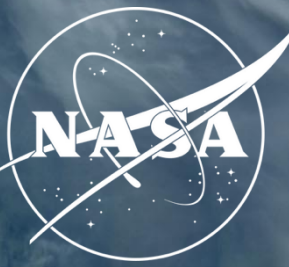


# Studying Atmospheric Composition on the Global South with Geostationary Satellites: South American Perspective

Arlindo da Silva  
NASA Goddard Space Flight Center

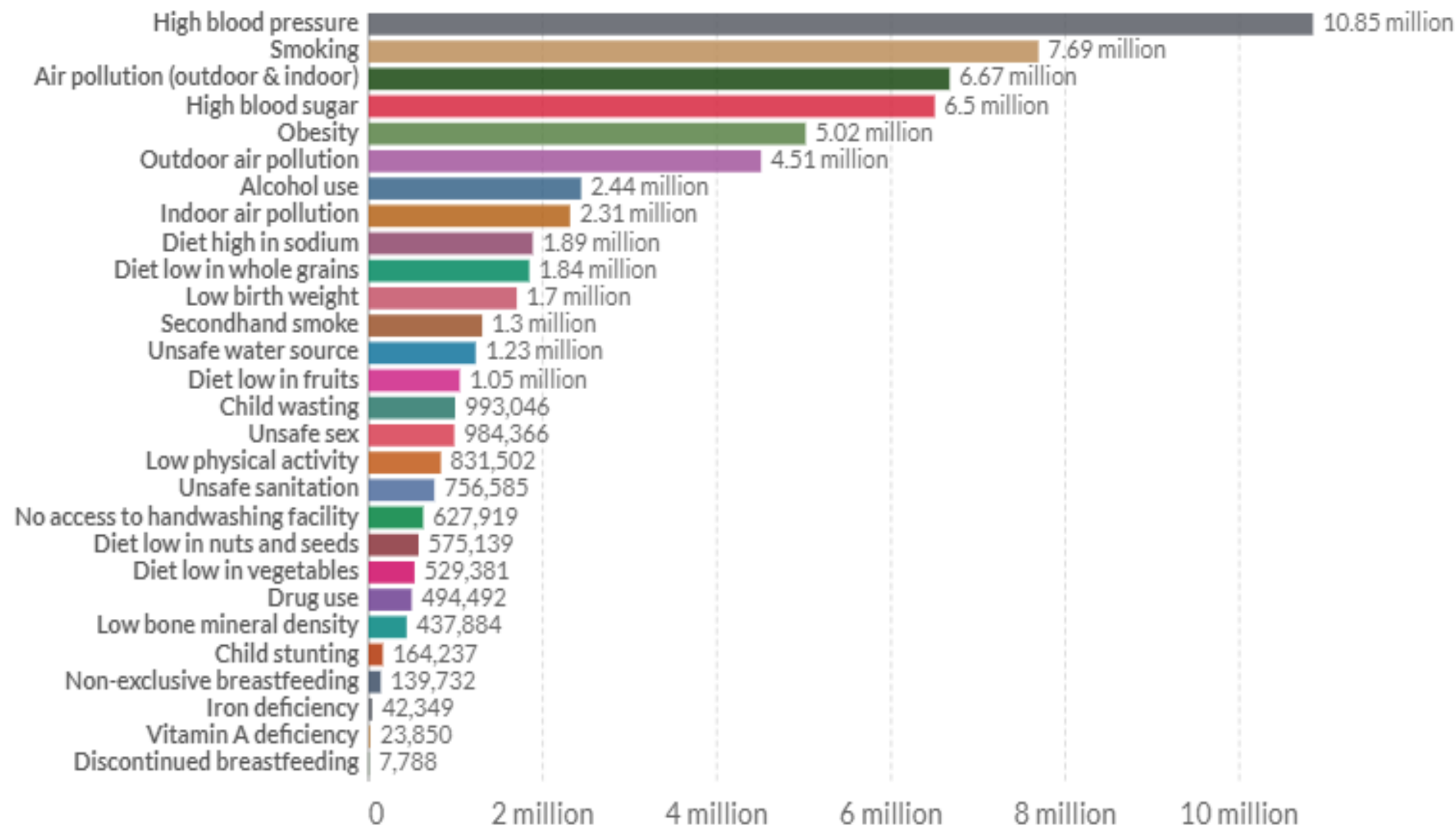
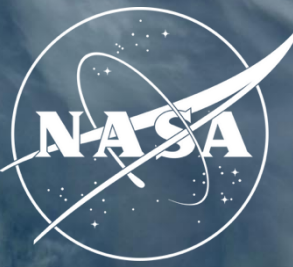
With contributions from the Geostationary Global South Community  
(See Slide 2 for names and affiliations.)

# The Emerging Atmospheric Composition Geostationary Global South Community



| Team Member           | Email                                          | Institution                                                                                                |
|-----------------------|------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| Pieter Levelt         | levelt@ucar.edu                                | NCAR Atmospheric Chemistry Observations and Modeling Laboratory (ACOM)                                     |
| Drobot Sheldon        | sheldon.drobot@baesystems.us                   | BAE Systems                                                                                                |
| Omar Eman             | omar.emam@intospass.org                        | INTOSPASS – International Outer Space Association                                                          |
| Barry Lefer           | barry.lefer@nasa.gov                           | NASA Headquarters                                                                                          |
| Ryan Pavlick          | ryan.p.pavlick@nasa.gov                        | NASA Headquarters                                                                                          |
| Ali Omar              | ali.h.omar@nasa.gov                            | NASA Langley Research Center                                                                               |
| Arlindo da Silva      | arlindo.dasilva@nasa.gov                       | NASA Goddard Space Flight Center                                                                           |
| Eloise A. Marais      | e.marais@ucl.ac.uk                             | London's Global University                                                                                 |
| Wenfu Tang            | wenfut@ucar.edu                                | NCAR Atmospheric Chemistry Observations and Modeling Laboratory (ACOM)                                     |
| Sara Martinez-Alonso  | <a href="mailto:sma@ucar.edu">sma@ucar.edu</a> | NCAR Atmospheric Chemistry Observations and Modeling Laboratory (ACOM)                                     |
| David Edwards         | Edwards@ucar.edu                               | NCAR Atmospheric Chemistry Observations and Modeling Laboratory (ACOM)                                     |
| Helen Worden          | hmw@ucar.edu                                   | NCAR Atmospheric Chemistry Observations and Modeling Laboratory (ACOM)                                     |
| Henk Eskes            | eskes@knmi.nl                                  | Royal Netherlands Meteorological Institute (KNMI)                                                          |
| Pepijn Veefkind       | pepijn.veefkind@knmi.nl                        | Royal Netherlands Meteorological Institute (KNMI)                                                          |
| Steve Brown           | steven.s.brown@noaa.gov                        | NOAA CSL                                                                                                   |
| Collins Gameli Hodoli | cghodoli@uesd.edu.gh                           | University of Environment and Sustainable Development, PMB, Somanya, Eastern Region, Ghana West Africa     |
| Allison Felix Hughes  | ahughes@ug.edu.gh                              | School of Physical and Mathematical Sciences<br>College of Basic and Applied Sciences, University of Ghana |
| Dan Westerfelt        | danielmw@ldeo.columbia.edu                     | Columbia University, USA                                                                                   |

# Air-quality & Human Health



Source: IHME, Global Burden of Disease (GBD)

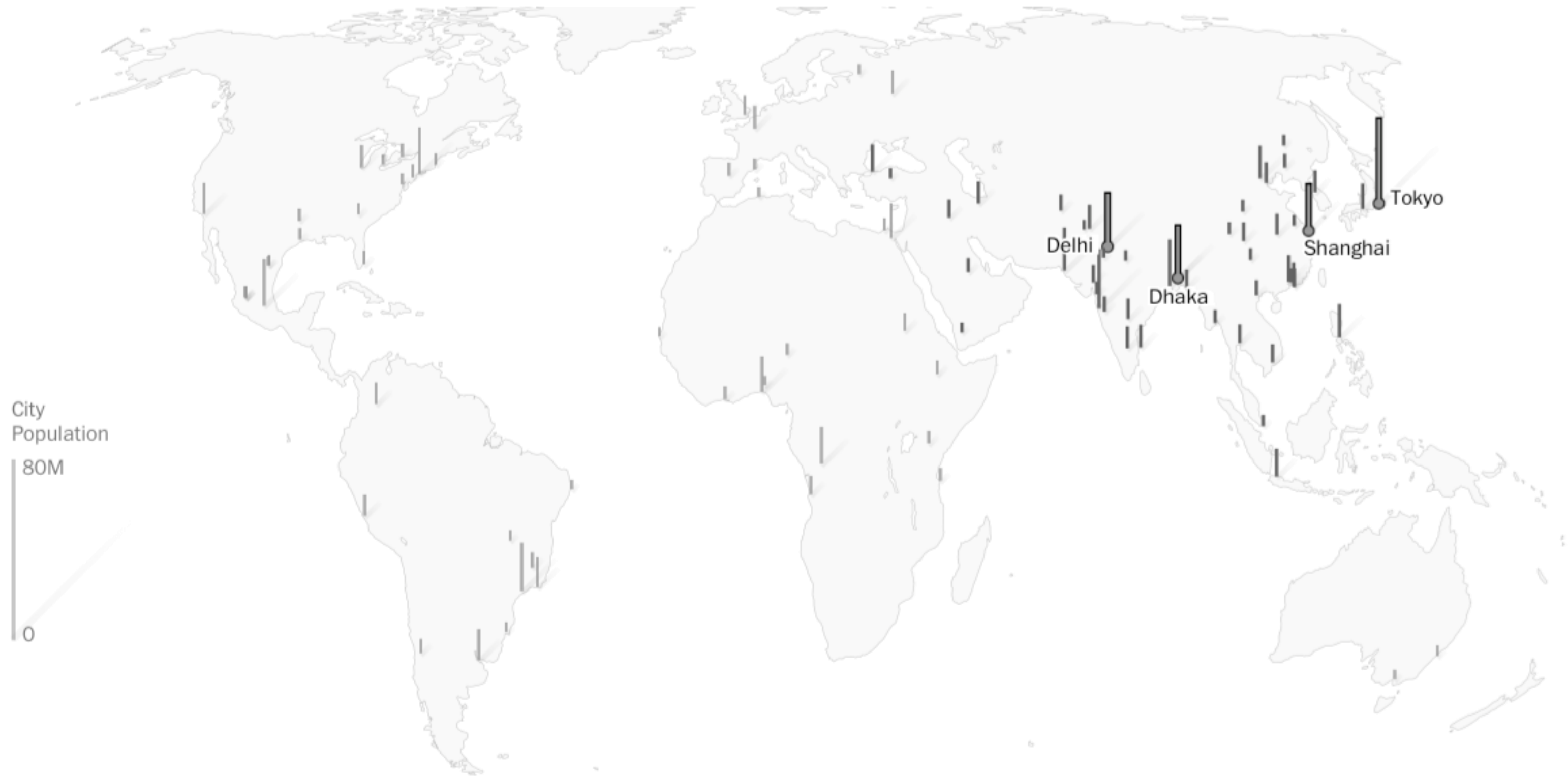
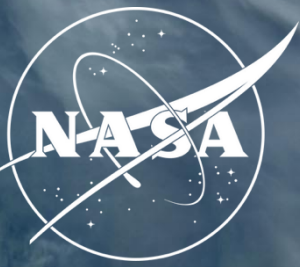
OurWorldInData.org/causes-of-death • CC BY

4 million premature deaths  
attributed to outdoor air  
pollution

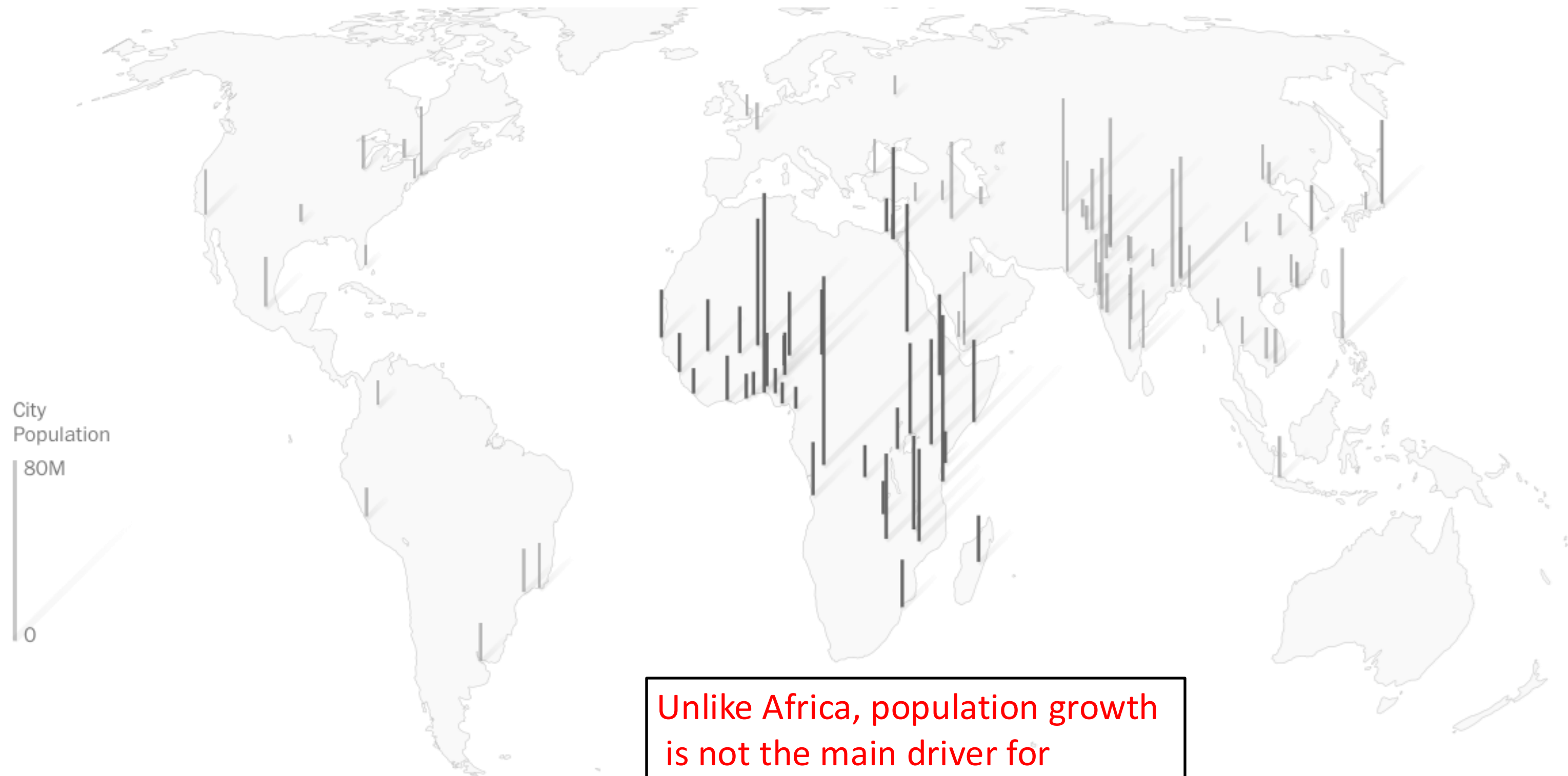
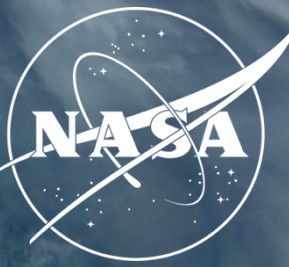
Poor air quality is leading cause  
of premature fatalities

World Bank estimates air  
pollution costs global economy  
\$8.1 Trillion dollars in losses

# 100 Largest Megacities in 2025

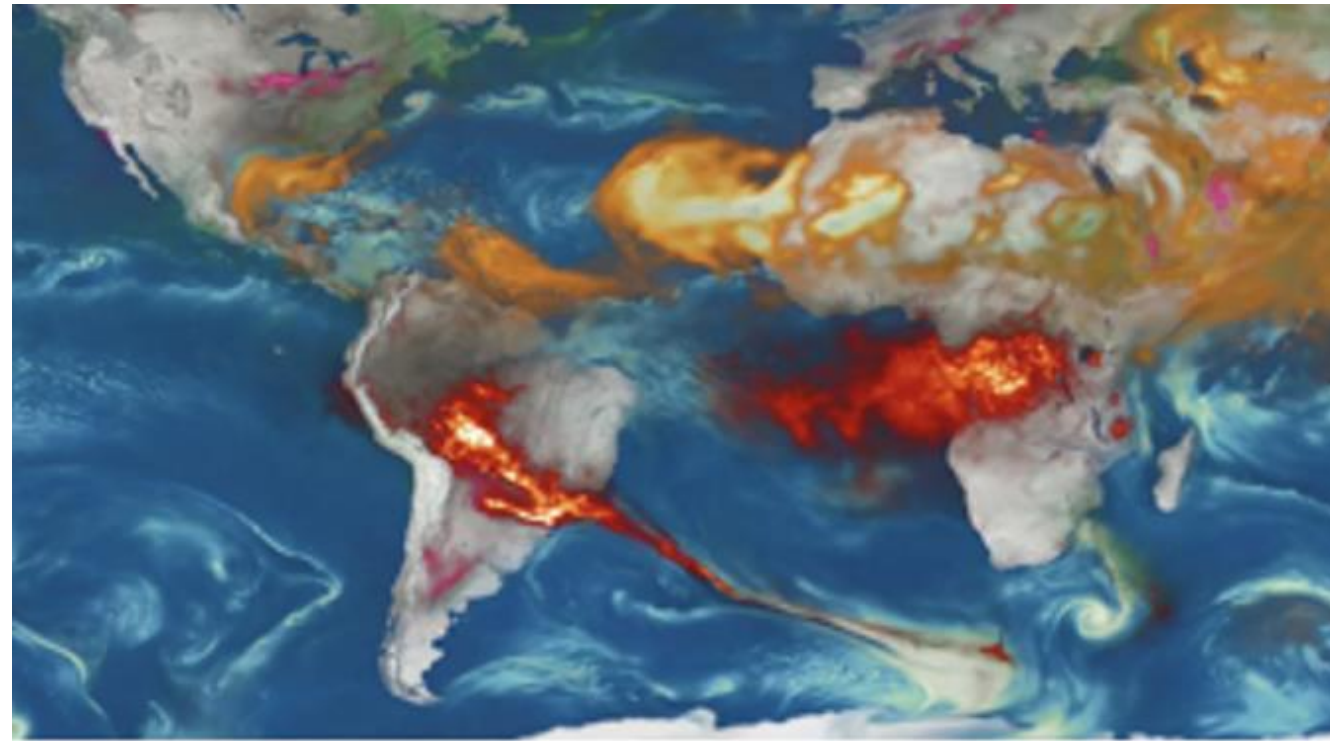
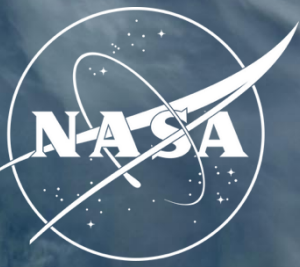


# 100 Largest Megacities in 2100



Unlike Africa, population growth is not the main driver for increased air pollution in the rest of the world

# Increased Wildfire Threat



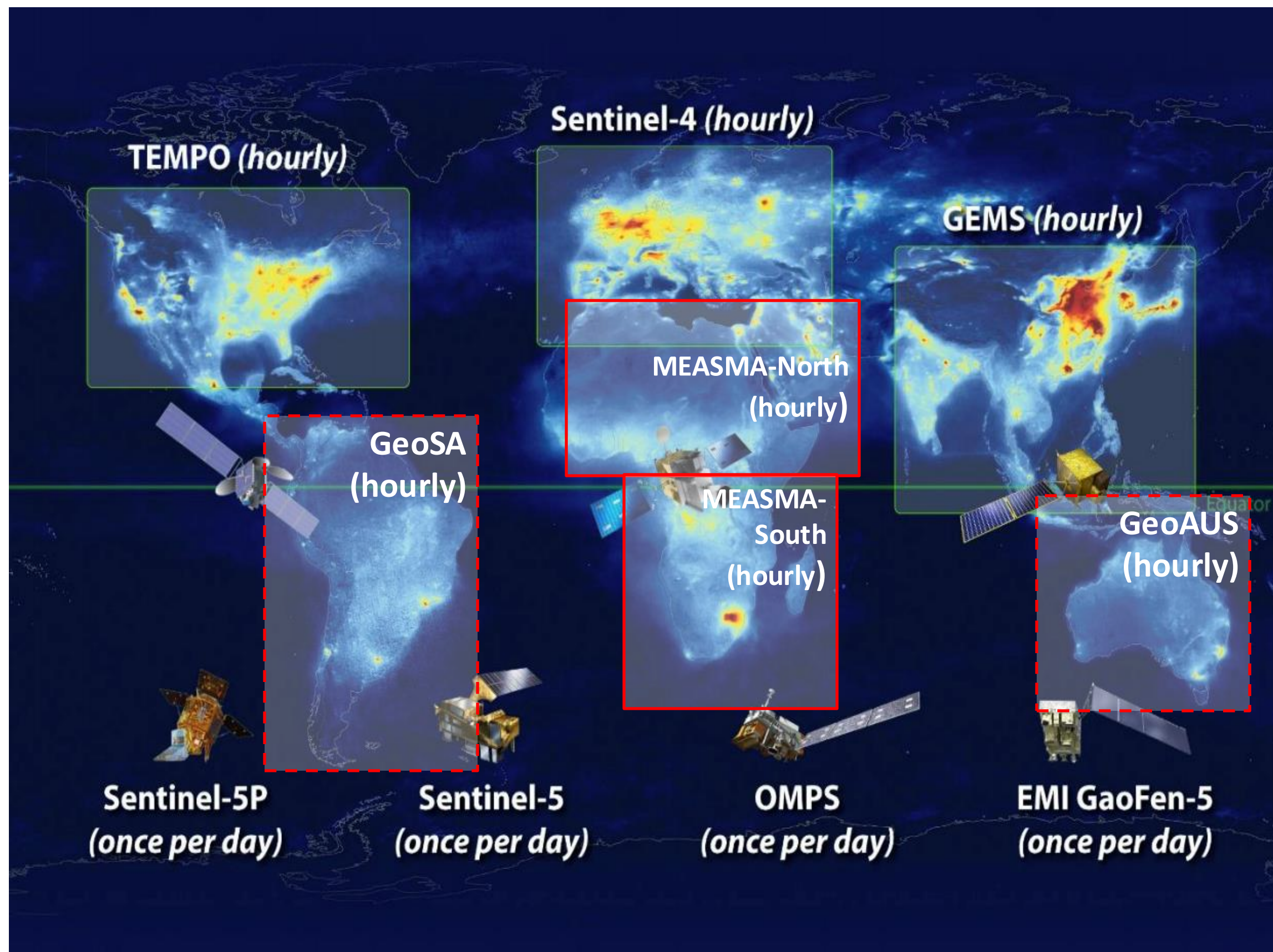
Smoke AOD from the GEOS-FP Aerosol Data Assimilation System

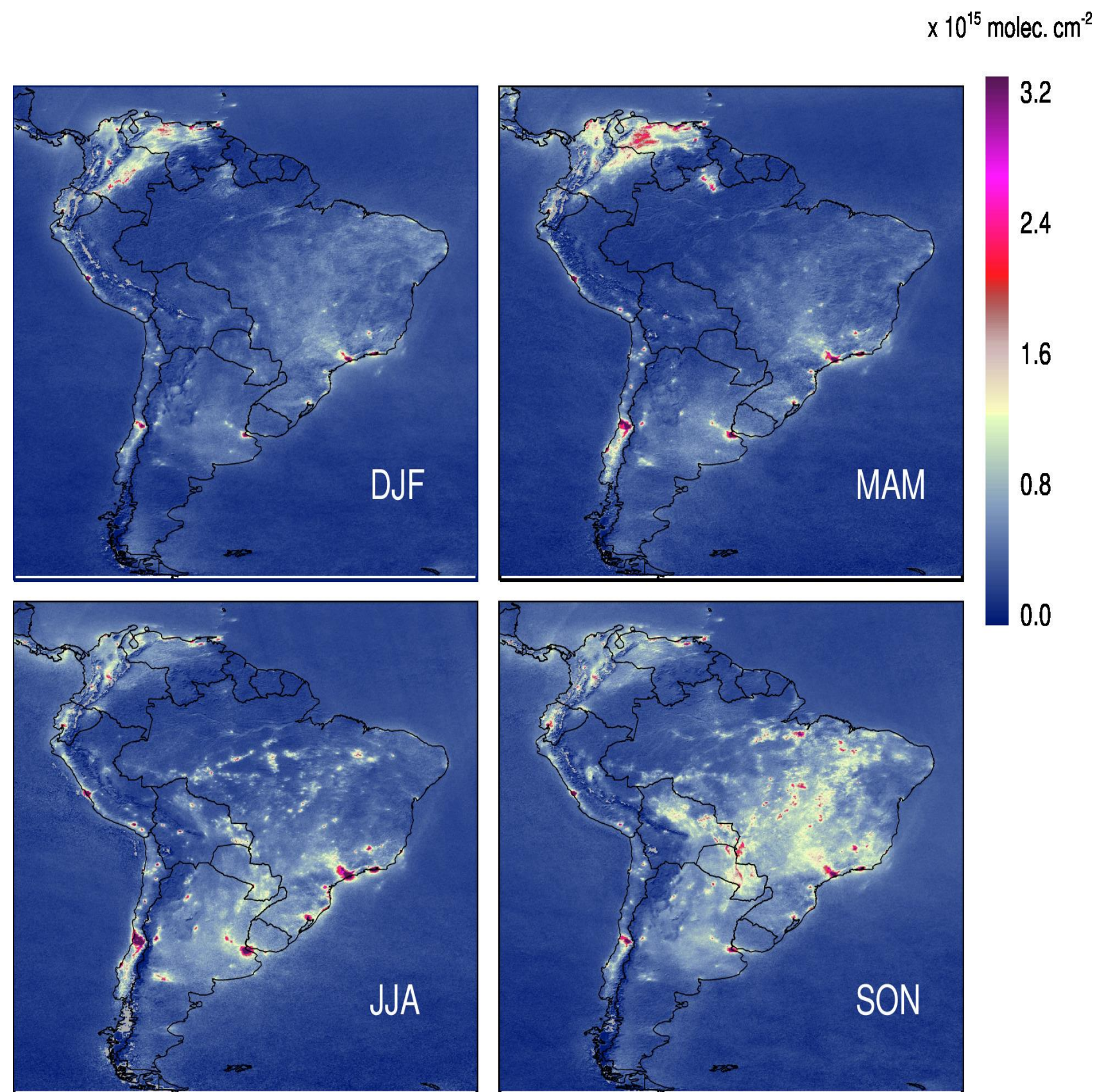


São Paulo in the middle of the day

*Source: The Washington Post*

- The Low-Earth Orbit (LEO) satellites, while offering global coverage, provide only once per day measurements
- The geostationary satellites TEMPO, GEMS and Sentinel-4 are offering revolutionary approaches for high spatial and temporal air quality monitoring, especially over North America, Europe, and Southern & Eastern Asia
- However, significant coverage gaps remain across the southern hemisphere.





All pollution sources are present in South America:

Smoke – biomass burning  
 O<sub>3</sub> – anthropogenic emissions  
 NO<sub>2</sub> – fossil fuel combustion  
 HCHO – Biogenic Emissions

There are limited ground-based measurements

There is a lack of emission estimates over South America

There is an urgent need for new capability for air quality management for health and environment

# OMI NO<sub>2</sub> Measurements over South America: COVID Lockdown

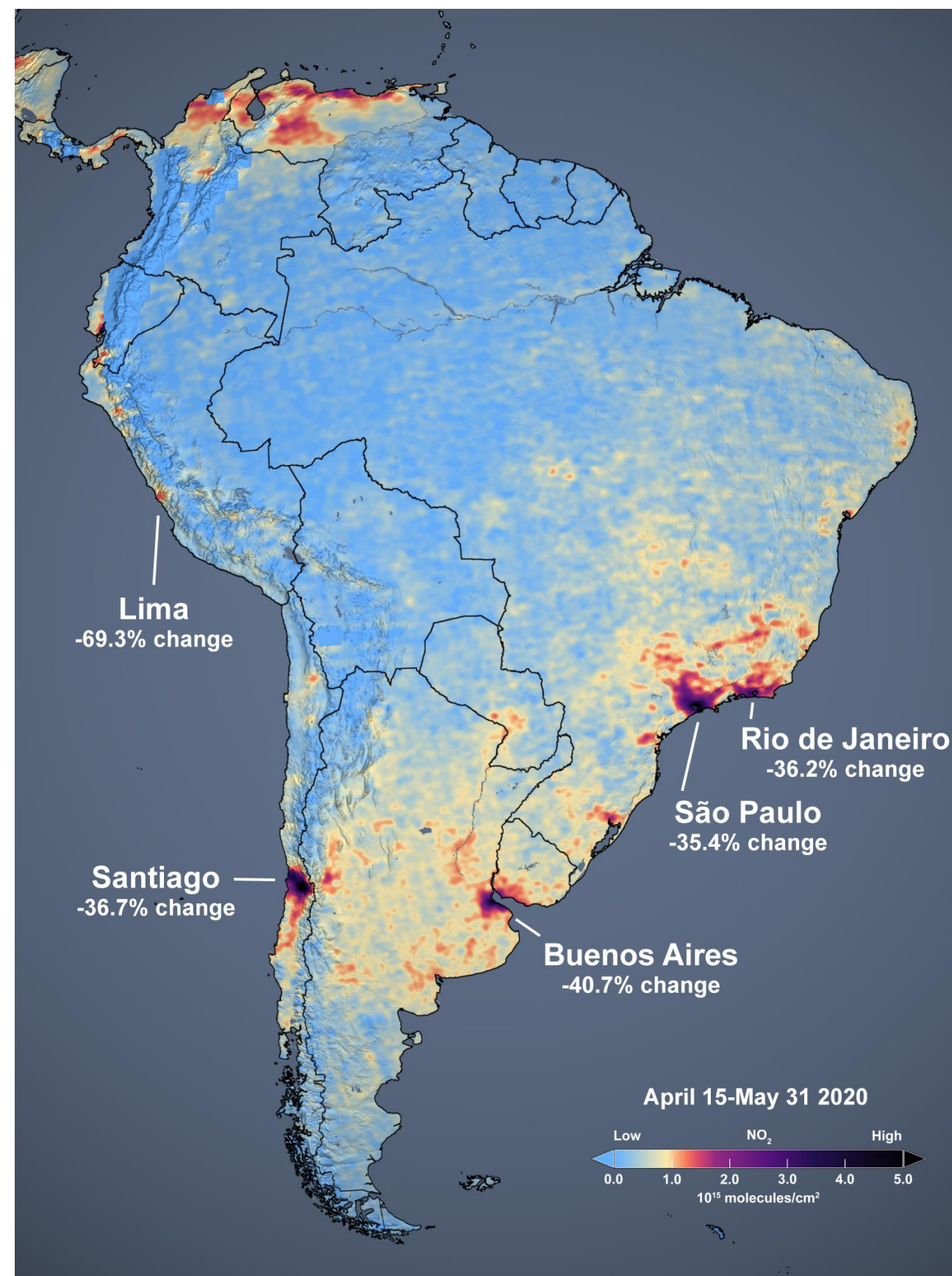
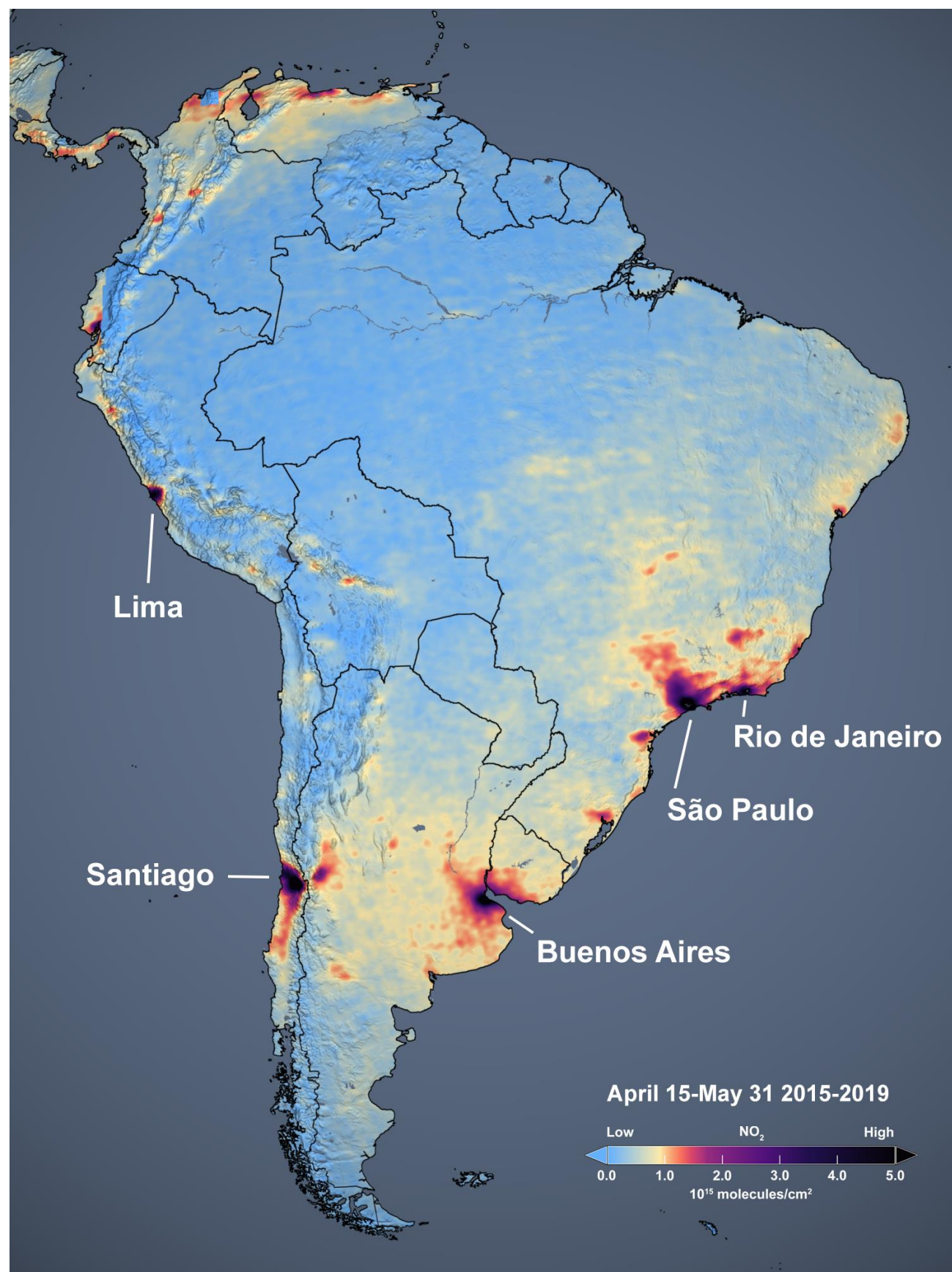


*Image Credit:*  
[NASA GSFC](#)  
[Scientific](#)  
[Visualization](#)  
[Studio](#)

*Slide Courtesy:*  
*A. da Silva*  
*(NASA/GSFC)*

# OMI NO<sub>2</sub> Measurements over South America: COVID Lockdown

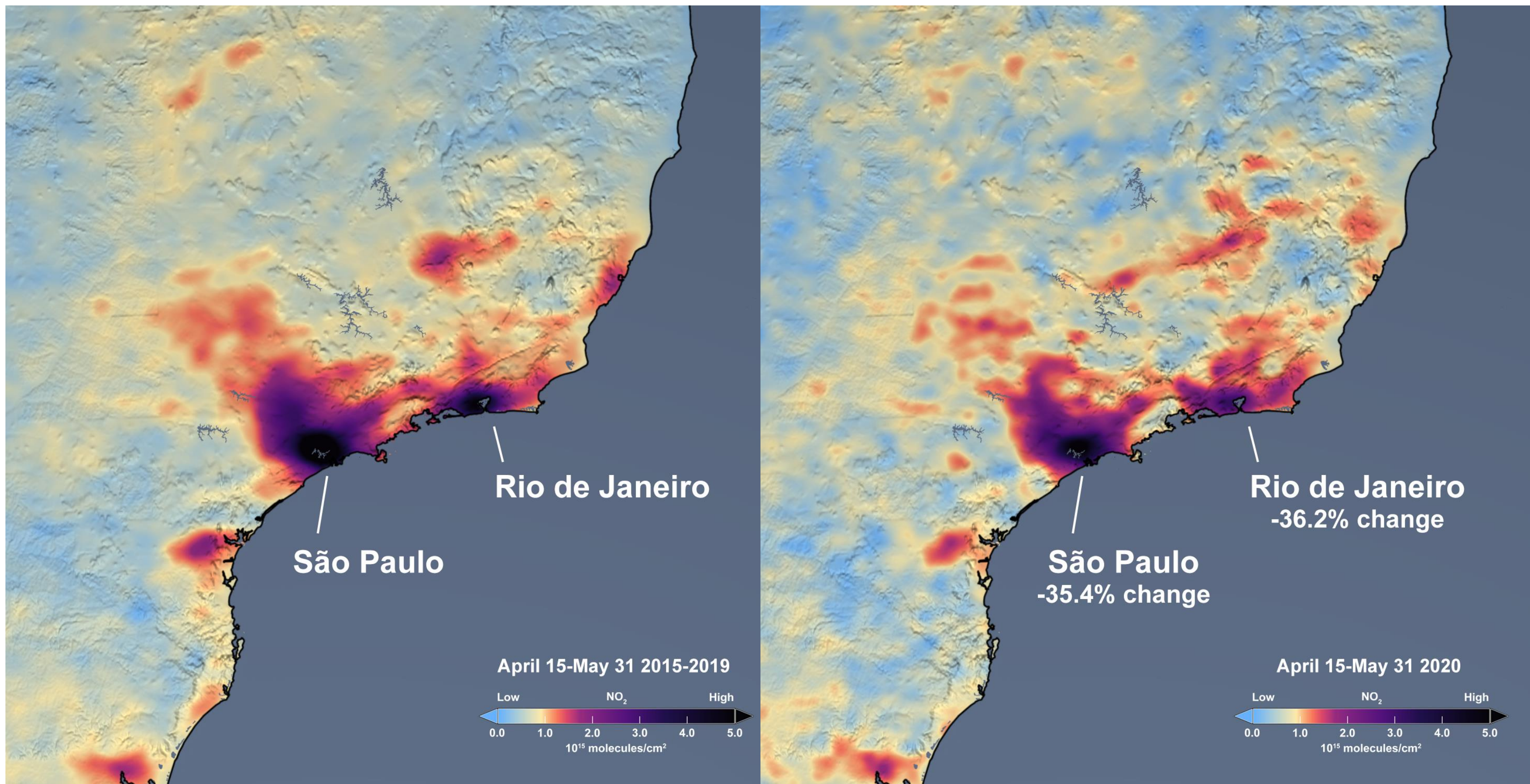
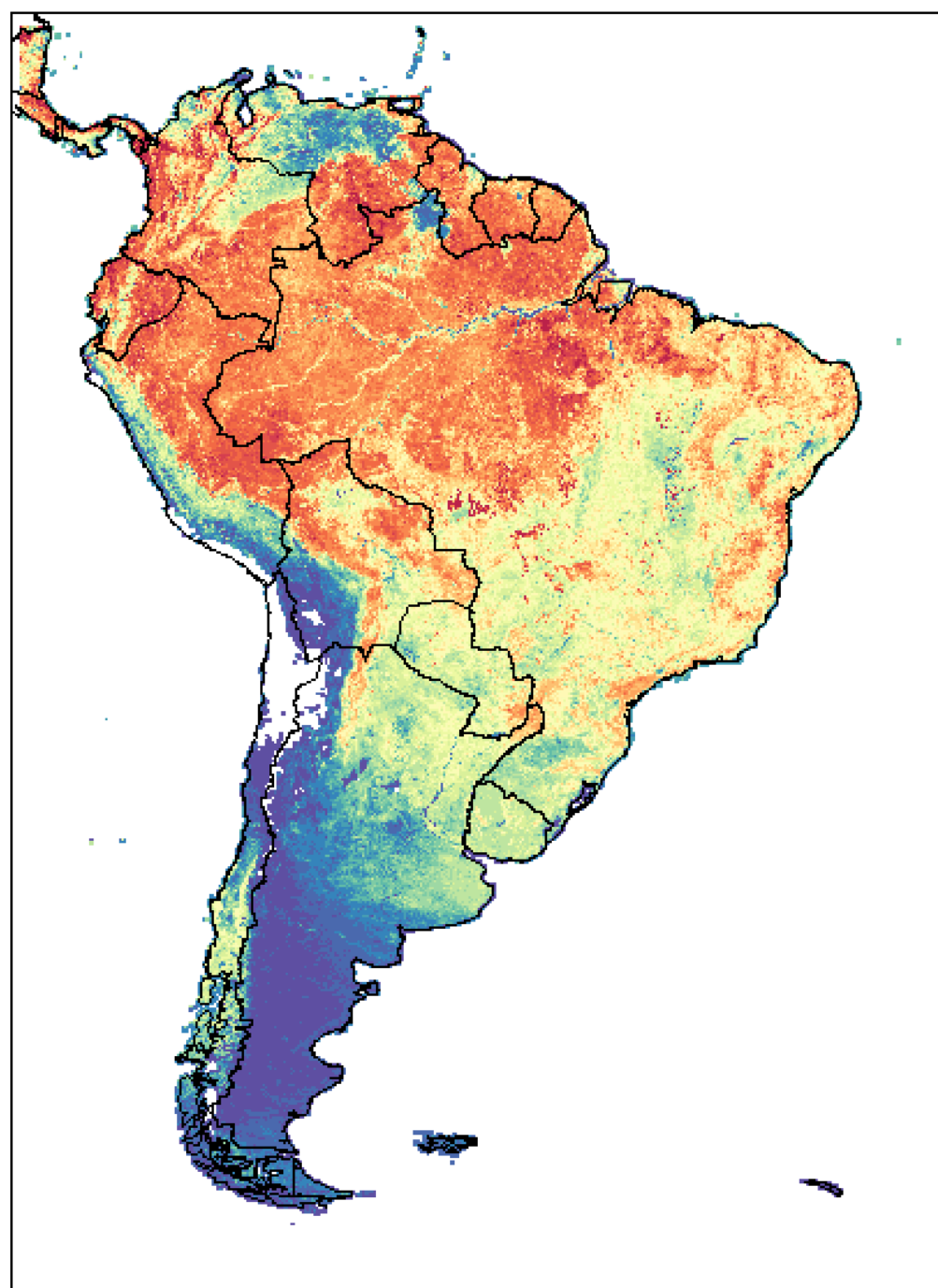


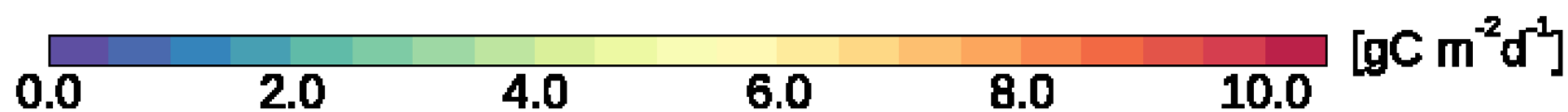
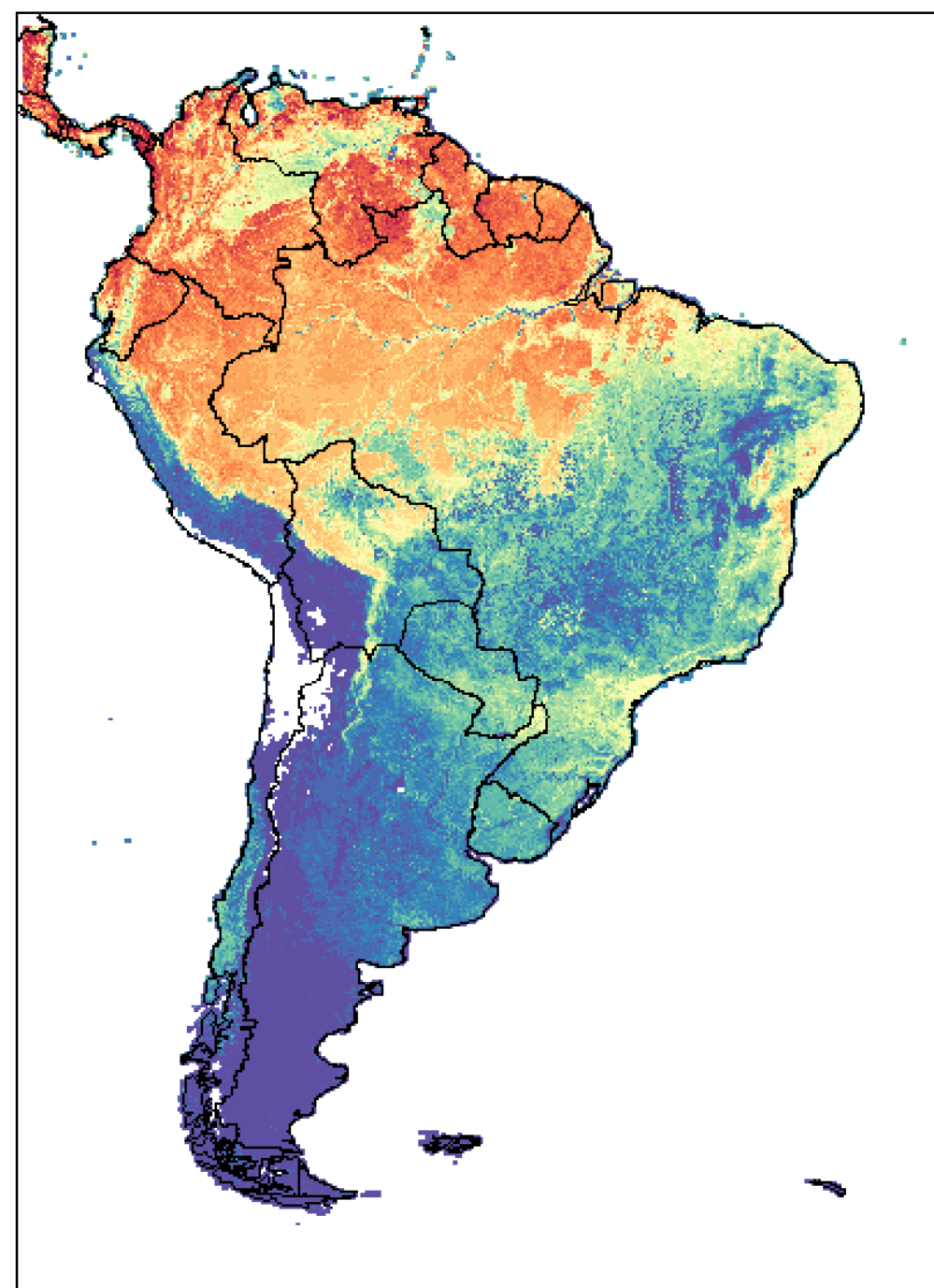
*Image Credit:*  
[NASA GSFC](#)  
[Scientific](#)  
[Visualization](#)  
[Studio](#)

*Slide Courtesy:*  
*A. da Silva*  
*(NASA/GSFC)*

FluxSat GPP Apr 2024



FluxSat GPP July 2024



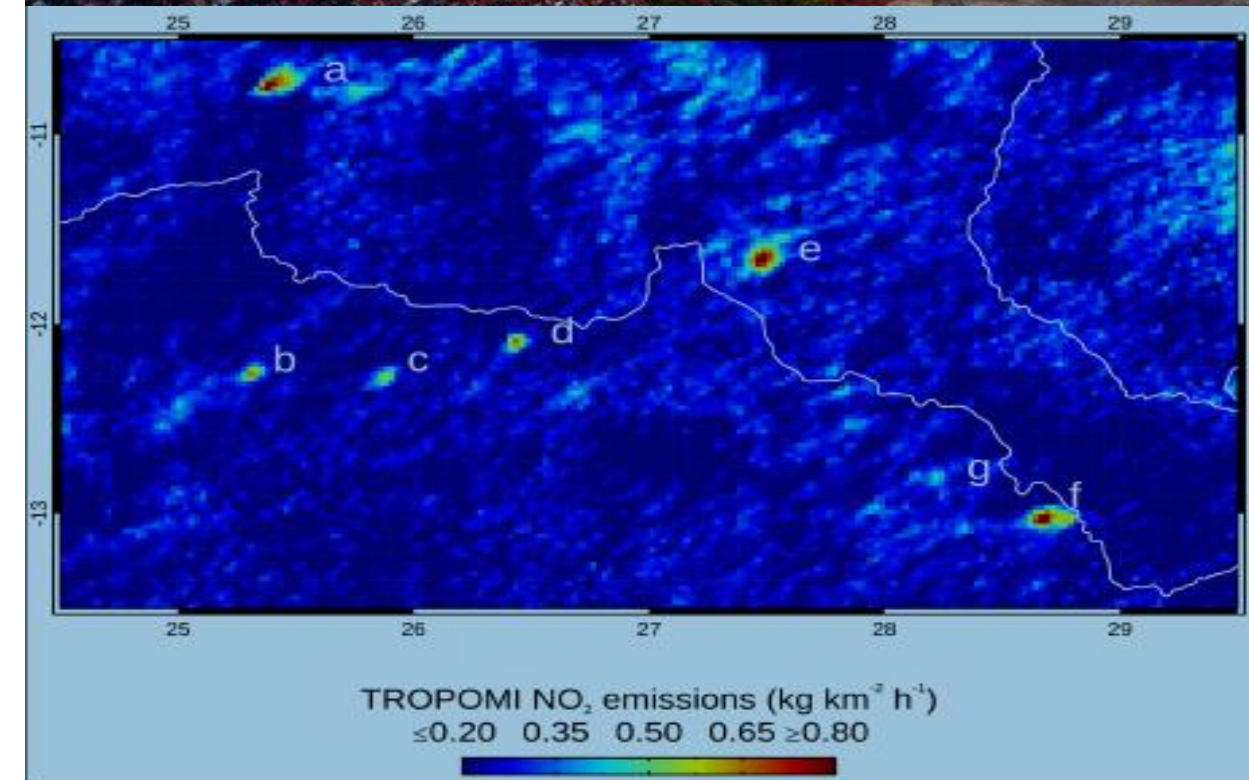
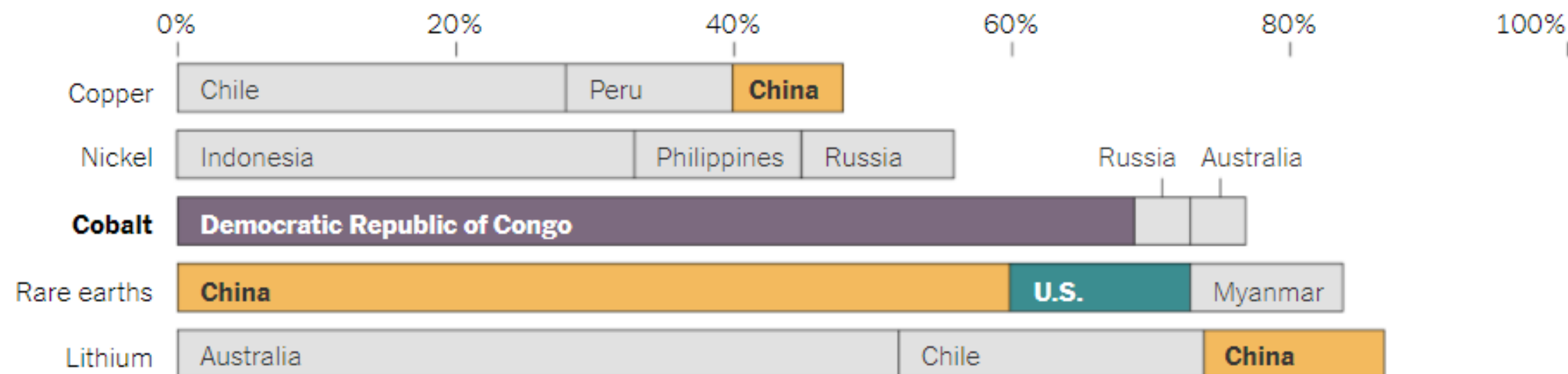
- MODIS generated GPP using AI/ML algorithm trained on Flux Tower Data
- With MODIS, a 16-day time window is required to produce these images
- With hyperspectral GEO data similar maps can potentially be created in near real-time, even under moderate cloudiness.

# Emissions from Metal Mining

## Where Clean Energy Metals Are Produced

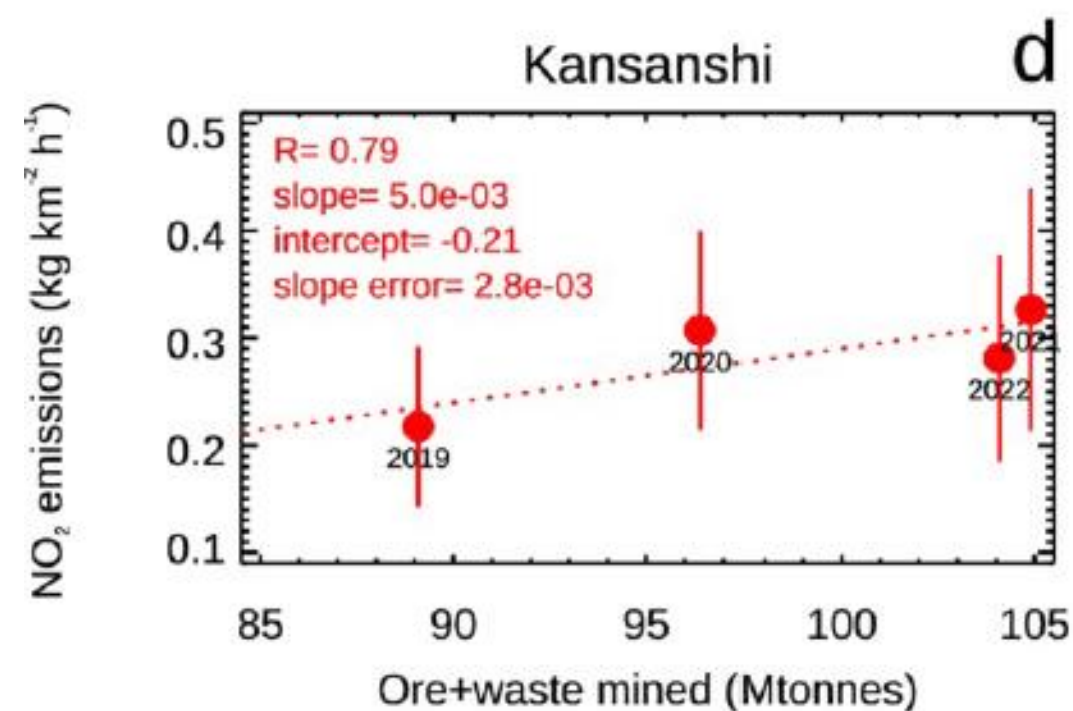
Source: New York Times 2021

Production of key resources is highly concentrated today. Charts show the top three producers.



## NOx Emissions follow Production

Martinez-Alonso et al., JGR 2023, NCAR ACOM



## Vision

*An integrated observing, modeling and warning system*

## Approach

*Integrate LEO, GEO, airborne and ground-based measurements into physical and AI/ML based modeling and data assimilation systems*

## Measurements

*Ozone, aerosols (such as PM<sub>2.5</sub>), NO<sub>x</sub>, SO<sub>x</sub>, and numerous other gases*

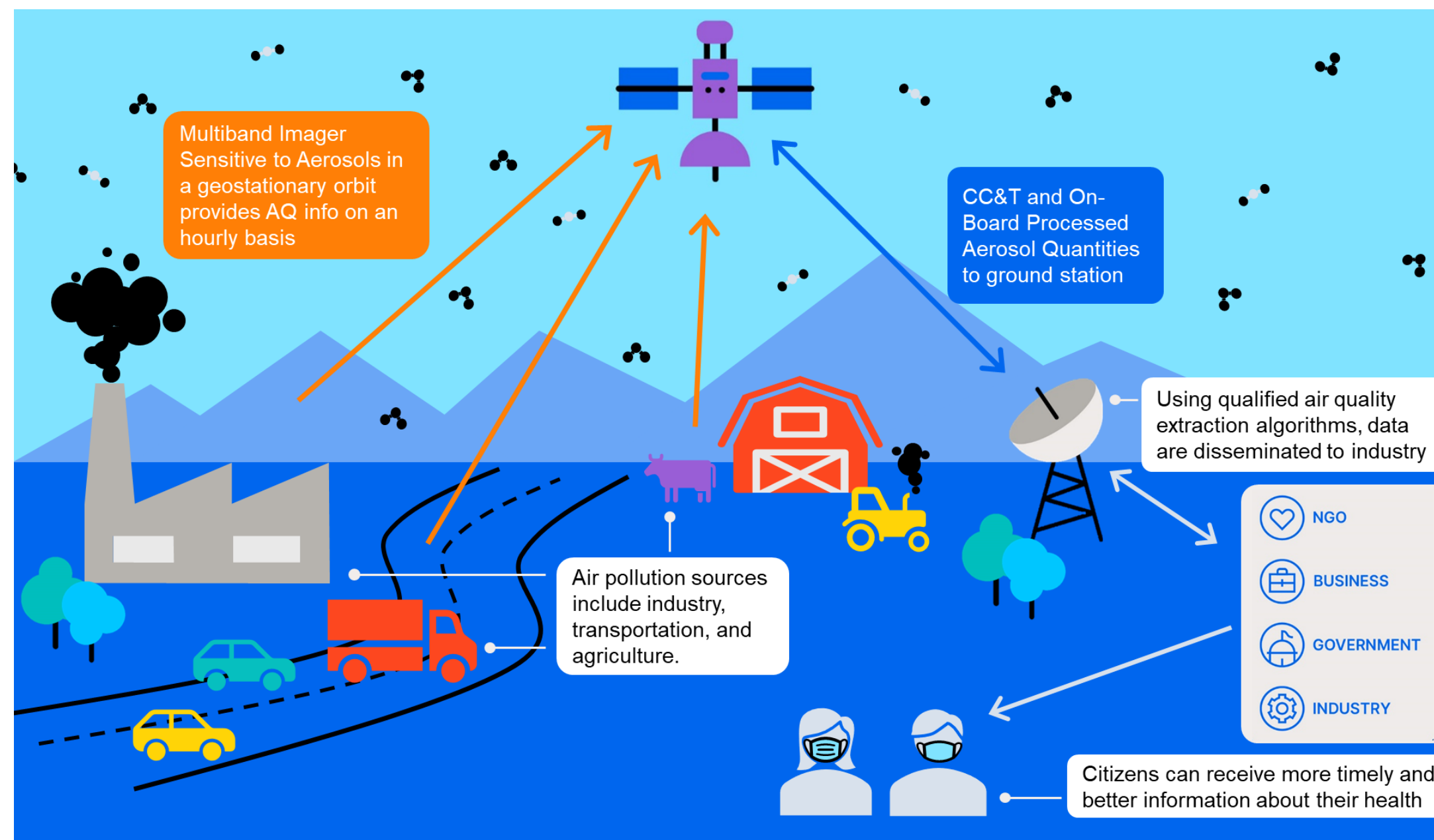


*Image Courtesy: BAE Systems*



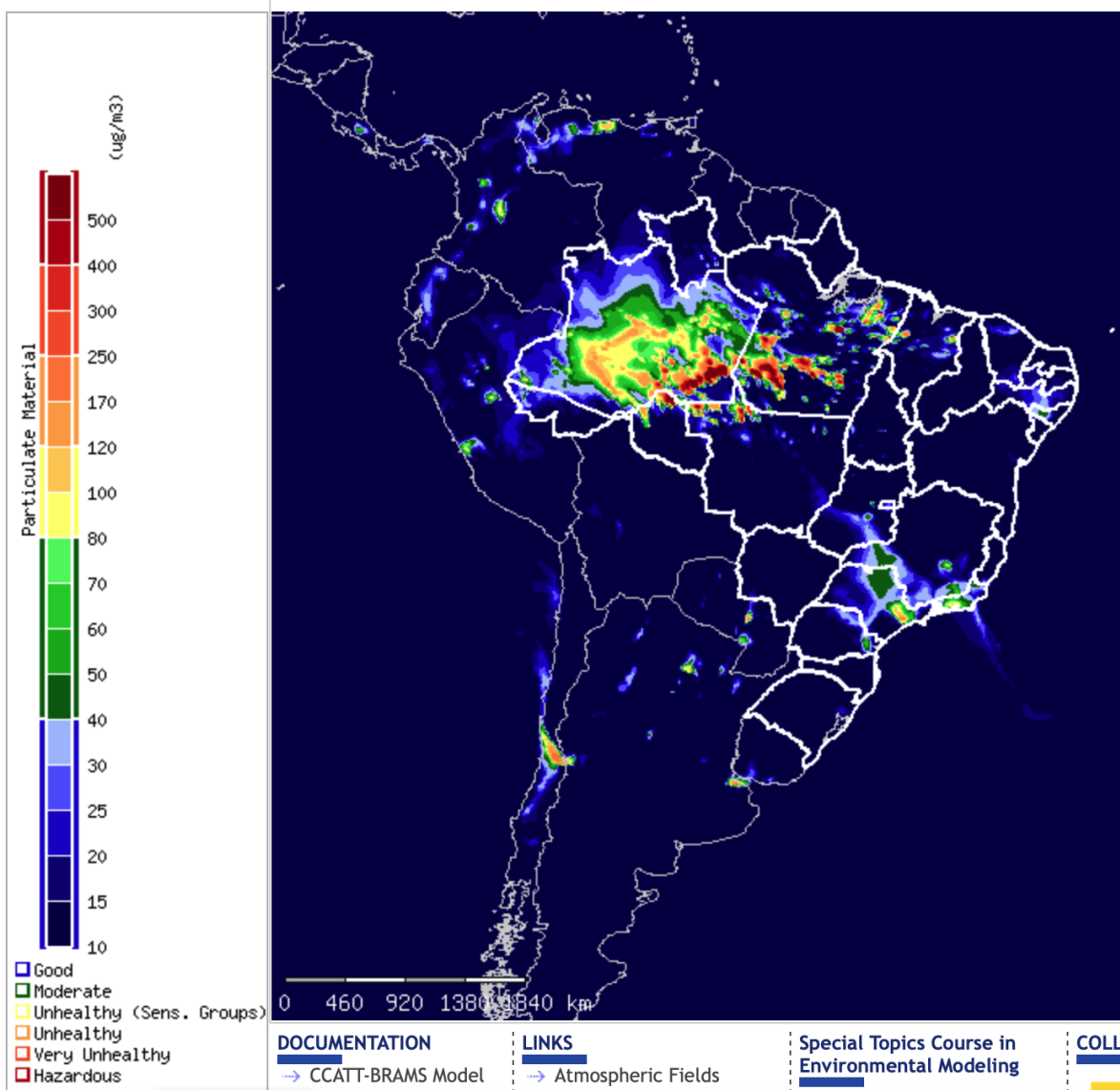
CENTRO DE PREVISÃO DE TEMPO E ESTUDOS CLIMÁTICOS  
Instituto Nacional de Pesquisas Espaciais



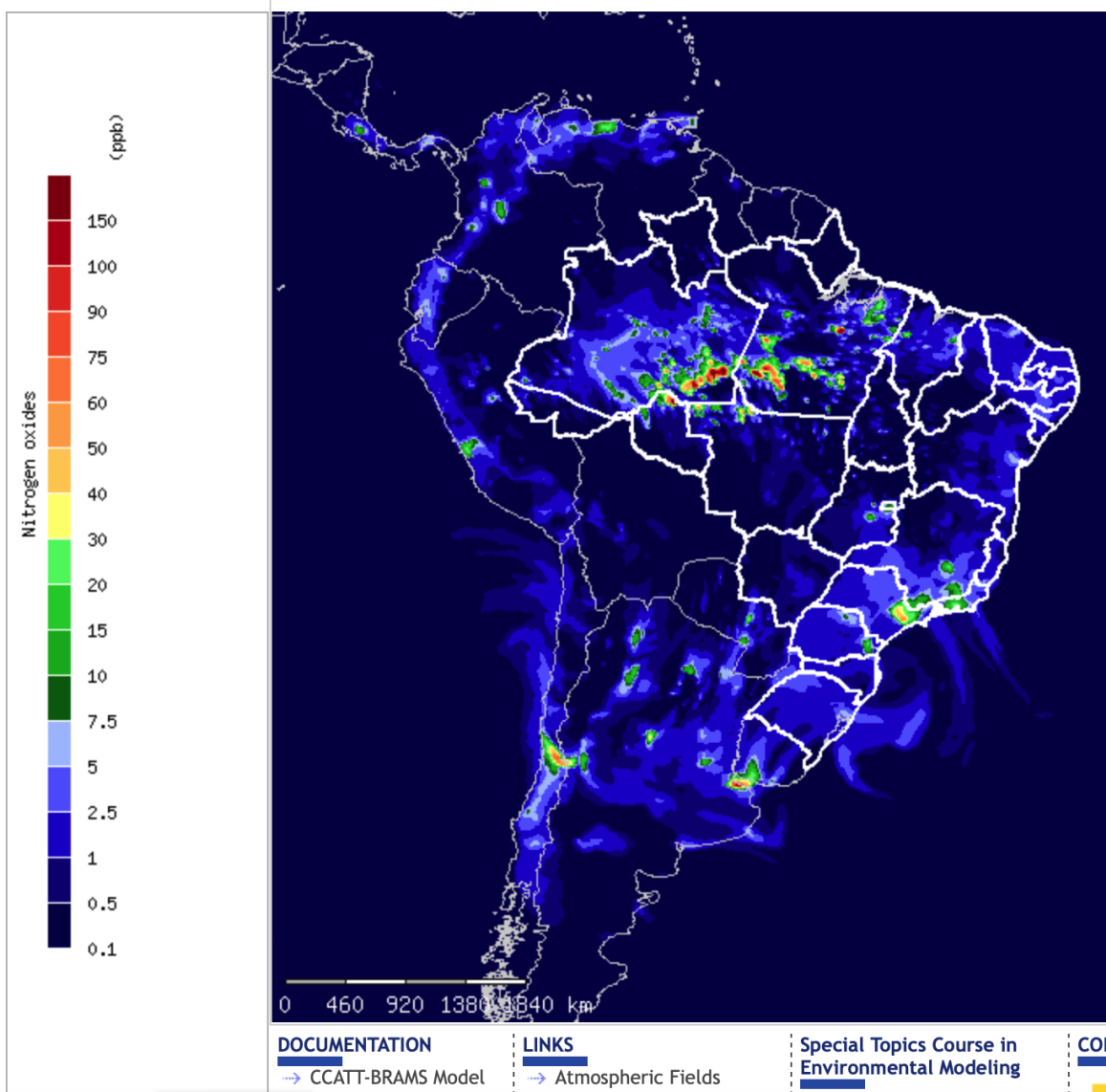
| Weather | Climate | (Numerical) Forecast | Satellite | Waves | Energy | Obs. & Instrumentation | Air Quality | Climate Change



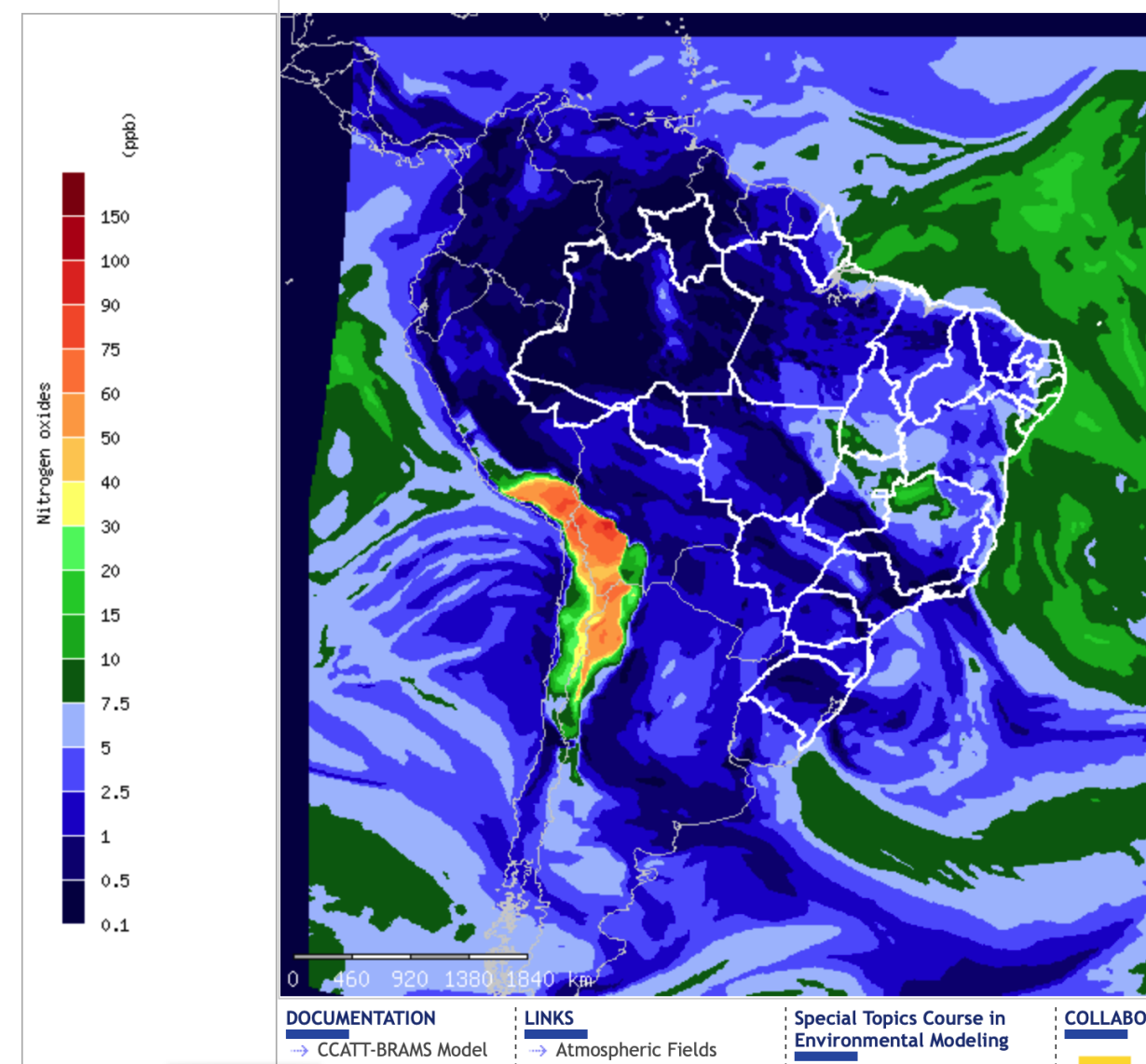
BRAMS 20km - CPTEC/INPE  
Particulate Material(dp<2.5um) (ug/m3) 40m  
10/AUG/2024 00Z (Initialization: 10/AUG/2024 00Z)



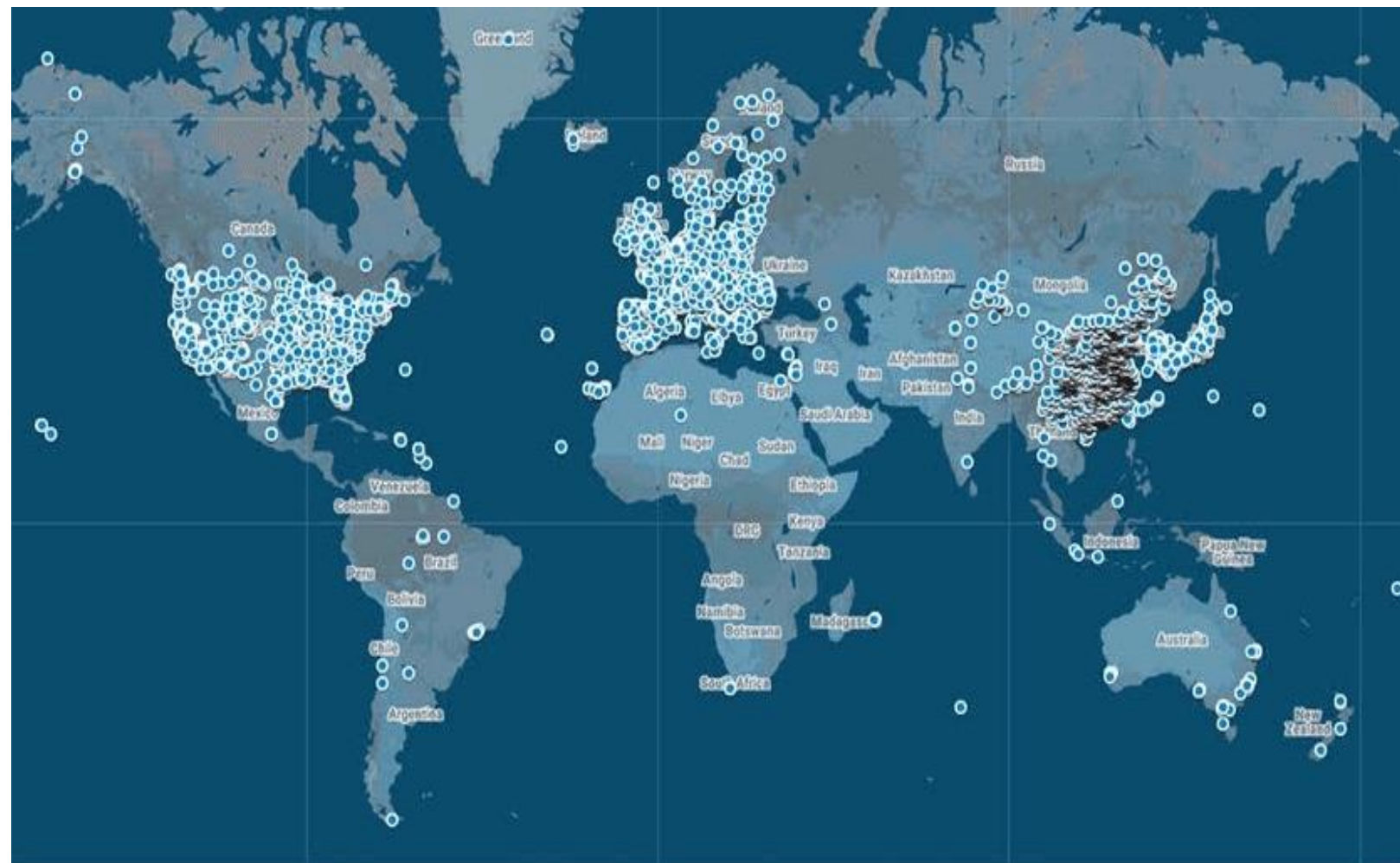
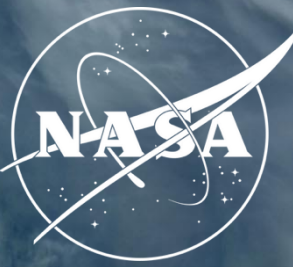
BRAMS 20km - CPTEC/INPE  
Nitrogen oxides (ppb) 40m - Total  
10/AUG/2024 00Z (Initialization: 10/AUG/2024 00Z)



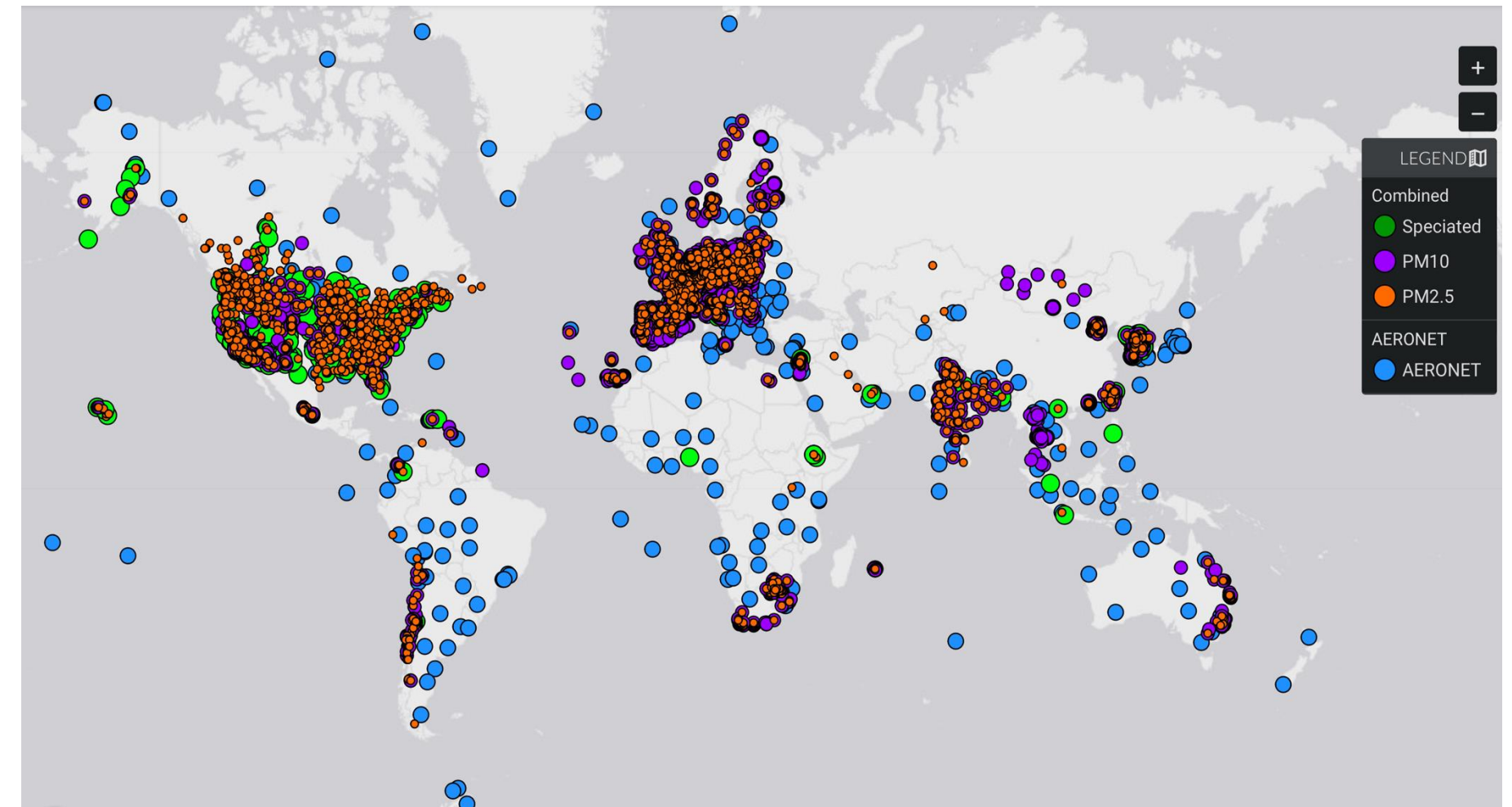
BRAMS 20km - CPTEC/INPE  
Ozone (ppb) 40m - Total  
10/AUG/2024 00Z (Initialization: 10/AUG/2024 00Z)



# Limited Ground-based Atmospheric Composition Observations in the Global South



Ozone Monitoring sites  
(TOAR and Open AQ)



Aerosol Surface Monitoring sites  
(MAIA Data Visualization Tool)

## Tropospheric Emissions: Monitoring of Pollution (TEMPO)

- Geostationary scanning ultraviolet/visible spectrometer
- Enables accurate air quality forecasting by providing hourly measurements of major pollutants
- First funded NASA Earth Venture Instrument
- Launched in 2023

## Geostationary Environment Monitoring Spectrometer (GEMS)

- Developed in tandem with TEMPO, capturing efficiencies
- Launched in 2020, monitoring air pollution over Asia
- Funded by Korea Aerospace Research Institute



**Nitrogen dioxide (NO<sub>2</sub>) is a byproduct of fossil fuel combustion, lightning, and wildfires. NO<sub>2</sub> contributes to the formation of ground-level ozone and particulate matter pollution and is itself a toxic gas (EPA criteria pollutant).**

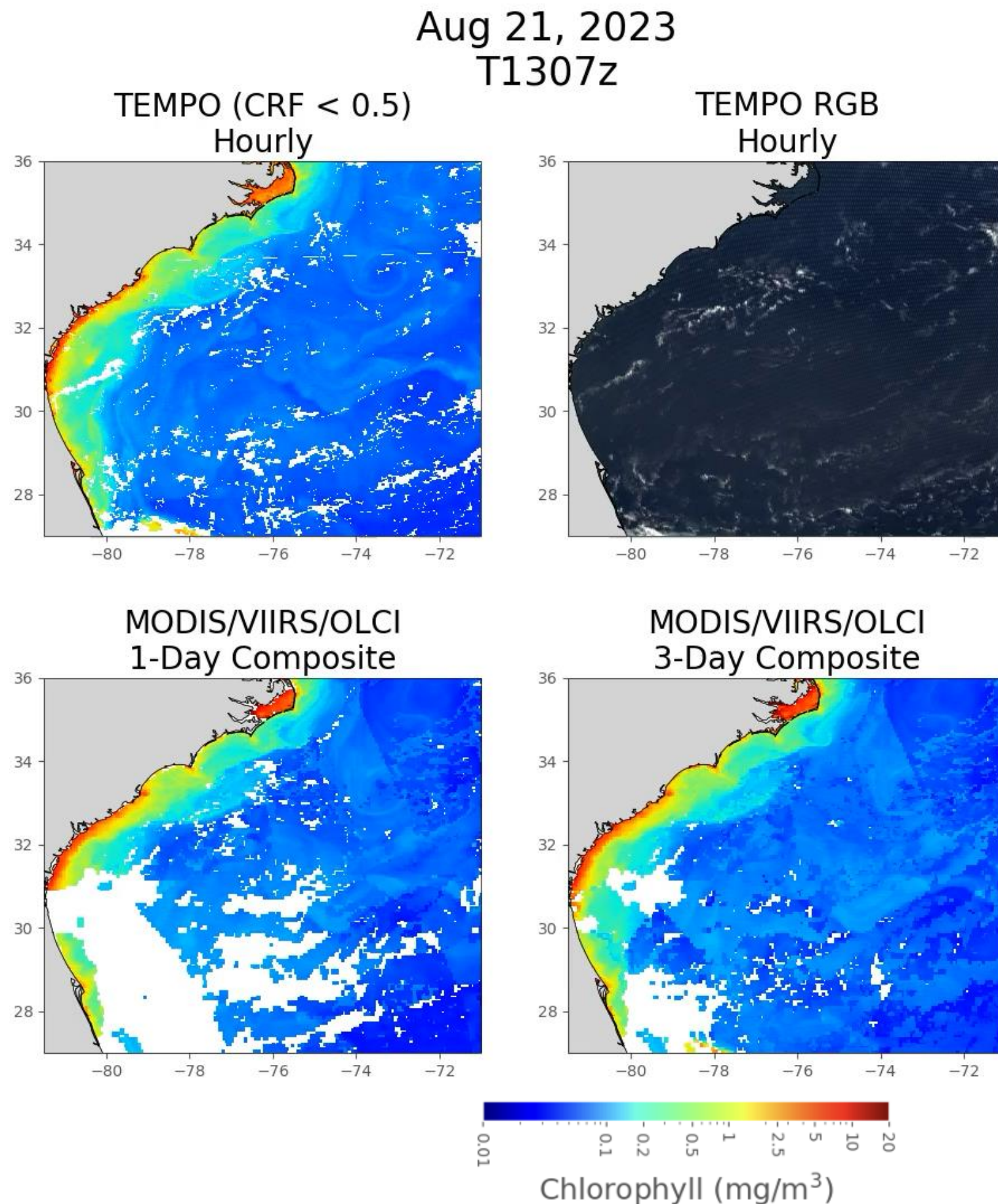
Credit: NASA's Scientific Visualization Studio. Data provided by the Smithsonian Astrophysical Observatory at the Center for Astrophysics | Harvard & Smithsonian.

# Hourly ocean color from TEMPO

## NASA's Tropospheric Emissions: Monitoring of Pollution (TEMPO) demonstrates hourly ocean color

- Machine learning with TEMPO's hyperspectral data produces parameters like chlorophyll even in glint and moderately cloudy conditions
- TEMPO provides hourly ocean color over N. America with coverage comparable to daily average of 3 multi-spectral LEO sensors
- Dynamic movement of the gulf stream is seen with TEMPO hourly data

*Presented at: European Geophysical Union, Vienna, Austria, April, 2024 (Z. Fasnacht et al.)*



Clearest-Sky Composite 22-28 Feb 2024

VIS 540-640 nm

Smearing from  
S/C Motion

Residual Cloud  
Background

- Hyperspectral Atmospheric Composition instruments can sense low clouds under moonlight
  - Thermal IR on imager/sounder has difficulty distinguishing low clouds from surface at night).
- Demonstration of night light measurements with TEMPO was possible from Autumn to Spring equinox when sun is not shining on the instrument
- With 12 second exposures, observations of clouds in moonlight as well as spectrally-resolved measurement of night lights can be achieved



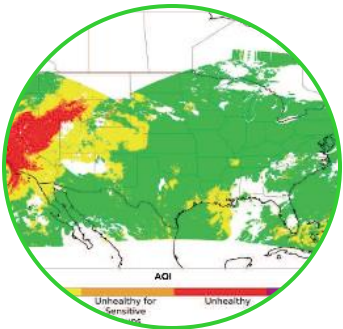
# GeoXO atmospheric composition will be a multi-instrument strategy for various NOAA applications



| Applications                                       |
|----------------------------------------------------|
| Near real time emissions   Air quality forecasting |
| Air quality monitoring   Fire weather forecasting  |
| Fire emissions monitoring   Ozone monitoring       |
| Hazards forecasting   Greenhouse gas monitoring    |
| Climate modeling and Earth system science research |

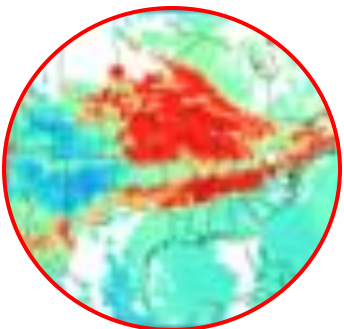
- Fire detection
- Fire radiative power
- Aerosol type
- Aerosol optical depth
- Aerosol concentration
- Large methane leaks
- Sulfur Dioxide (night)

**VIS-IR IMAGER  
GXI**



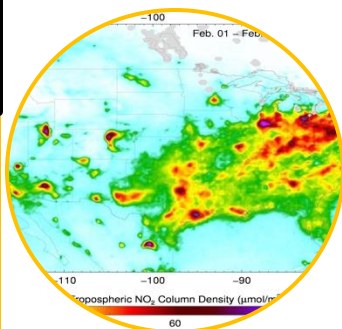
- Ozone
- Carbon monoxide
- Carbon dioxide
- Ammonia
- Isoprene

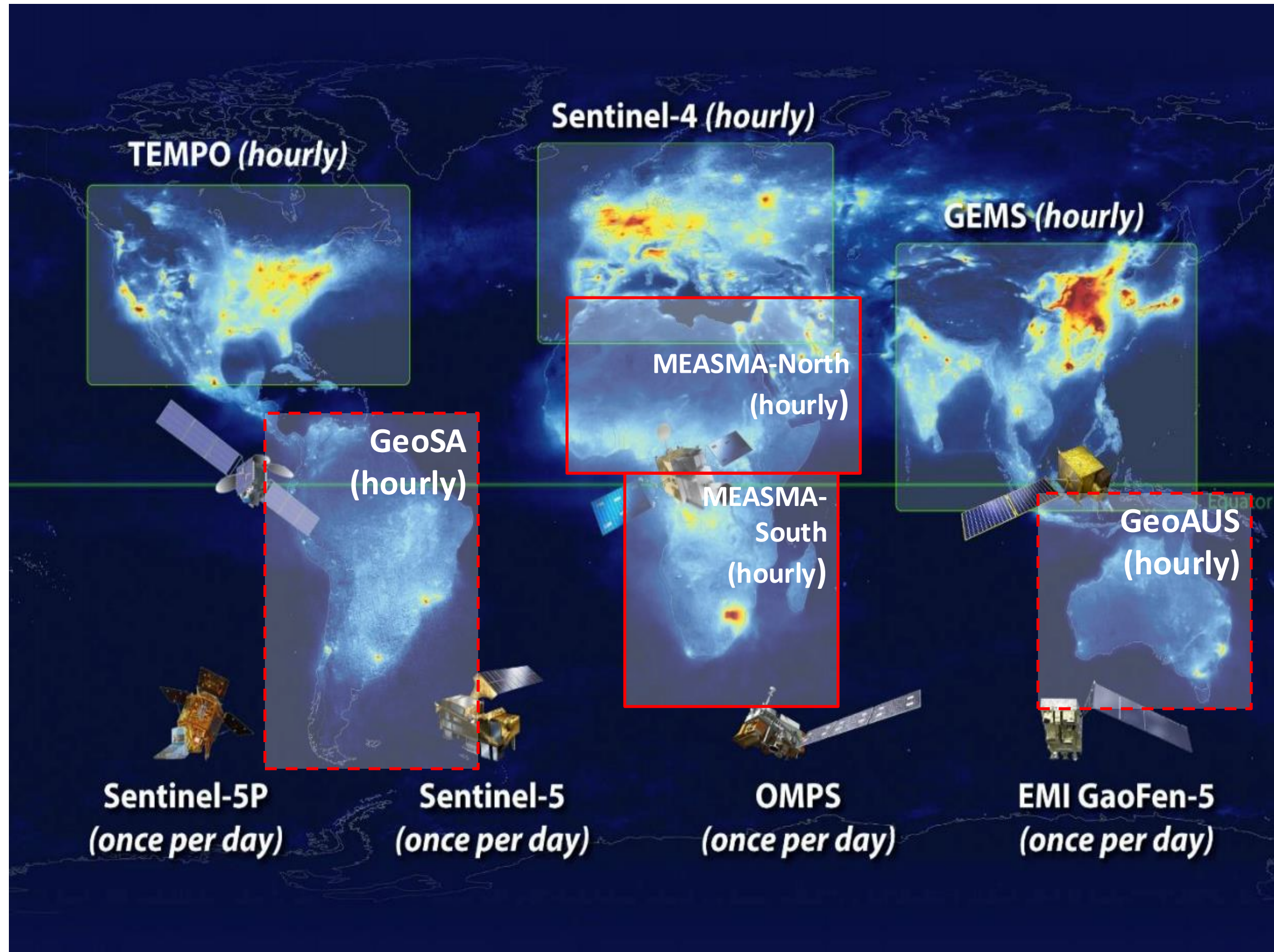
**IR SOUNDER  
GXS**



- Ozone
- Nitrogen dioxide
- Sulfur dioxide
- Formaldehyde
- Aerosol layer height
- UV aerosol index
- UV aerosol optical depth

**UV-VIS  
SPECTROMETER ACX**





## GEO AC Program of Record:

- TEMPO
- GEMS
- Sentinel-4

## Initiatives:

- MEASMA-North
- MEASMA-South

## Seeking Interest:

- Geo South America
- Geo Australia

## Existing Initiatives

- There are 2 initiatives lead by BAE Systems (formerly Ball Aerospace) and members of the scientific community at large:
  - **MEASMA-North** – focused on Northern Africa and the Middle East
  - **MEASMA-South** – focused on Southern Hemisphere Africa
- Meeting with INPE leadership in Brazil (August 2024) to discuss the GeoSA concept.
- In the process of requesting the formation of a CEOS AC-VC committee focused on geostationary AQ for the Global South
  - This committee will write a scientific concept paper for the need of geostationary Atmospheric Composition measurements over the Global South
- BAE Corporate, INTOPASS in talks with private funders and foundations

## Meetings

- **AGU 2023**
  - Townhall Meet at AGU with leaders in the field and cross disciplinary
  - Papers at AGU, one from Levelt, one from BAE Systems, in different sessions
- **EGU 2024**
  - Oral presentation in the AQ constellation session (Levelt)
- **GeoXO** meeting May 6-8, 2024 in Washington DC
- **OMI-TROPOMI** Science Team Meeting June 3-6 2024 at NCAR-ACOM (also TEMPO, GEMS, GEO over the Global South)
- **TEMPO-GEMS** Science Team Meeting in August 2024 in Hawaii

- Increase in air pollution, particularly from enhanced biomass burning, is expected to increase on the coming years
- The ability to measure trace gases, vegetation parameters and ocean color from space on an hourly frequency calls for spaceborne hyperspectral geostationary measurements
- GeoAQ sensors such as those on TEMPO, GEMS and Sentinel-4 have the ability to provide such measurements in near real-time
  - These measurements greatly complement other geostationary meteorological sensors (imagers and sounders)
  - Great synergisms enabled by hyperspectral capability
- While GeoAQ sensors have been deployed for the Northern Hemisphere, a great gap exists in the *Global South*
- Existing initiatives such as MEASMA addresses this gap for Africa and the Middle-east
- We are seeking the leadership from INPE and other Brazilian and South American institutions to develop a Geo South American capability.
  - Engagement of other South American countries very desirable
  - Great opportunity for integrating the South American science community

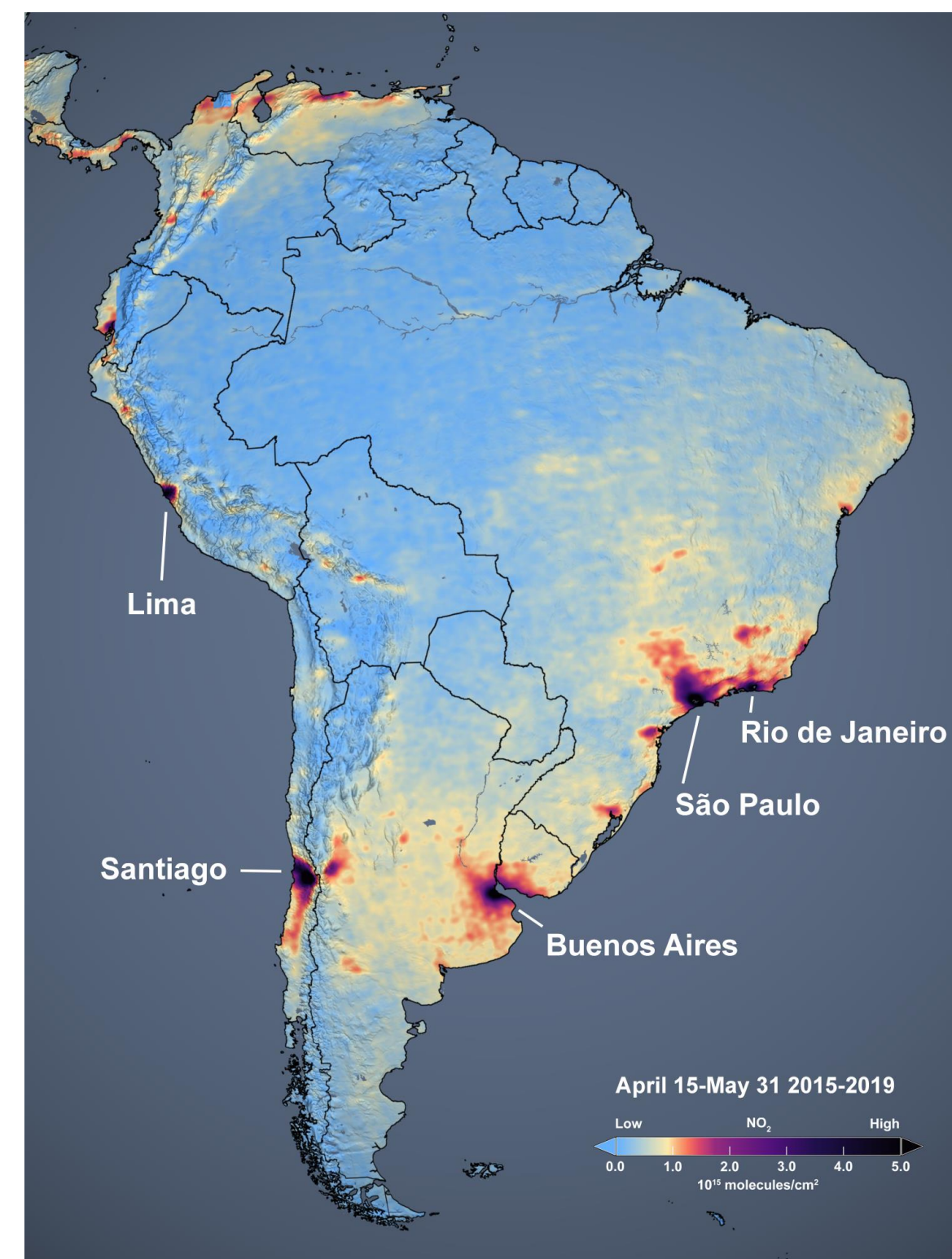


Image Credit: [NASA GSFC Scientific Visualization Studio](#)

