

National Aeronautics and Space Administration



High Resolution Air Pollution Forecasting Using the NASA GEOS Model

Megan Damon¹, Emma Knowland²,
Christoph Keller², Steven Pawson³

Supercomputing 2022
Thursday, November 17th, 2022

1. Science Systems and Applications, Inc.

2. Morgan State University

3. Goddard Space Flight Center

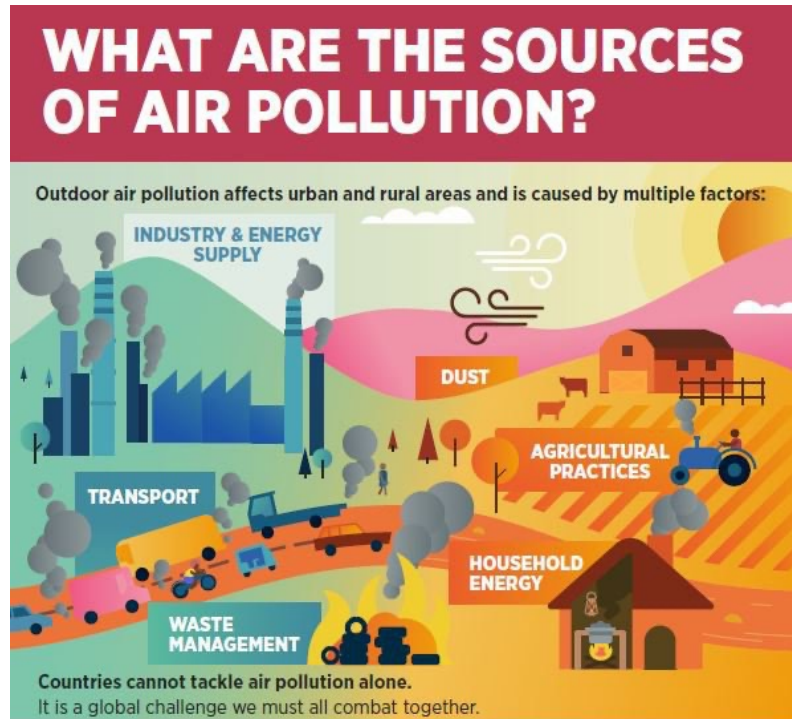
www.nasa.gov

Motivations for Air Pollution Forecasting



Pollution forecasting aids in decision making for human health and agriculture studies:

- 9/10 people worldwide breathe polluted air
- 1/9 deaths is linked to air pollution (Heart disease, Pneumonia, Stroke)
- \$5 Trillion in welfare losses each year (World Bank)
- 50% crop loss due to ozone has been observed



CLEAN AIR FOR HEALTH

#AirPollution



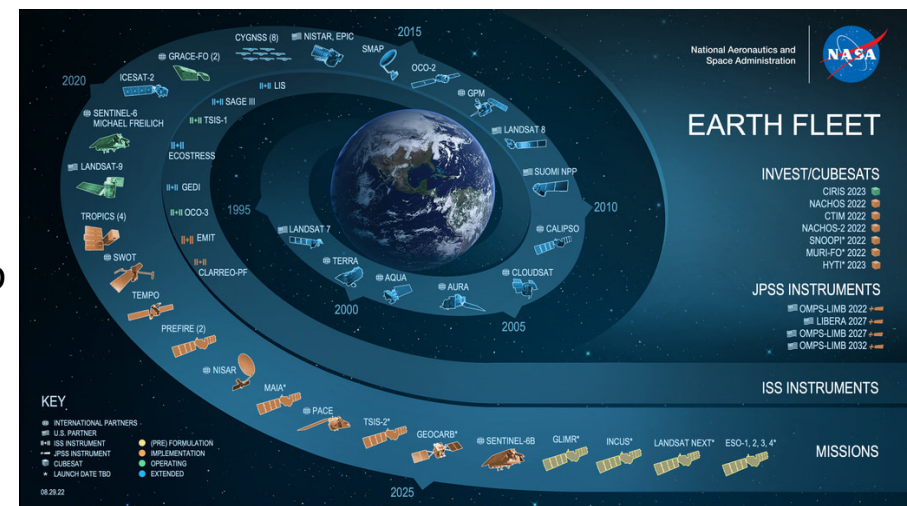
Image credit Climate & Clean Air Coalition

ccacoalition.org/en/news/world-health-organization-releases-new-global-air-pollution-data

Numerical Weather Prediction with GEOS



- Numerical Weather Prediction (**NWP**) models
 - Simulations of the flow of fluids through governing equations
 - Earth's atmosphere initial state is combined with observational data
- NWP ingests millions of Earth observations to predict weather events and forecast pollution:
 - Balloons launches
 - Ground monitoring stations
 - Aircraft and ships
 - *Satellites
- GMAO's Goddard Earth Observing System (GEOS) NWP, and more



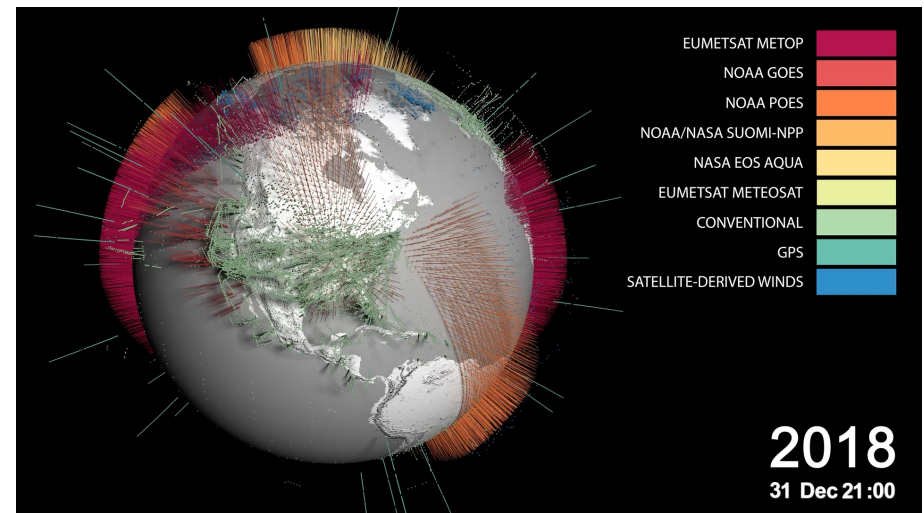
NASA's current Earth Fleet. Image credit NASA-GSFC Scientific Visualization Studio.
<https://svs.gsfc.nasa.gov/>

GEOS DAS & Space Observations



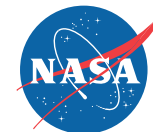
Earth observations are *assimilated* into NASA's GEOS Data Assimilation System (DAS)

- Millions of satellite observations
- Operation analysis runs four times a day at the synoptic times :
0z, 6z, 12z, 18z
- Initial state of atmosphere comprised of Earth observations plus a previous 6-hour forecast (data assimilation)

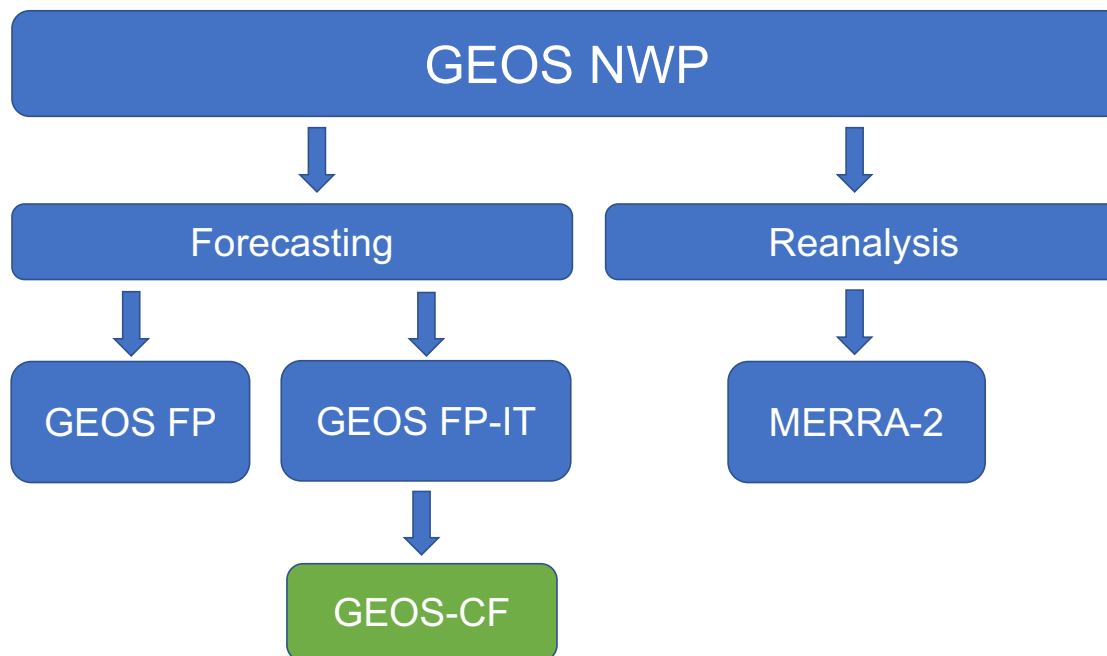


Meteorological Observing Systems, 2018. Data is revealed within a moving 1.5-hour window centered on the time shown. Movie credit NASA-GSFC Scientific Visualization Studio. <https://svs.gsfc.nasa.gov/>

Air Pollution Forecasting with GEOS-CF



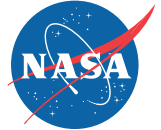
GEOS-CF (Composition Forecasting) uses the Global Modeling and Assimilation Office's (GMAO) GEOS with the latest advancements in Atmospheric Chemistry



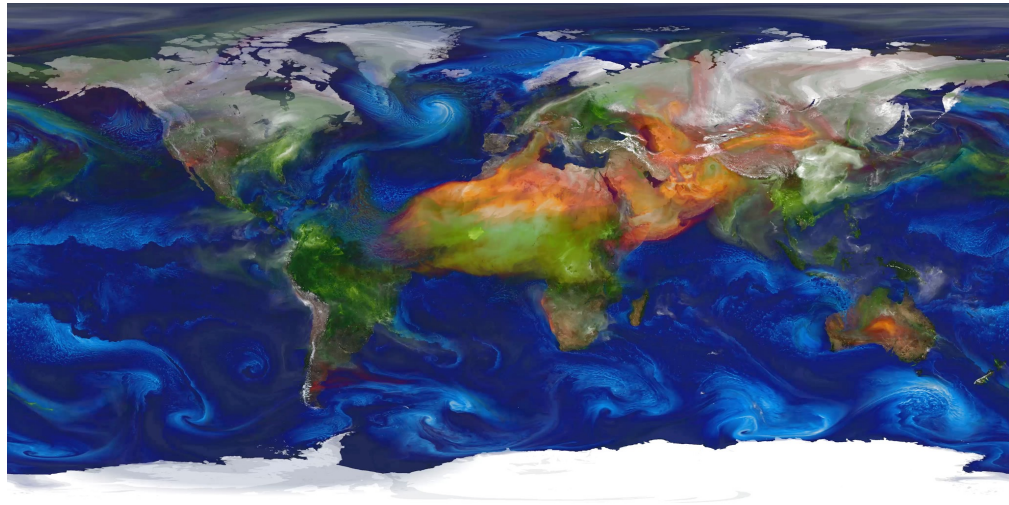
GMAO

Global Modeling and Assimilation Office
gmao.gsfc.nasa.gov

GOCART in GEOS



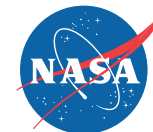
- Goddard Chemistry Aerosol Radiation & Transport (GOCART) Model simulates major aerosol components including:
 - Organic/black carbon (green)
 - Dust (red)
 - Ocean sea salt (blue)
 - Sulfates (white)
- GEOS 10-km global mesoscale Nature Run (NR) uses GOCART



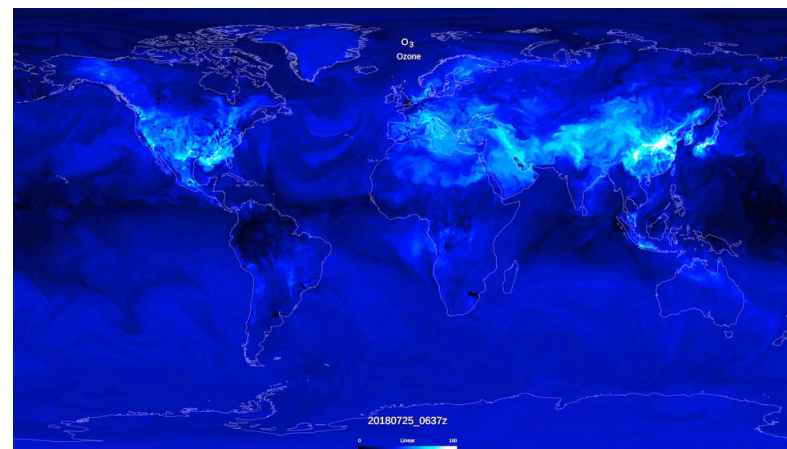
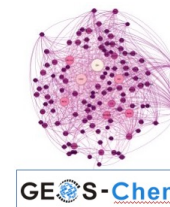
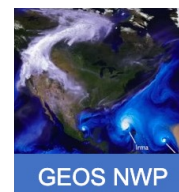
GEOS-5s Nature Run explores the evolution of surface temperatures as the sun heats the Earth and fuels cloud formation, and the dispersion of global aerosols from dust, biomass burning, and fossil fuel emissions.

Image credit: NASA's Goddard Space Flight Center/Scientific Visualization Studio. <https://svs.gsfc.nasa.gov/>

Chemistry of GEOS-CF



- Trace chemicals, while tiny in abundance, correspond with toxic impacts on our environment
- The addition of **GEOS-Chem** (Harvard) in GEOS-CF allows for the computation of the solutions to chemical reactions
- GEOS-CF with GEOS-Chem, forecasts the chemistry solutions, including those of the complex chemistry of surface ozone (O₃), where we live and breathe:



Global surface ozone with high concentrations shown in white. Image credit: NASA's Goddard Space Flight Center/Scientific Visualization Studio.
<https://svs.gsfc.nasa.gov/>

- 
- GODDARD**
EARTH SCIENCES

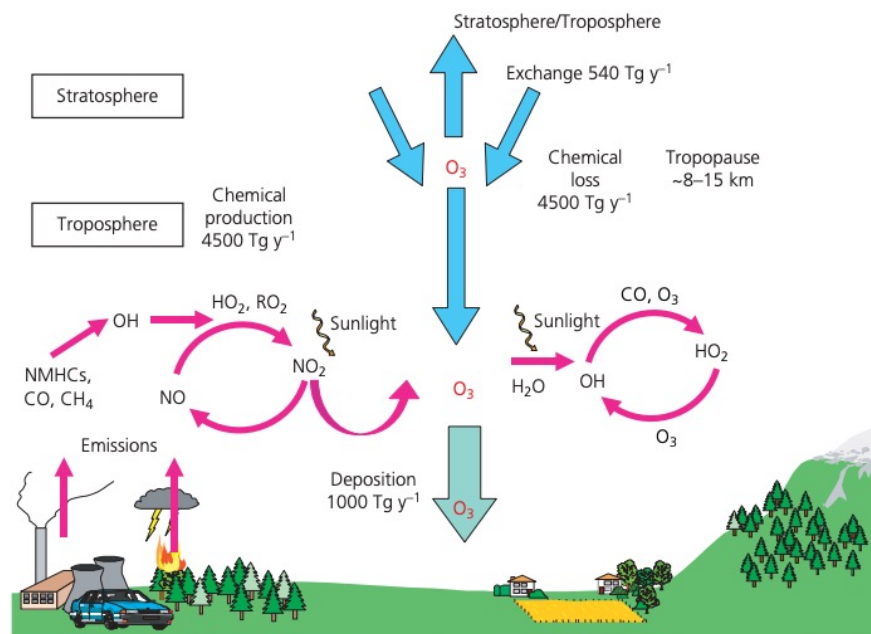
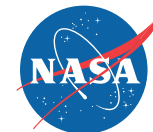
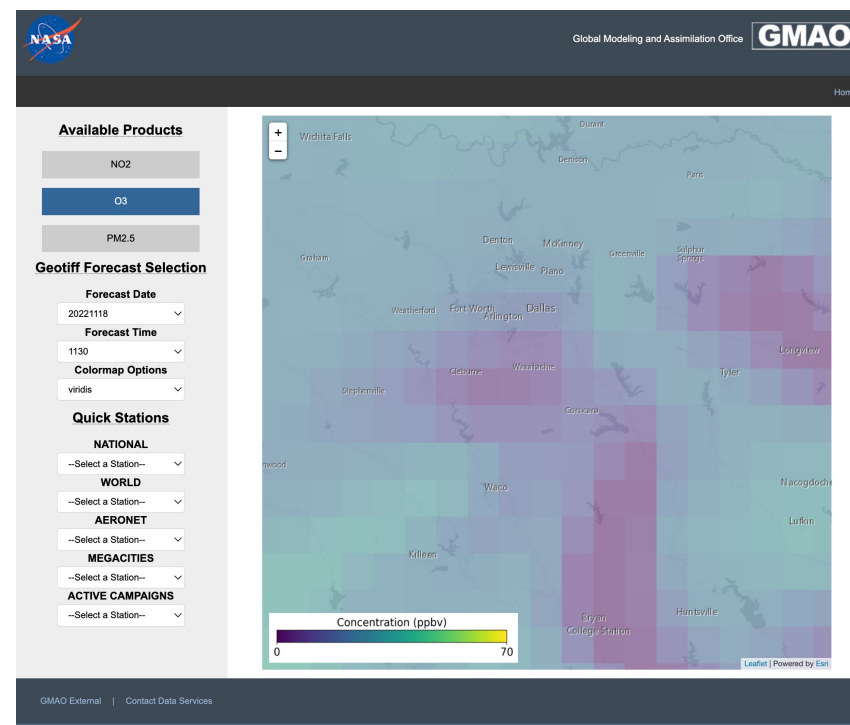


Image from “Ground-level ozone in the 21st century: future trends, impacts and policy implications”. Chapter 3. Figure 3.1

GEOS-CF 5-day Daily Forecast



- GEOS CF produces 5-day air quality (AQ) forecasts
- 1 day Replay to achieve best initial conditions using DAS constraints
- Most requested surface pollutants are O_3 , NO_2 , CO , $PM_{2.5}$, and SO_2
- Forecast Products
 - Surface chemistry and meteorology every 15 minutes
 - Hourly-average surface chemistry
 - Hourly-average 2D meteorology
 - Hourly-average 2D chemistry (inc. column diagnostics)
 - Hourly chemistry on 23 levels (1000-10 hPa)
 - Hourly meteorology on 23 levels (1000-10 hPa)
- GEOS-CF spatial resolutions are 10x more than conventional similar simulations



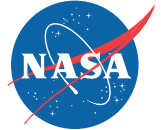
Today's CF forecast goes out to 11:30am November 18th.
Image Credit GSFC Fluid. <https://fluid.nccs.nasa.gov/>

NASA Center for Climate Simulation (NCCS)

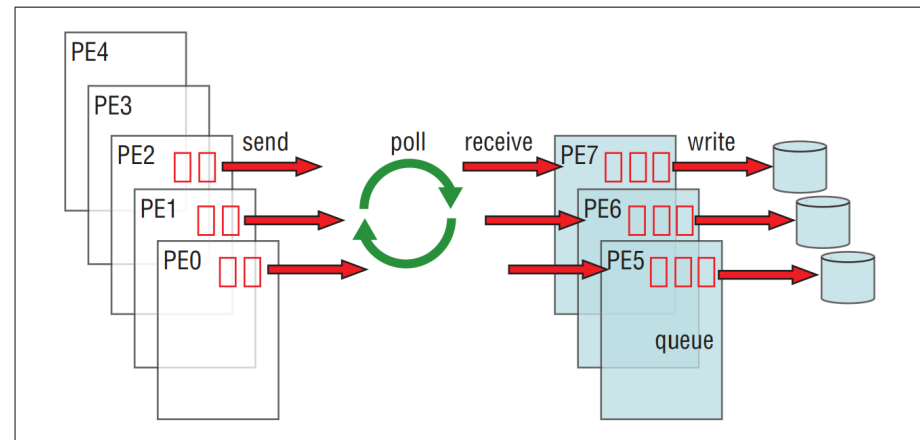


- NCCS's Discover (8.1 Petaflops) allows for high resolution forecasting of global air pollutants
- The GEOS-CF model utilizes 3,500 compute processes
- 28-CPU nodes / 4.5 GBs memory per CPU
- Intel Xeon Haswell processor cores / 2 14-core processors per node (transitioning to Cascade Lake nodes)
- 50 Petabytes of GPFS Storage

GEOS I/O

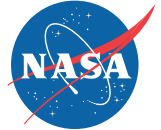


- Due to the high data resolution, GEOS-CF produces more than 225 Gigabytes of gridded data every day
- GEOS-CF spends significant computer time performing I/O operations
- CF simulations are accelerated by dedicating a subset of compute nodes to I/O
- I/O offloading takes advantage of PFIO, a high-performance client-server I/O layer

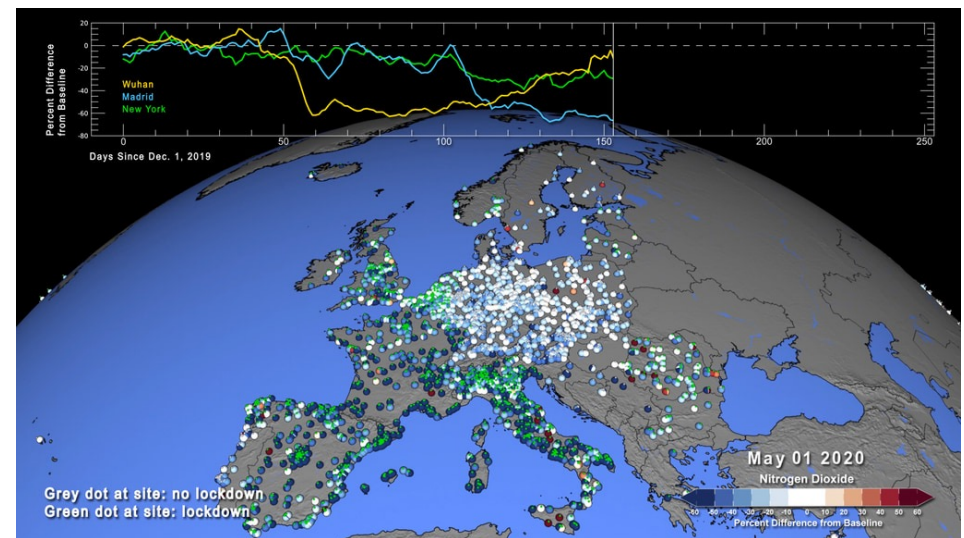


The GEOS PFIO layer sends model data from compute nodes to dedicated I/O nodes, data is stored in a queue. Data is pulled out of the queue and written to disk to relieve I/O bottlenecks. Image credit "Application Controlled Parallel Asynchronous Input/Output" Shujia Zhou, et al.

Pollution Levels in Response to COVID-19



- Using GEOS-CF Models, NASA researchers found reduction by nearly 20% of nitrogen dioxide concentrations in response to COVID-19 lockdowns
- Reduction is due to substantial decrease in human activity and traffic
- Study uses CF model simulation results, using bias correction, as well as ground measurements from 46 countries
- Wuhan 60% lower
- Milan 60%
- New York 45%

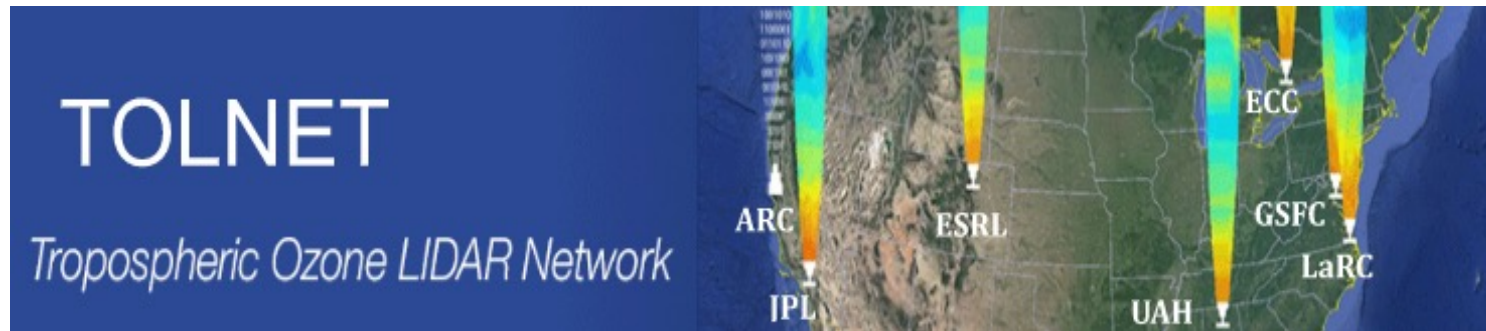


Deviation from modeled normal nitrogen dioxide levels after COVID-19 lockdowns. Image credit: NASA's Goddard Space Flight Center/Scientific Visualization Studio. <https://svs.gsfc.nasa.gov/>

GEOS-CF & TOLNet



- Tropospheric Ozone Lidar Network (TOLNet)
- NASA / NOAA collaboration
- TOLNet provides ground-based profiling of tropospheric ozone
- High-fidelity observations from Earth's surface to top of troposphere
- Better understanding of ozone spatial-temporal distribution
- TOLNet operators use GEOS-CF daily forecasts to inform their activities



GEOS-CF & TEMPO



- The Tropospheric Emissions: Monitoring Pollution (TEMPO) mission is the first space-based instrument to monitor air pollutants in North America (March 2023 goal)
- Geostationary orbit (GEO) to monitor hourly (across NA) variations in ozone, nitrogen dioxide, and more
- TEMPO gas trace retrievals will use GEOS-CF as prior information

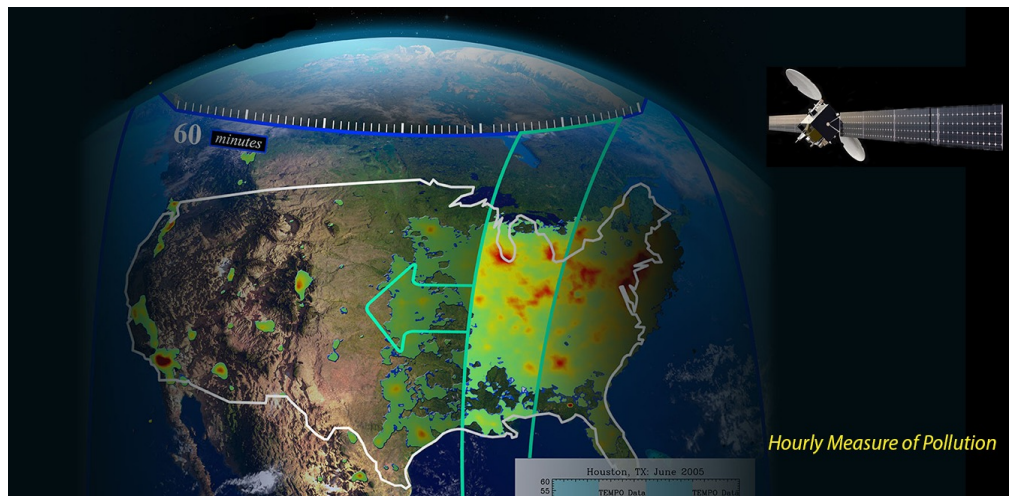


Image credit Tropospheric Emissions: Monitoring of Pollution. tempo.si.edu



The End
