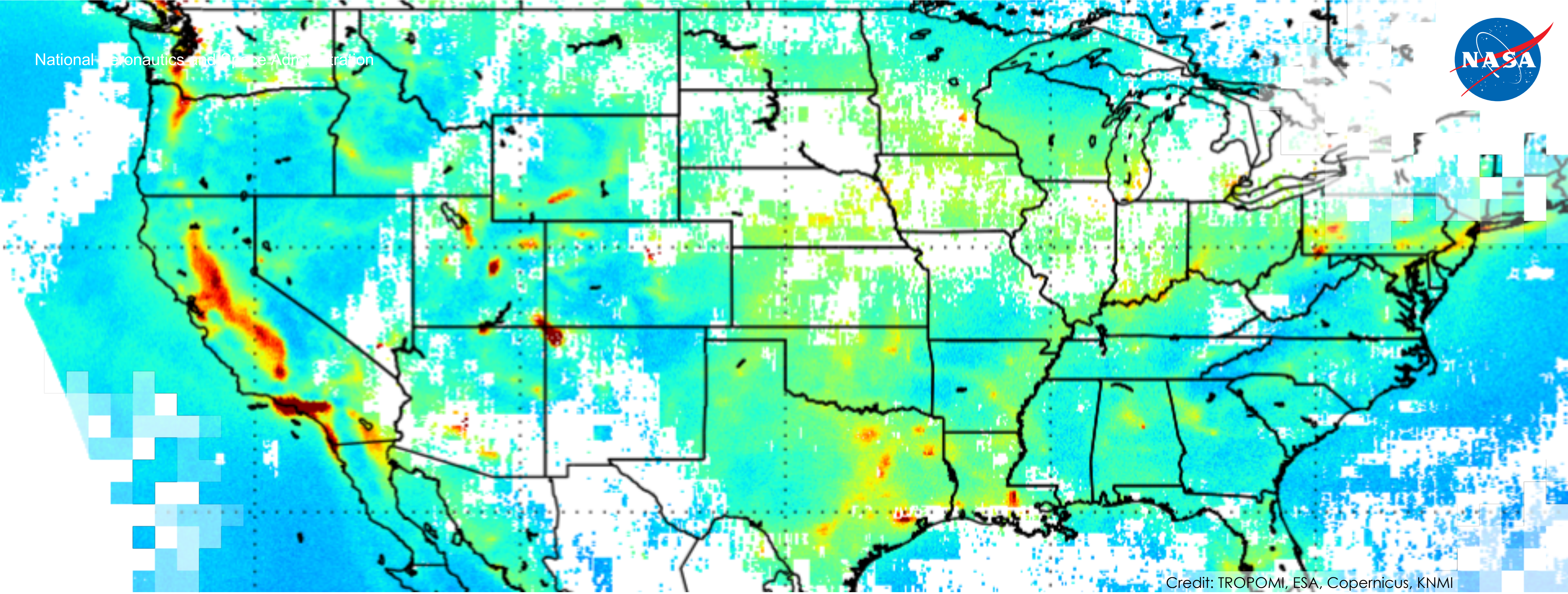
National Aeronautics and Space Administration



Credit: TROPOMI, ESA, Copernicus, KNMI

APPLIED REMOTE SENSING TRAINING PROGRAM
10 YEARS OF TRAINING
TRAIN - EMPOWER - ADVANCE

Trace Gas Air Quality Products from OMI and TROPOMI

Melanie Follette-Cook and Pawan Gupta

Application of Satellite Observations for Air Quality and Health Exposure, Oct 9 and 11, 2019

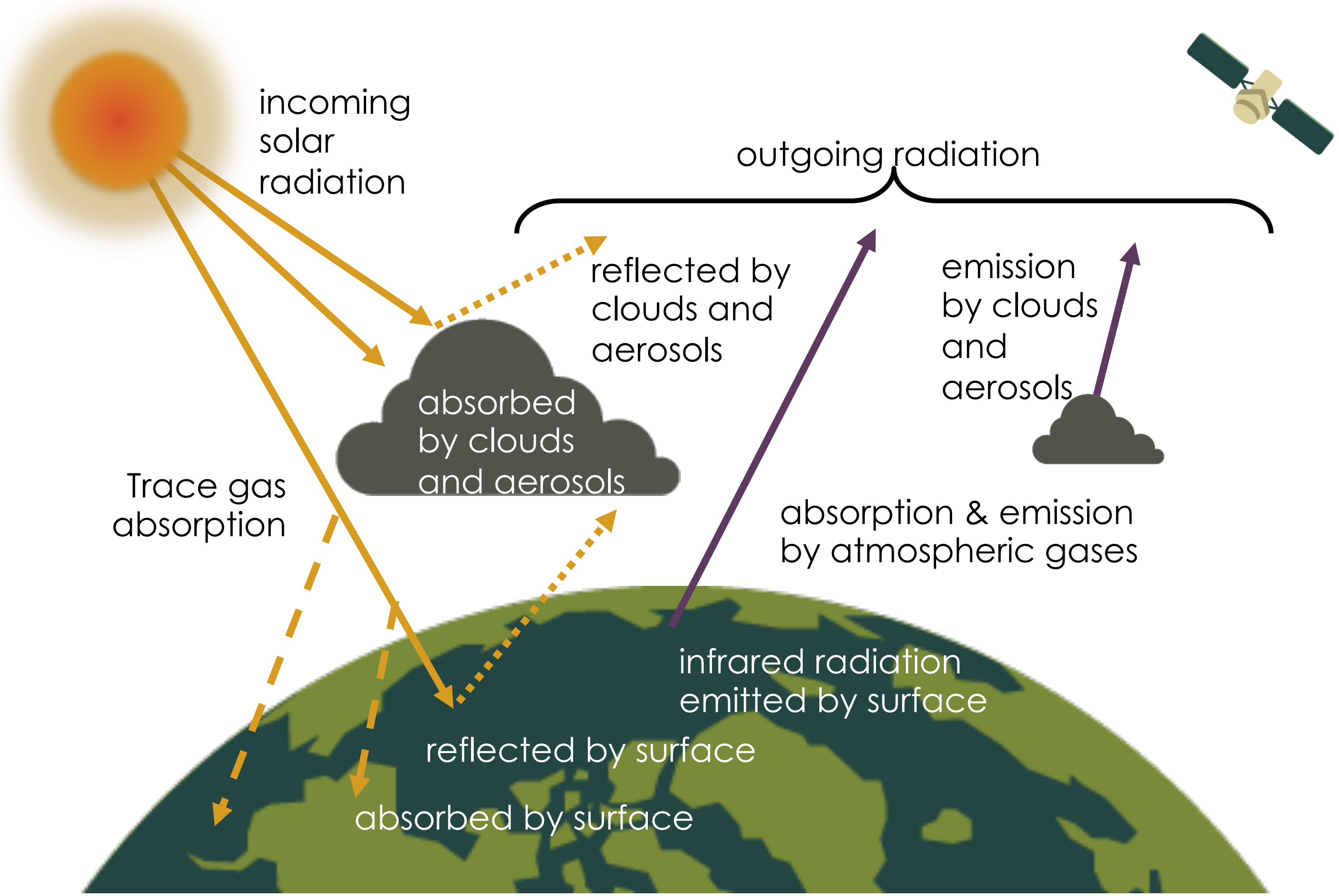
Learning Objectives

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

- Describe existing satellite capabilities for global observations of several trace gases
- Describe current data products available from the Ozone Monitoring Instrument (OMI) and the TROPOspheric Monitoring Instrument (TROPOMI)
- Identify various air quality monitoring applications utilizing OMI NO_2 observations
- Identify where and how to download OMI and/or TROPOMI data

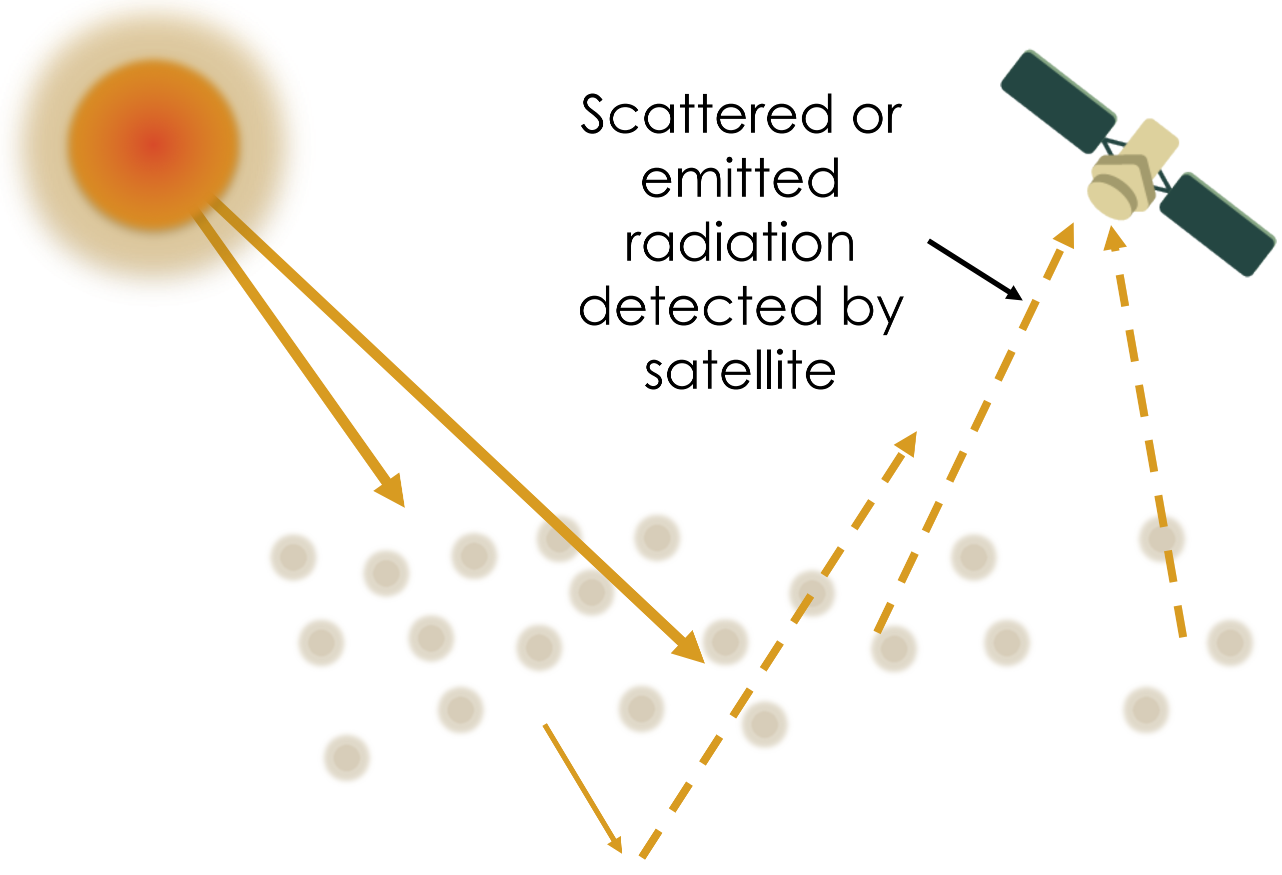
What do Satellites Measure?

- 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

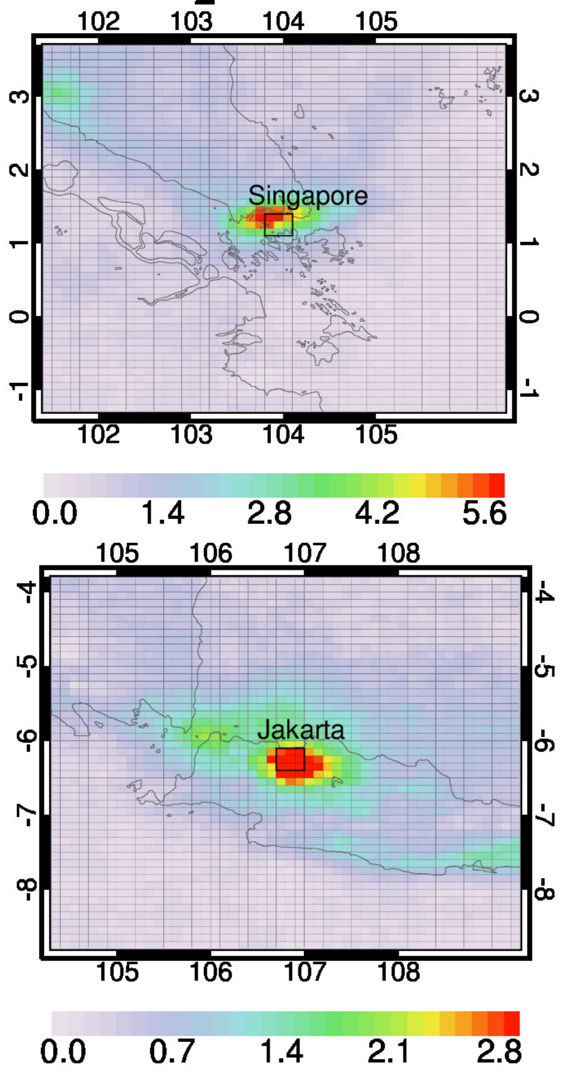
- Satellites detect backscattered UV, visible, and/or emitted thermal radiation
- We know the distinct absorption spectra of each trace gas
- We can identify a "spectral fingerprint" for each atmospheric constituent
- Retrieval algorithms (a model) infer physical quantities such as number density, partial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



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

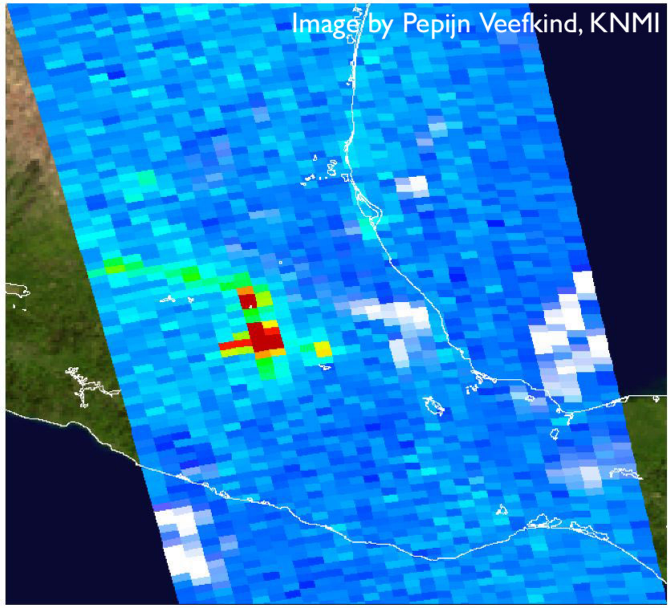
Spatial Resolution: Trace Gases

- 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

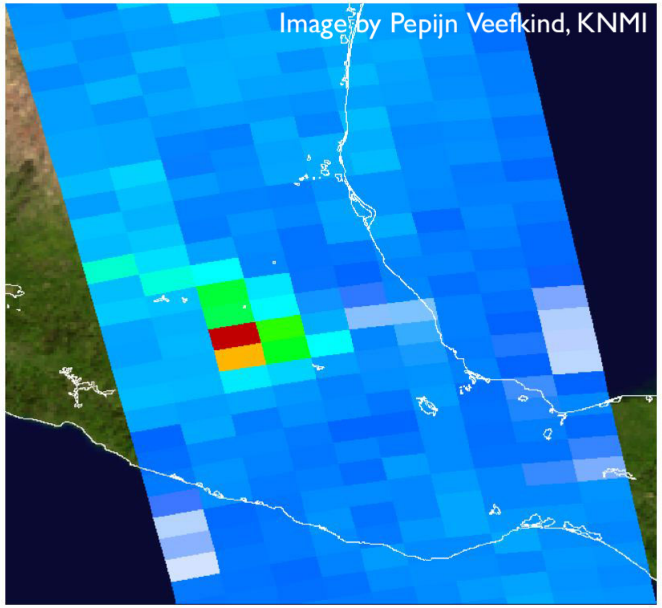
Source: Richter, 2010

Perspective…

Spatial Resolution



OMI 24x13 km^2



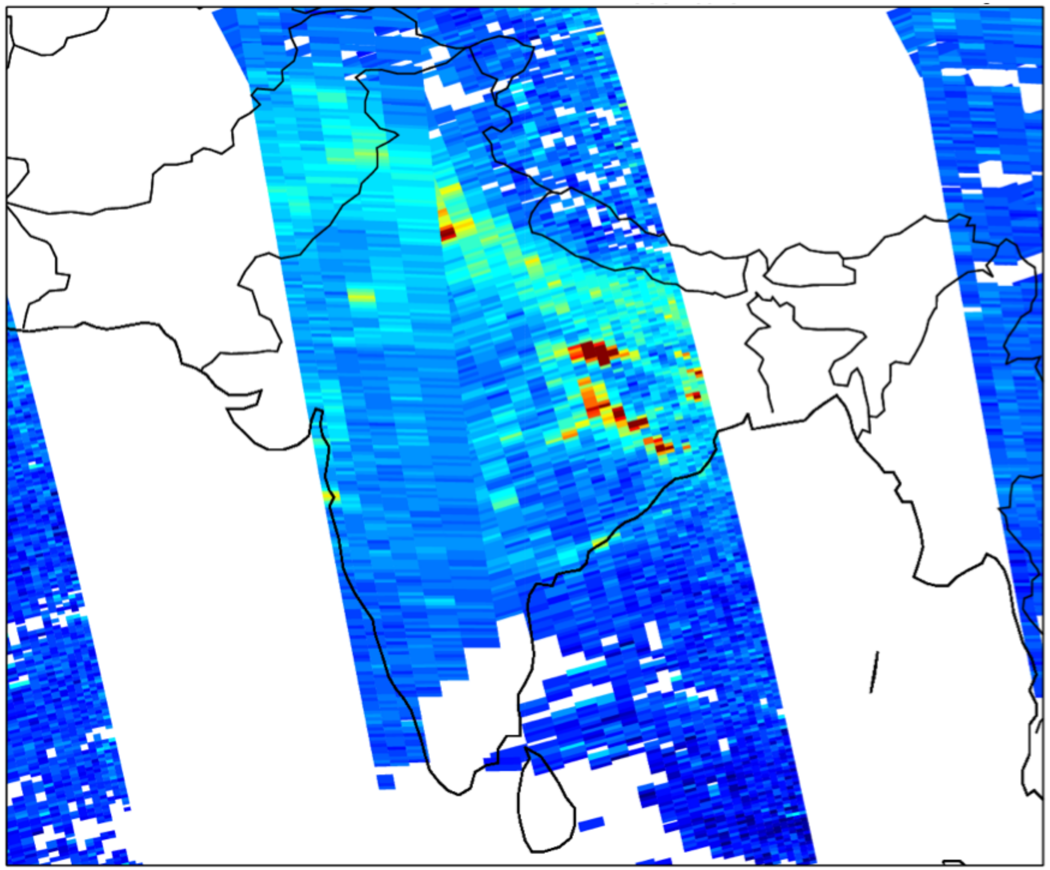
Approx. GOME-2 72x39 km^2

Mexico City, Jan. 20, 2005

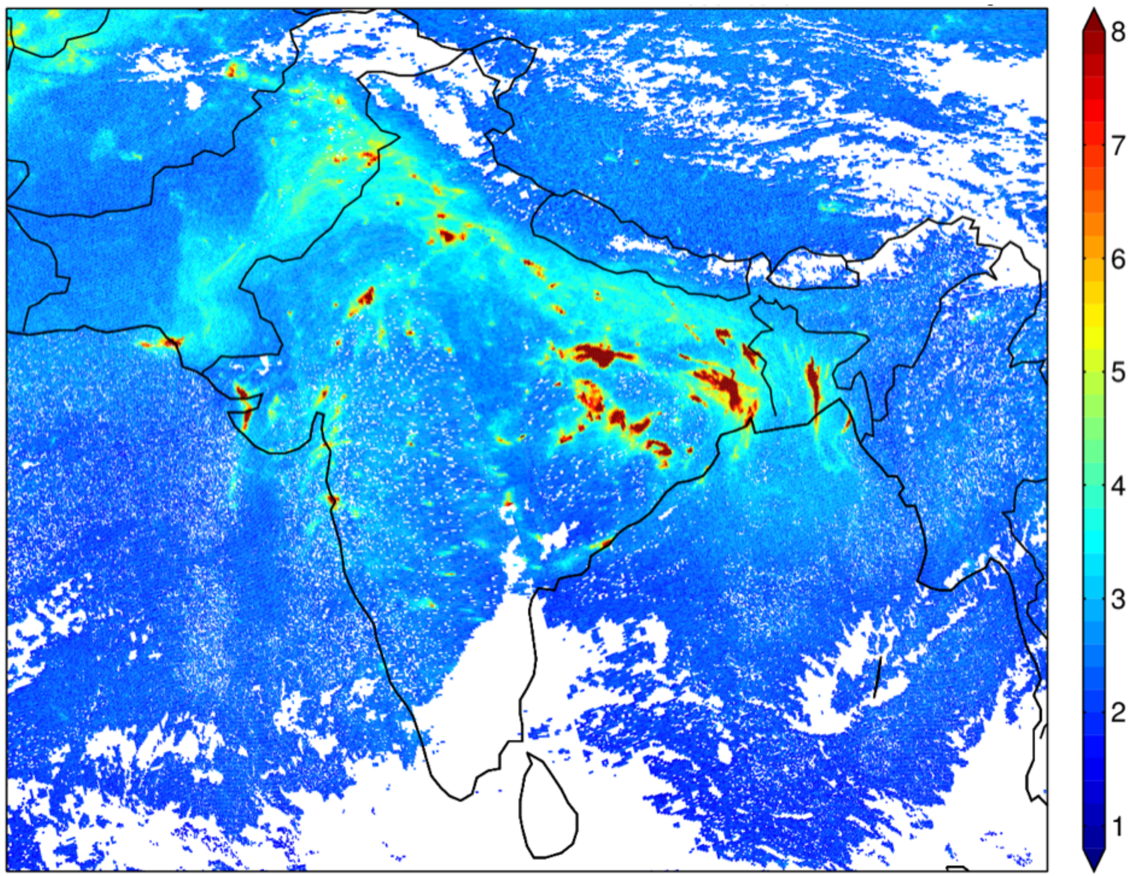
TROPOMI: Impact of Resolution

November 28, 2017

OMI NO_2

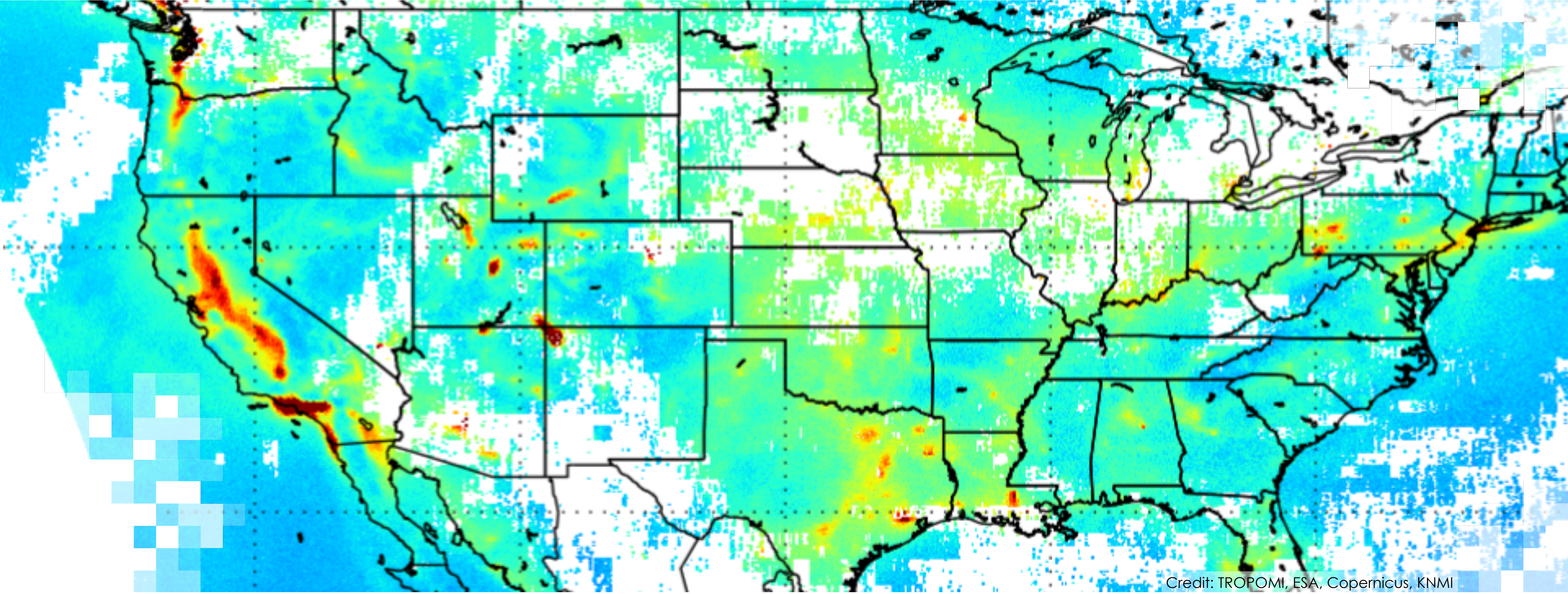


TROPOMI NO_2



Spatial Resolution = 3.5 x 7.0 km^2

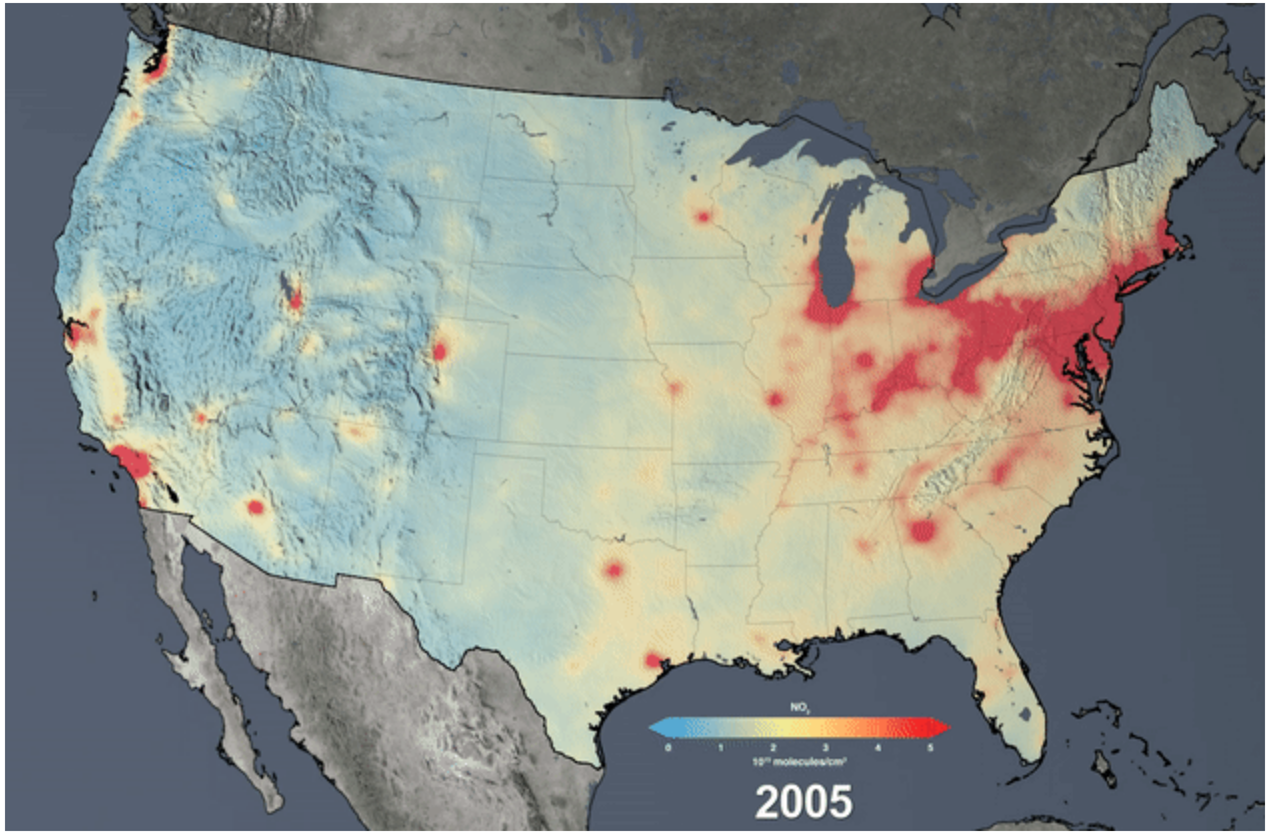
TROPOMI data courtesy of ESA



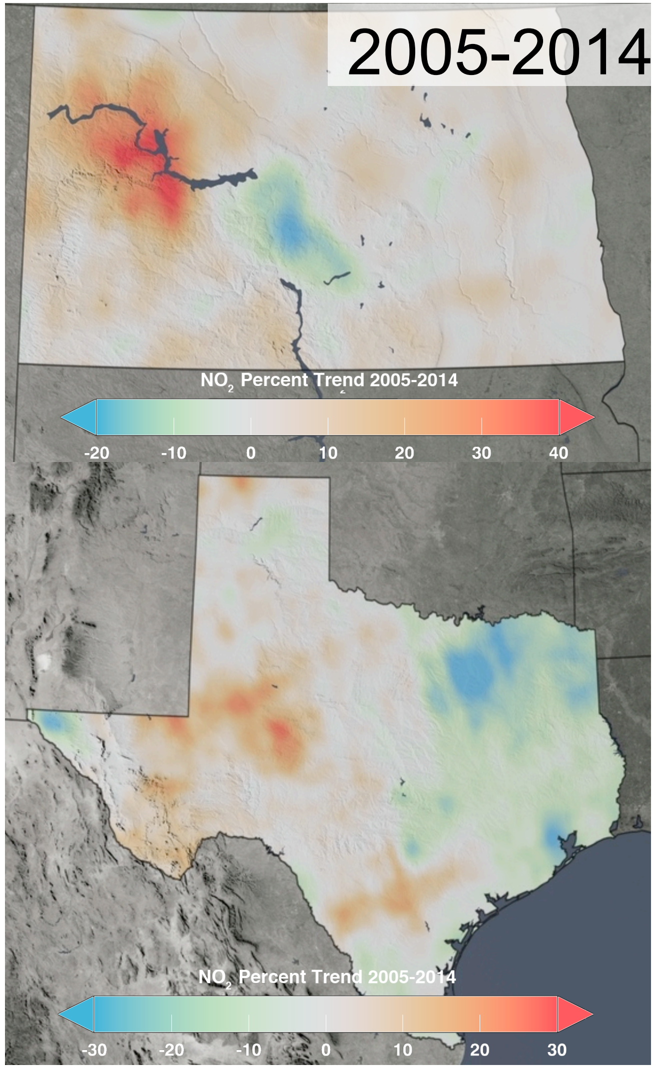
Applications and Research Using OMI data

OMI Detects NO_2 Changes in Pollution Over Time

2005 – 2016



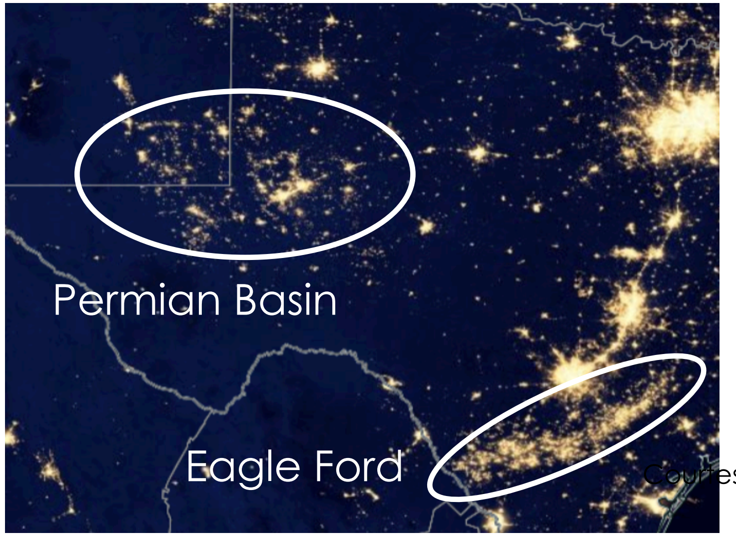
OMI Detects NO_2 Increases from ONG Activities



North Dakota

Suomi NPP VIIRS Lights at Night

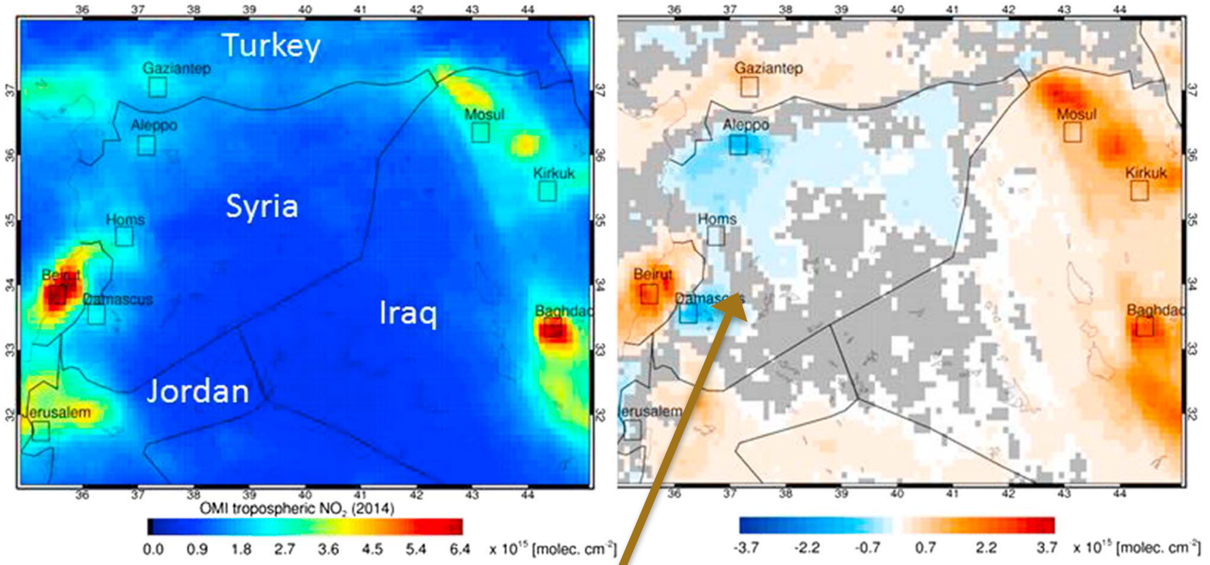
Texas



Courtesy of: Bryan Duncan

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

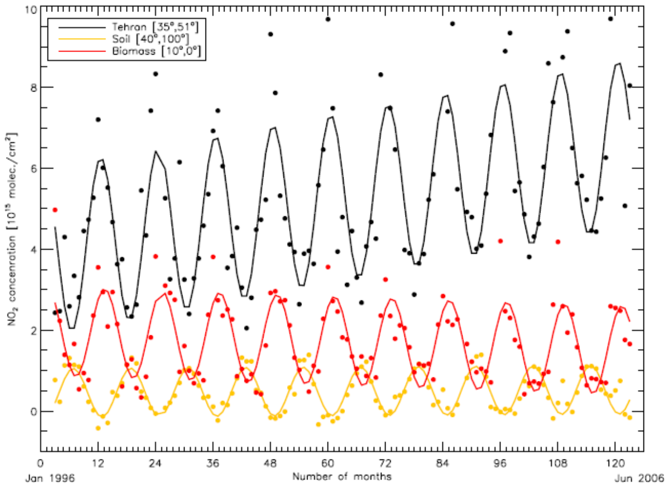


NO_2 Trends from OMI
Damascus: -37.1 ± 10.9%
Aleppo: -40.2 ± 13.6%

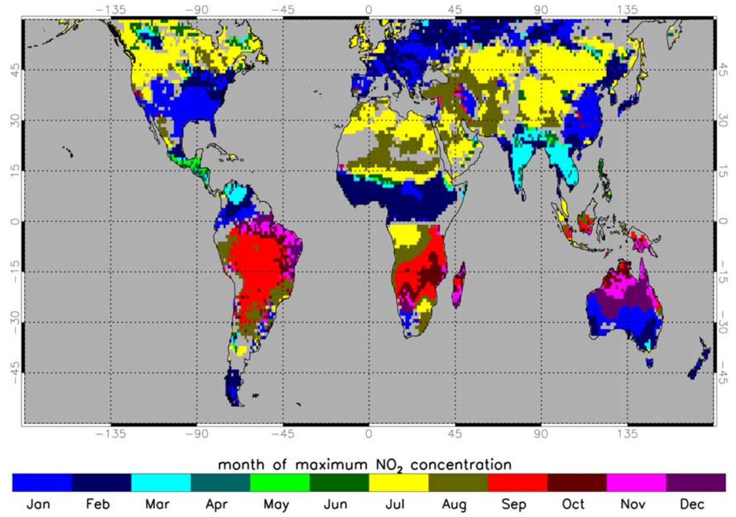
Image credit: Figure 11 from Duncan et al. 2016

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



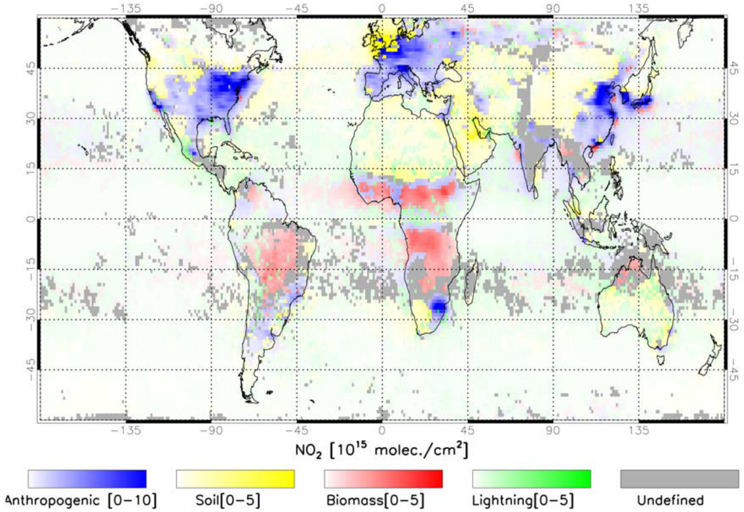
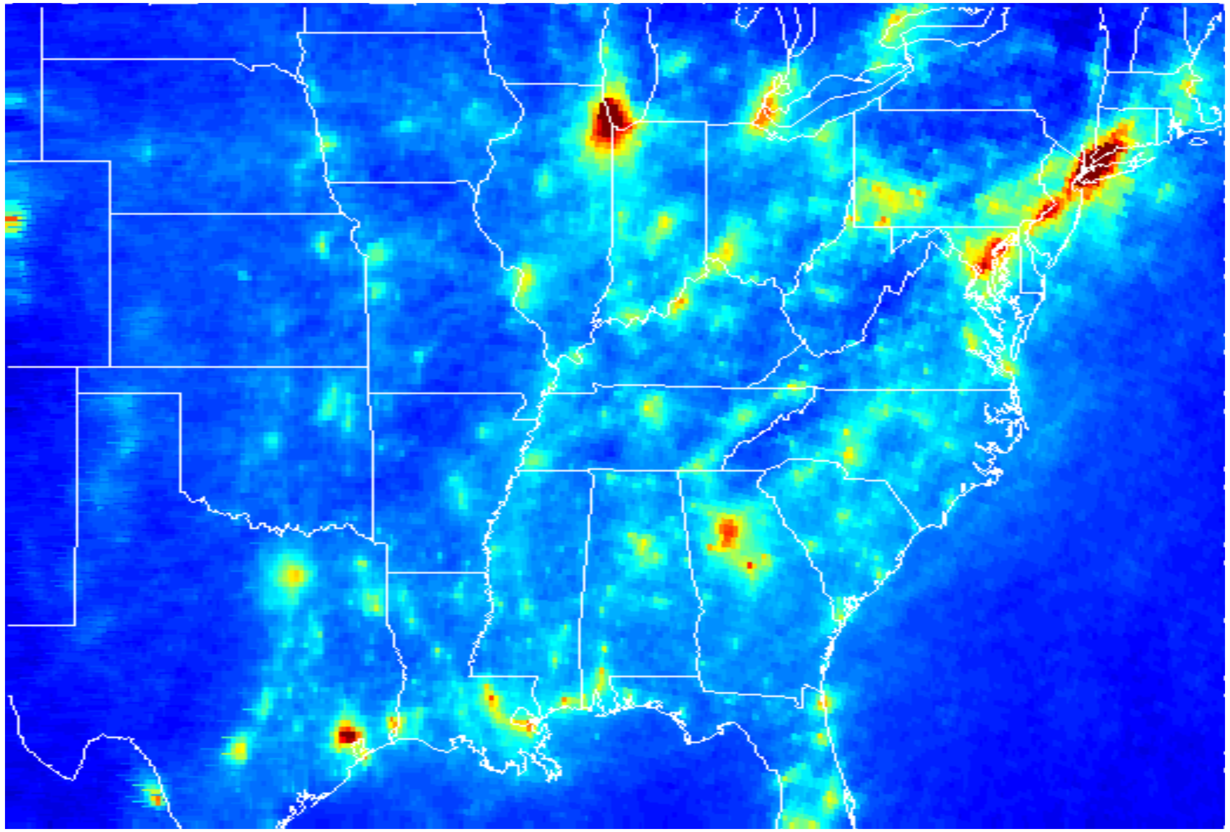


Image credit: Figures 3, 5, and 7 from van der A. et al. 2008

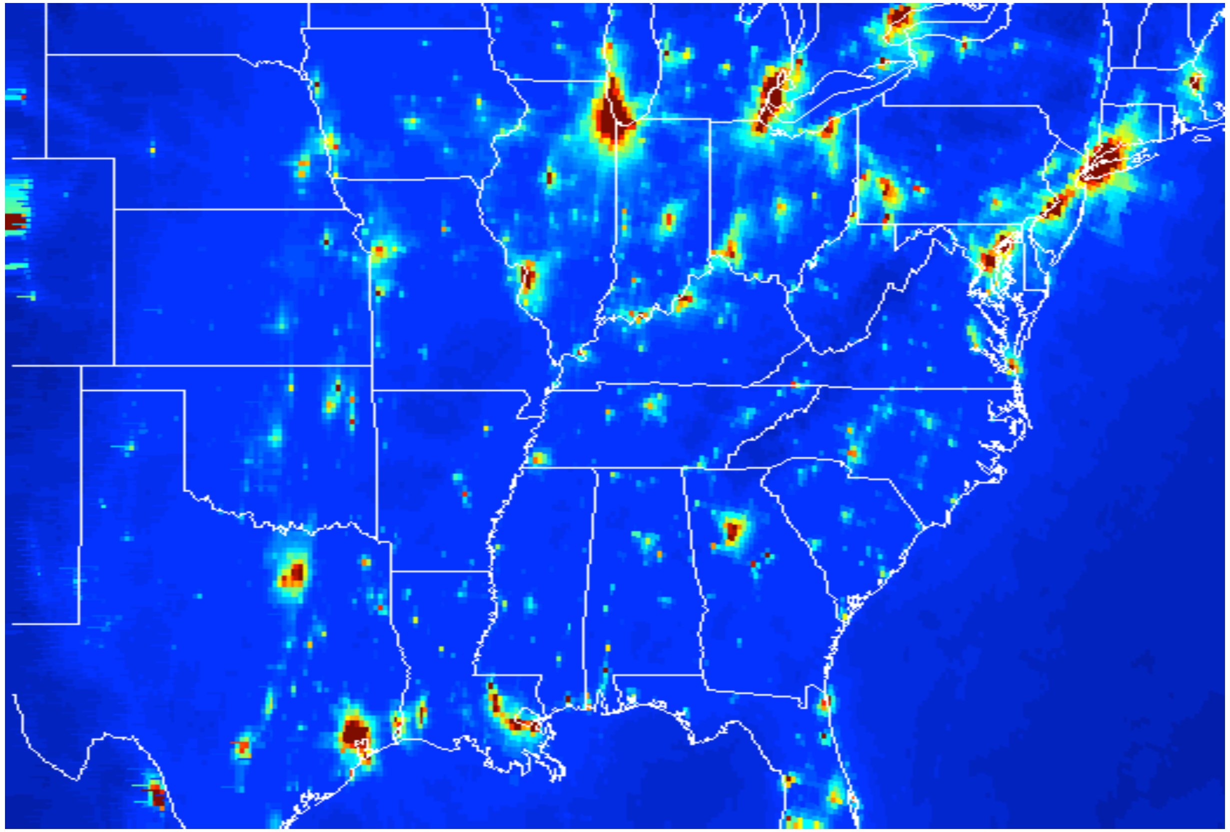
NASA's Applied Remote Sensing Training Program

Model-Satellite Inter-Comparison

OMI NO_2



CMAQ Model NO_2



OMI Trends in NO_2 Correlate Well With Surface Trends

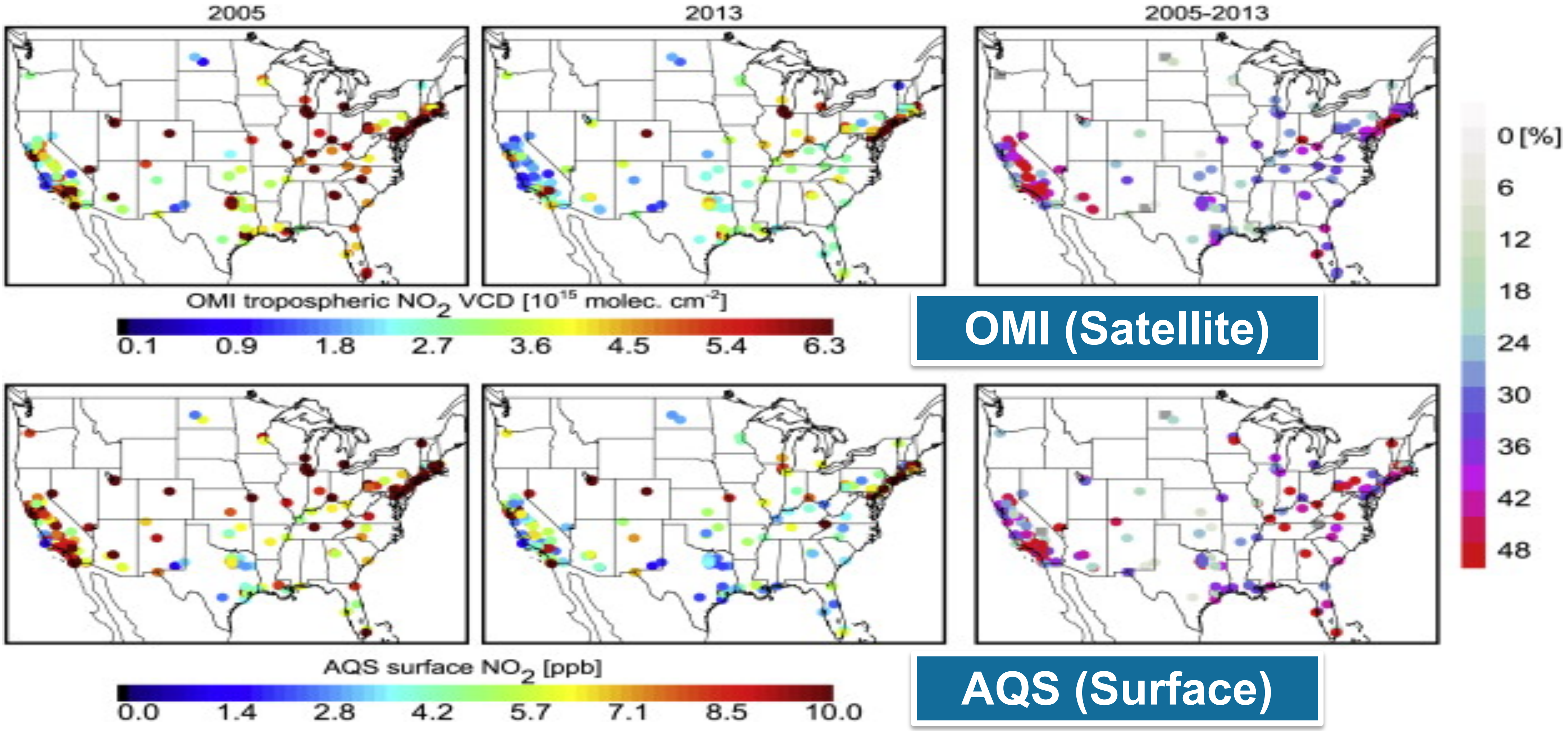
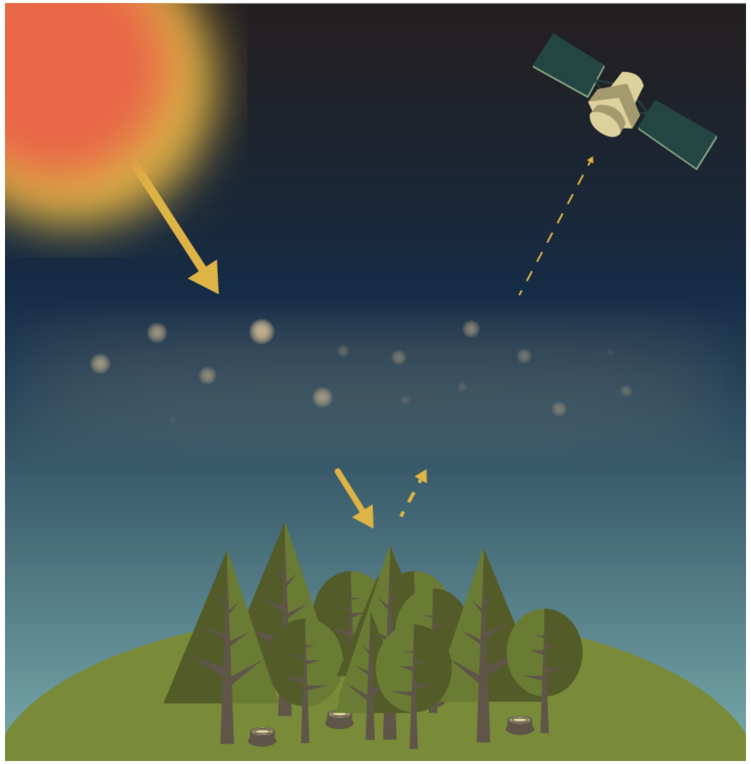
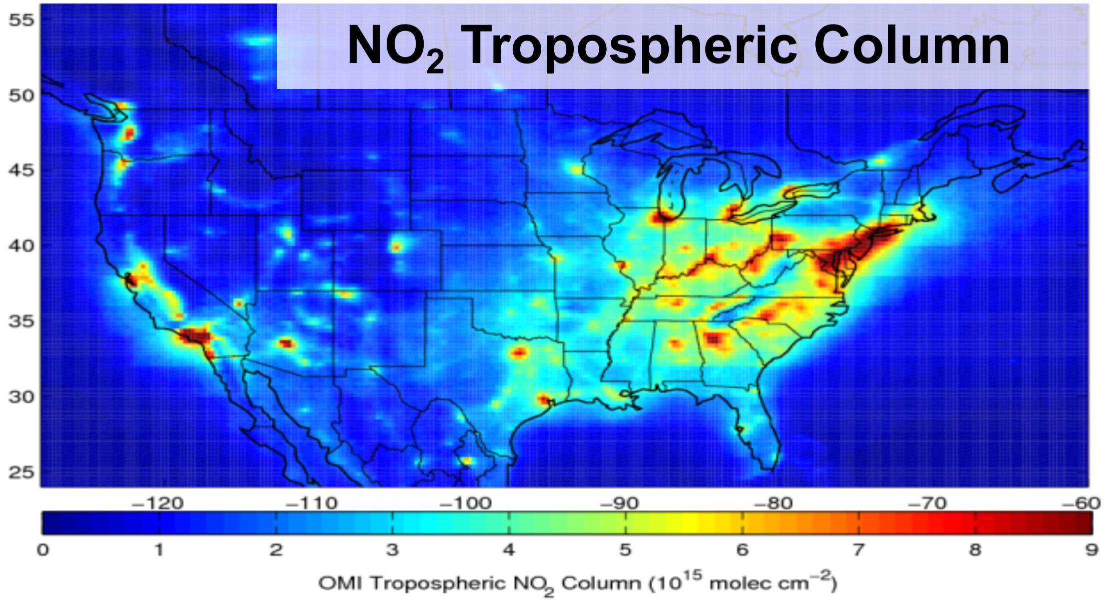


Image credit: Lamsal et al. (2015)

Estimating Surface NO_2 From the Tropospheric Column

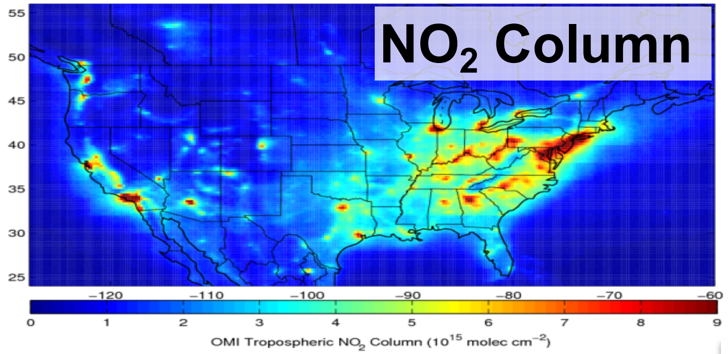




Satellites measure backscattered radiation, from which vertical column densities can be calculated

Courtesy of Randall Martin

Estimating Surface NO_2 From the Tropospheric Column



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

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

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

Lamsal et al. (2008)

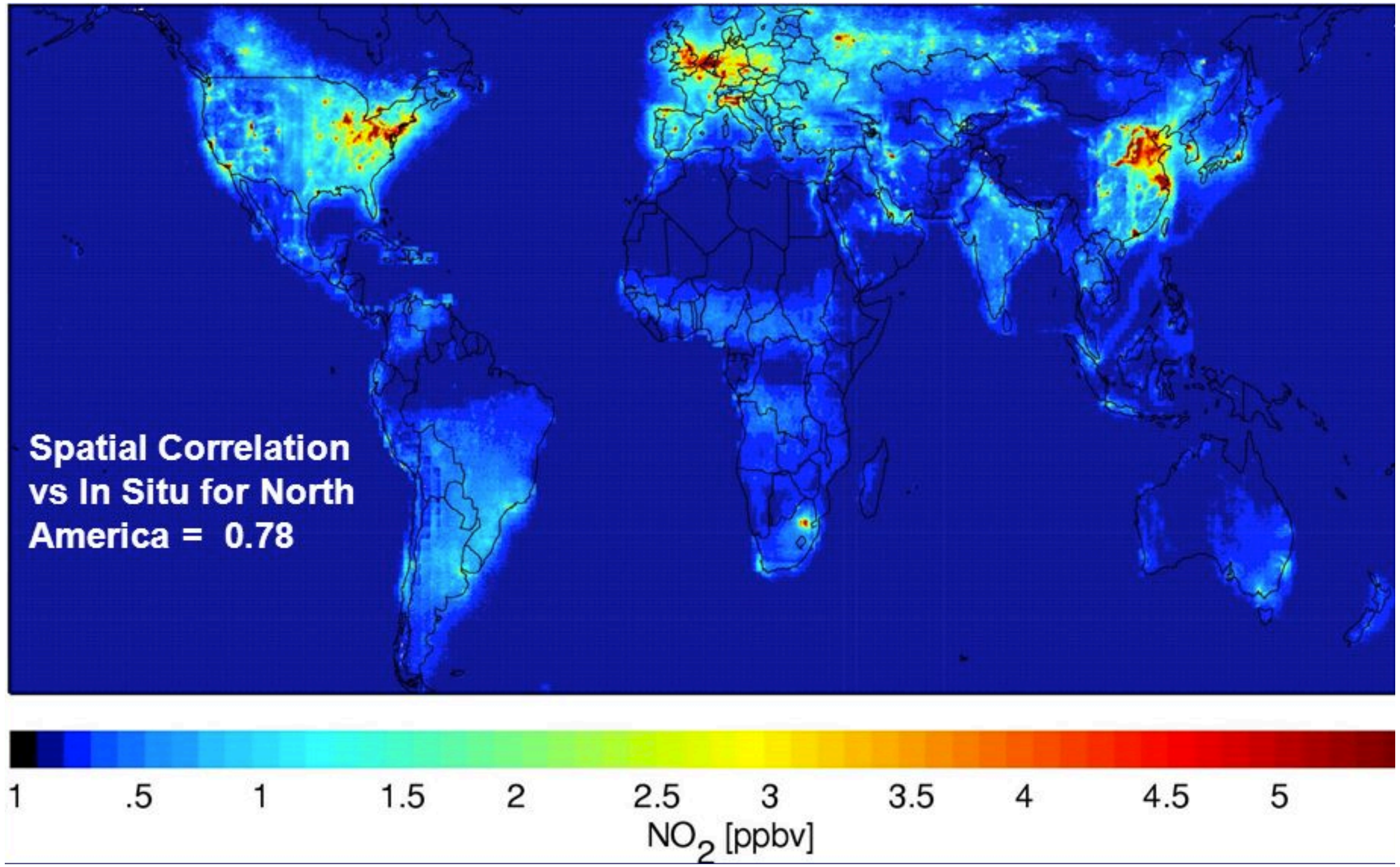
S = Surface Concentration

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° 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 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

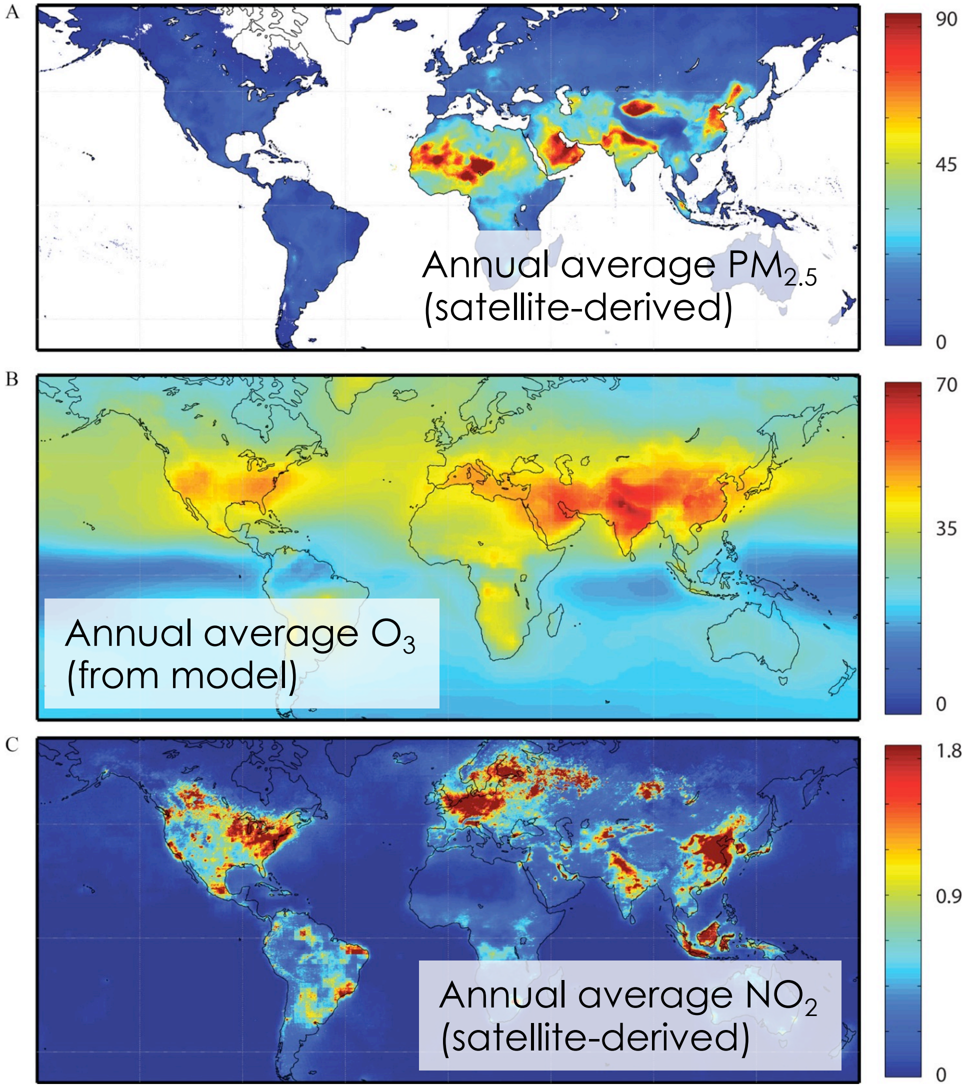


Image credit: Anenberg et al. 2018

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

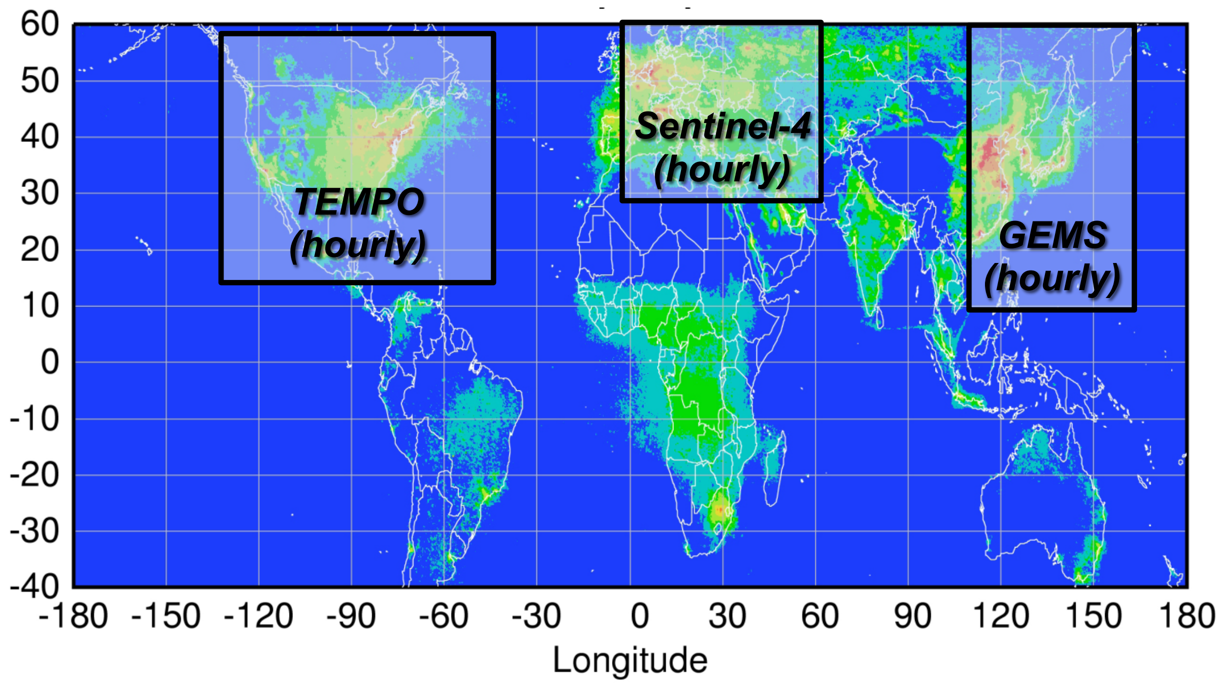
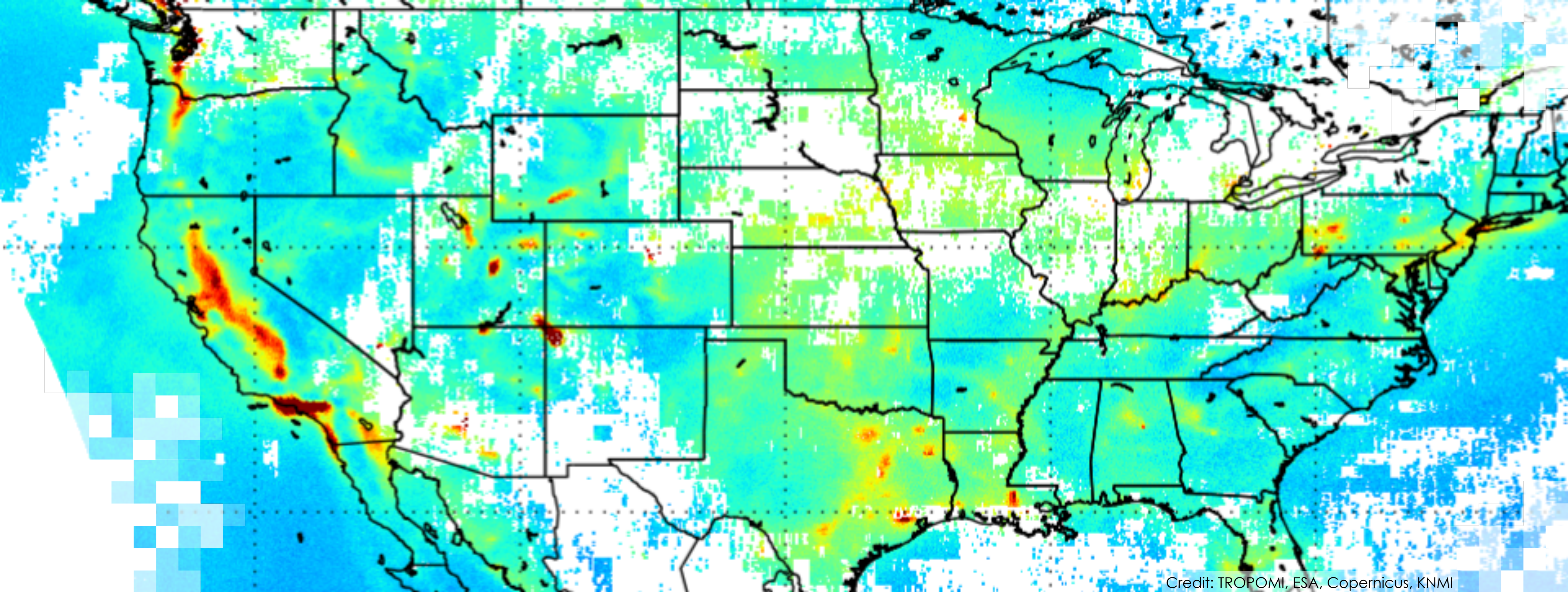


Image Credit: Courtesy Jhoon Kim, Andreas Richter



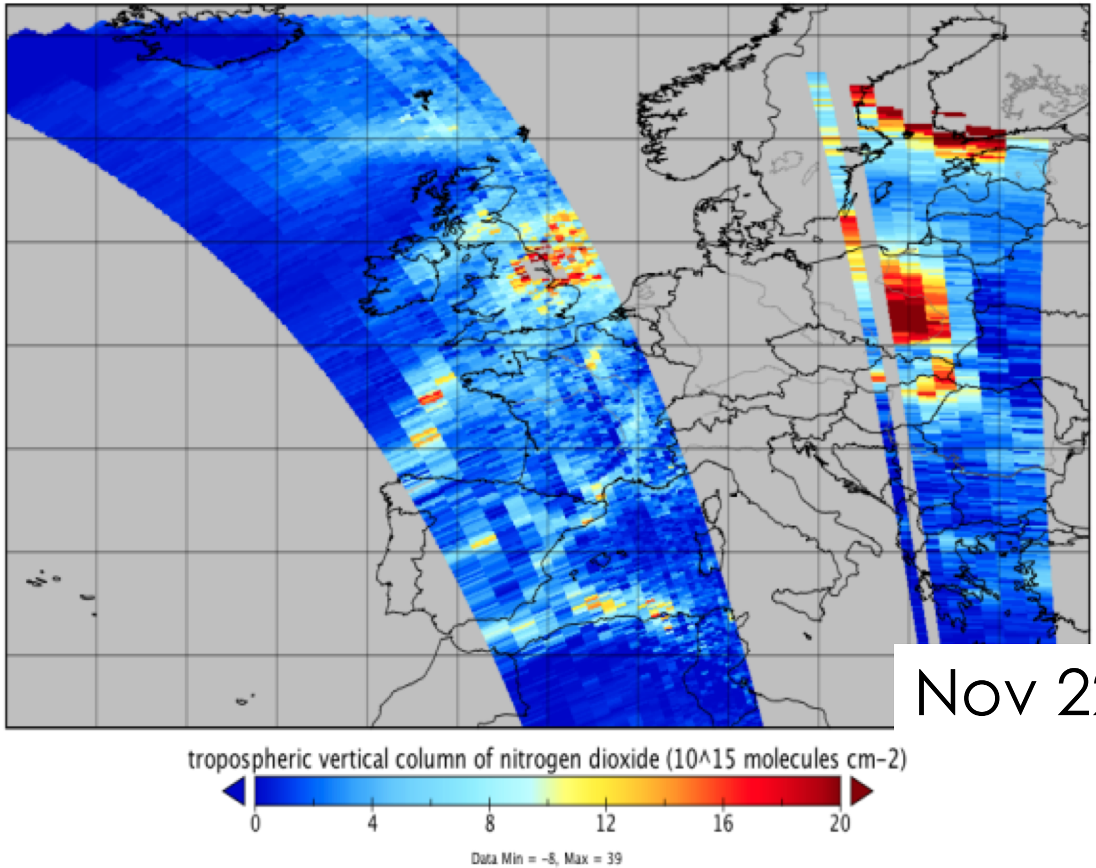
OMI and TROPOMI

OMI vs TROPOMI

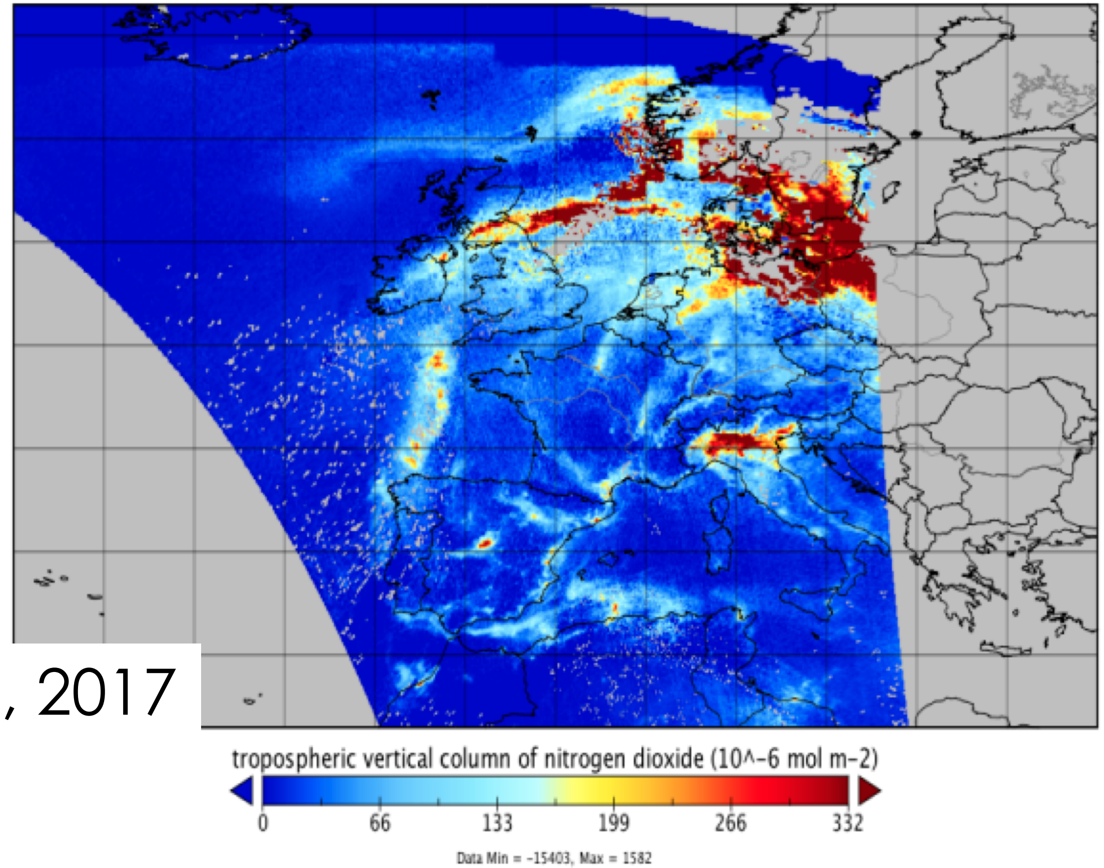
OMI		TROPOMI
Aura	*Satellite*	Sentinel-5P
July 2004	*Launched*	Oct 2017
nadir-viewing imaging spectrometer	*Instrument*	nadir-viewing imaging spectrometer
264 – 504 nm (UV/VIS)	*Spectral Range*	270 nm – 2.3 μm (UV/VIS/NIR/SWIR)
0.42 – 0.63 nm	*Spectral Resolution*	0.55 nm
13x24 km^2 at nadir	*Spatial Resolution*	7 x 3.5 km^2 7 x 28 km^2 (UV1 band) 7 x 7 km^2 (SWIR bands)
Daily	*Global Coverage*	Daily

Spatial Resolution

OMI Tropospheric Column NO_2



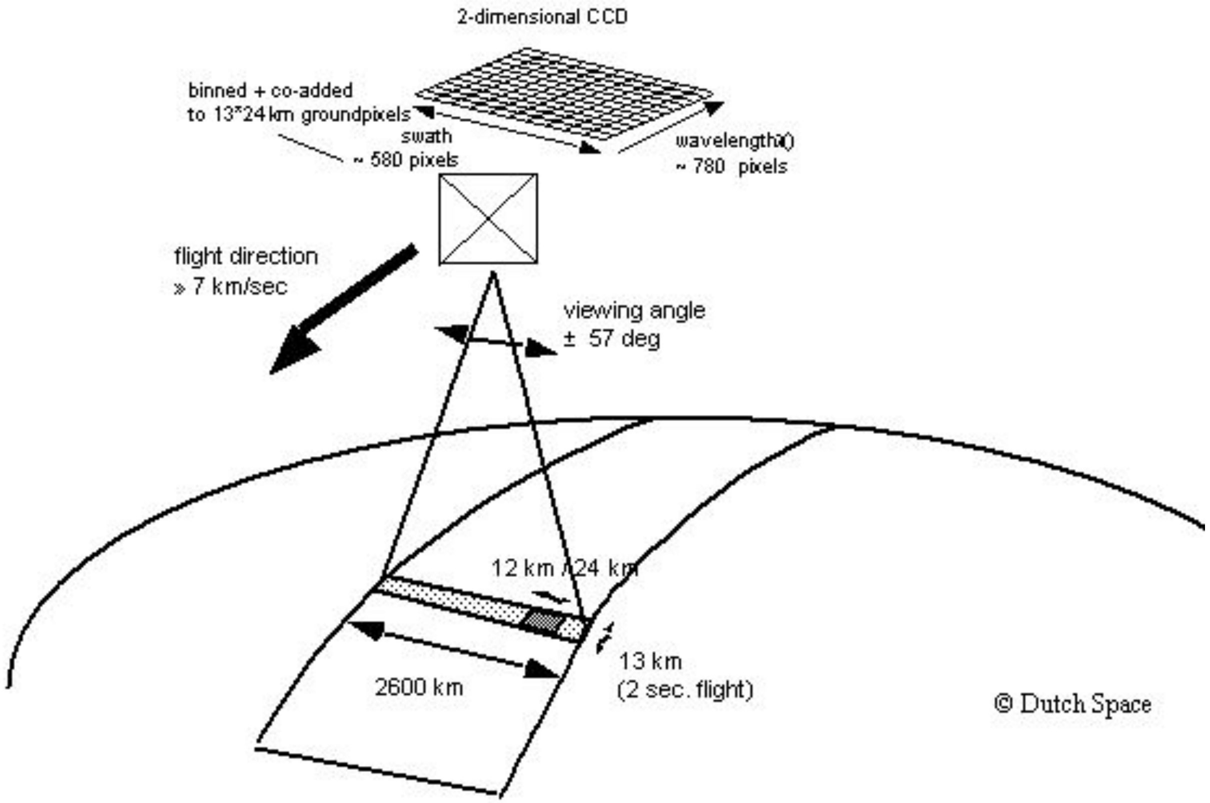
TROPOMI Tropospheric Column NO_2

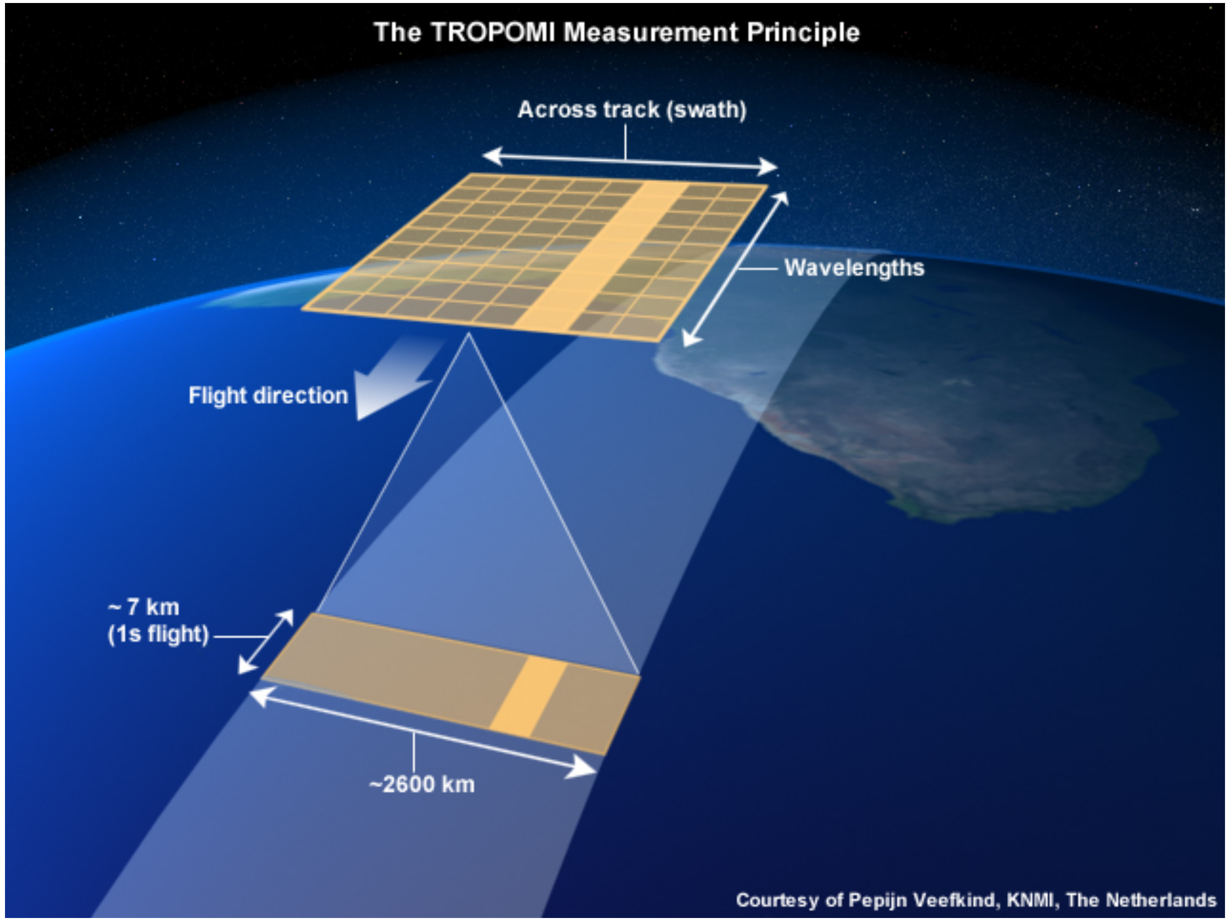


Nov 22, 2017

Sentinel-5 Precursor and the upcoming Sentinels for monitoring atmospheric Composition. (2018, October). Presented at the CAMS 3rd General Assembly, Lisbon, Portugal. Retrieved from https://atmosphere.copernicus.eu/sites/default/files/2018-11/2_Zehner_S5p_CAMS_18.pdf

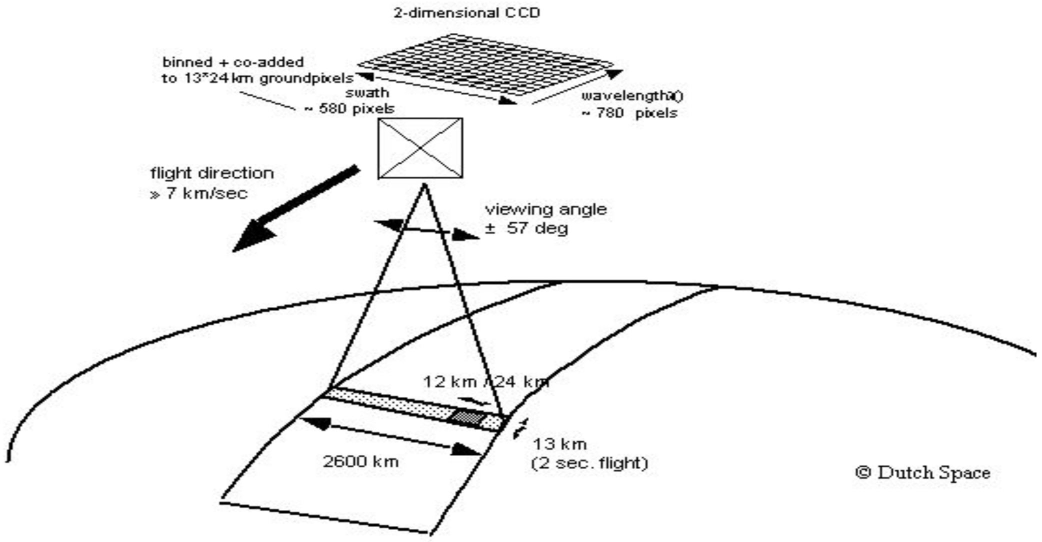
Similar measurement strategies

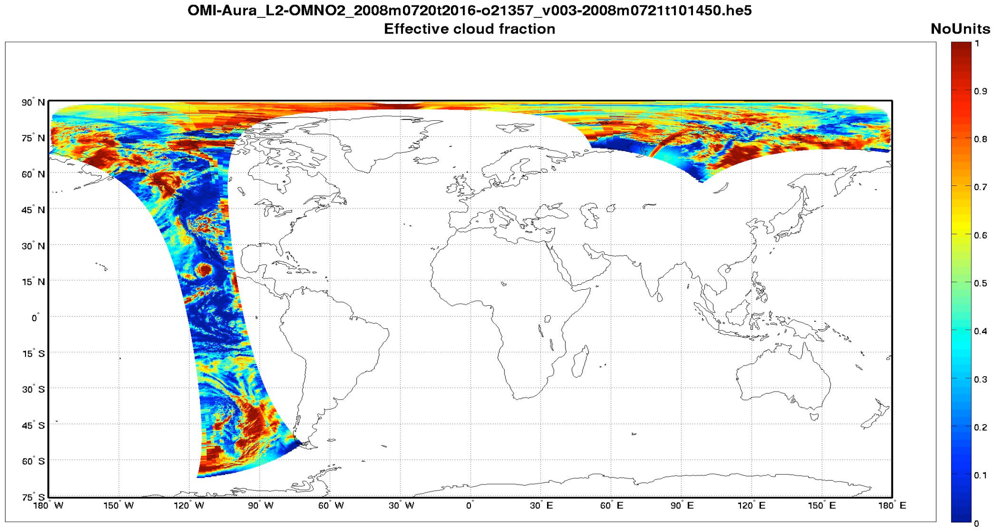




Data Granule

- 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

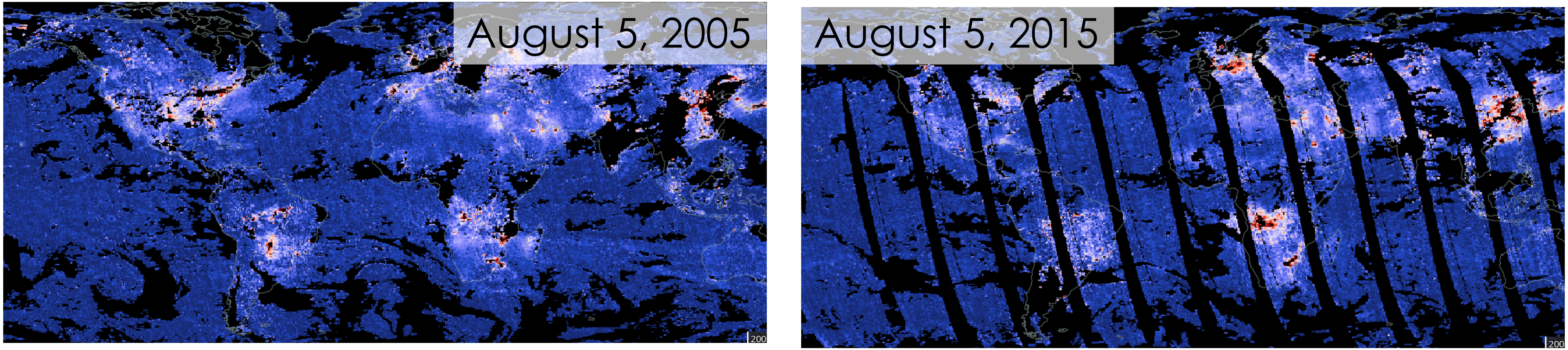




Effect of the OMI Row Anomaly

- 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

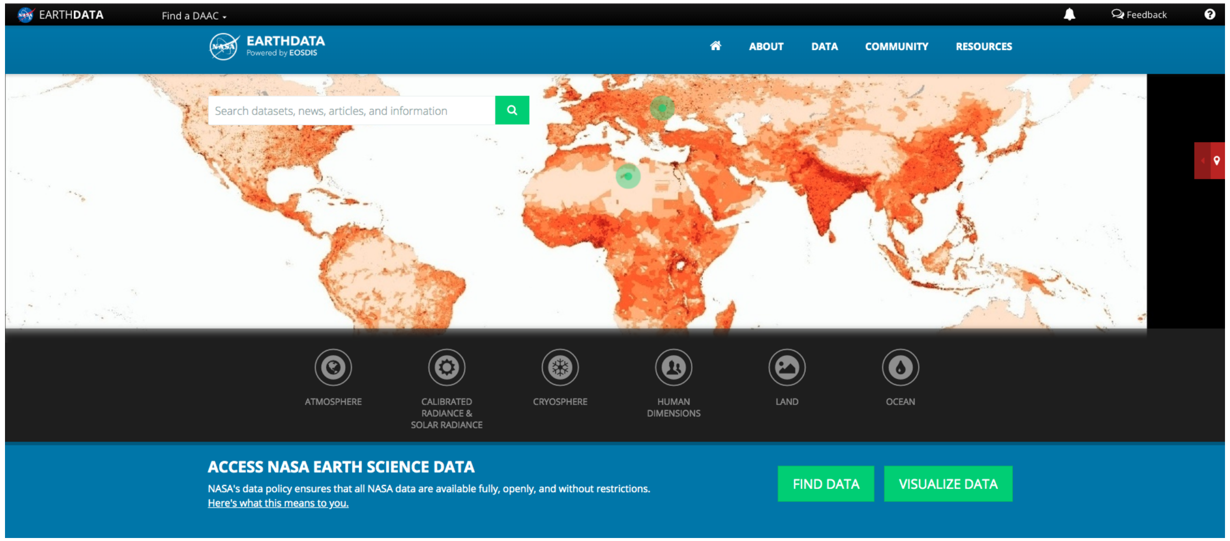


Products from OMI vs TROPOMI

OMI		TROPOMI	
Tropospheric and Total Column NO_2	Swath, gridded (0.25° and 0.1°)	Total Column NO_2	Swath (7 km x 3.5km)
Total Column SO_2	Swath, gridded (0.25°)	Total Column SO_2	Swath (7 x 3.5 km)
Aerosol Index	Swath	Aerosol Index	Swath (7 x 3.5 km)
Total Column HCHO	Swath, gridded (0.1°)	Total Column HCHO	Swath (7 x 3.5 km)
Tropospheric and Total Column O_3	Gridded (0.25°)	Tropospheric and Total Column O_3	Swath (7 x 3.5 km)
		Aerosol Layer Height	Not released
		Carbon Monoxide (CO)	Swath (7 km x 7 km)
		Methane (CH_4)	Swath (7 km x 7 km)

Data Access

NASA – Earthdata
https://earthdata.nasa.gov/



ESA – Copernicus Open Access Hub
https://scihub.copernicus.eu/