Near real-time air quality forecasts using the NASA GEOS model

K. Emma Knowland

USRA/GESTAR

NASA Global Modeling and Assimilation Office (GMAO)

In collaboration with:

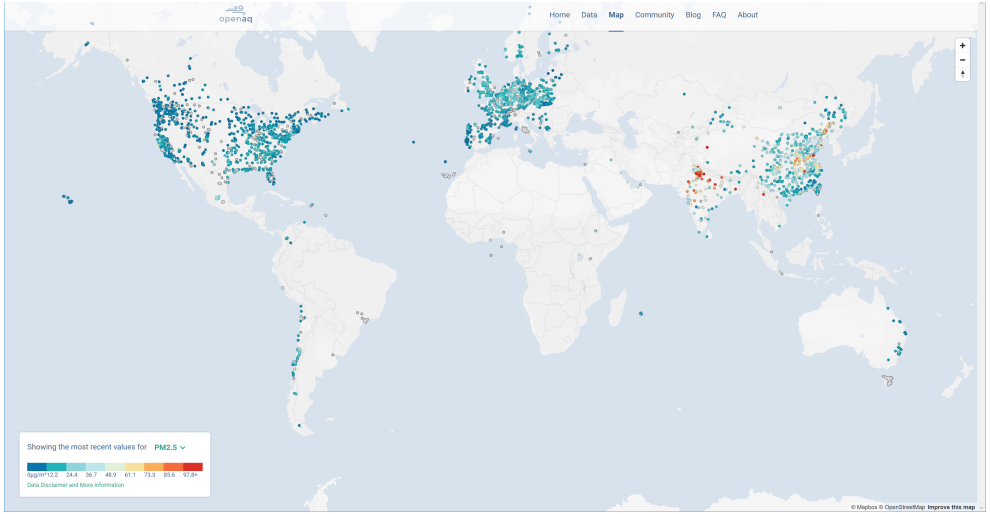
GMAO: Christoph Keller, Lesley Ott, Steven Pawson, Emily Saunders, Pamela Wales

Atmospheric Chemistry and Dynamics Lab: Bryan Duncan, Melanie Follette-Cook, Junhua Liu, Julie Nicely

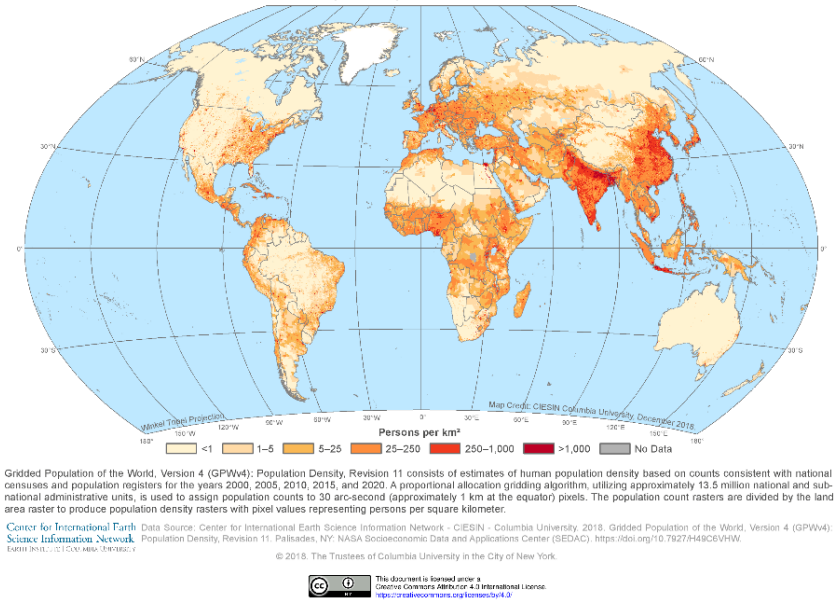
June 13, 2019

Sparse surface AQ monitors

OpenAQ Surface Monitor Locations



Population Density



Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11 consists of estimates of human population density based on counts consistent with national censuses and population registers for the years 2000, 2005, 2010, 2015, and 2020. A proportional allocation gridding algorithm, utilizing approximately 13.5 million national and sub-national administrative units, is used to assign population counts to 30 arc-second (approximately 1 km at the equator) pixels. The population count rasters are divided by the land area raster to produce population density rasters with pixel values representing persons per square kilometer.

Center for International Earth Science Information Network

Data Source: Center for International Earth Science Information Network - CIESIN - Columbia University. 2018. Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H49C6VHW.

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Potentially Useful Space-based Observations for the Air Quality Community

- Aerosols (AOD, fire detection) → can be used to infer "nose-level" $PM_{2.5}$ with atmospheric models
- Nitrogen dioxide (NO_2) → most straightforward to observe & excellent tracer of combustion
- Carbon monoxide (CO) → another tracer of combustion
- Ozone (O_3) → no information on "nose-level" concentrations
- Sulfur dioxide (SO_2), Ammonia (NH_3) , Formaldehyde (HCHO) → precision and accuracy not suitable for most health studies

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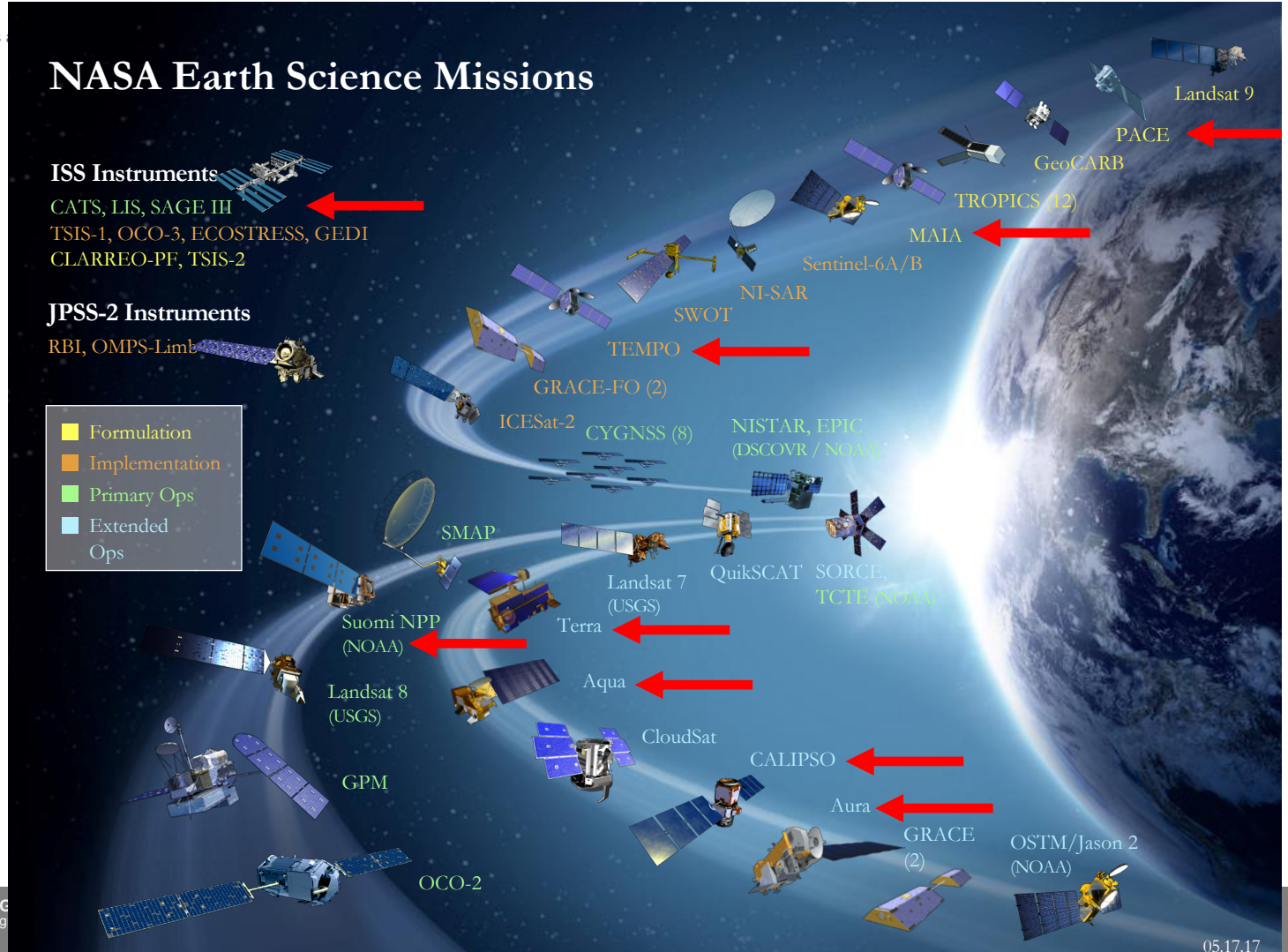
NASA Earth Science Missions
ISS Instruments
CATS, LIS, SAGE III
TSIS-1, OCO-3, ECOSTRESS, GEDI
CLARREO-PF, TSIS-2
JPSS-2 Instruments
RBI, OMPS-Limb
Formulation
Implementation
Primary Ops
Extended Ops
Landsat 9
PACE
GeoCARB
TROPICS (12)
MAIA
Sentinel-6A/B
NI-SAR
SWOT
TEMPO
GRACE-FO (2)
ICESat-2
CYGNSS (8)
NISTAR, EPIC
(DSCOVR / NOAA)
SMAP
Landsat 7
(USGS)
QuikSCAT
SORCE,
TCTE (NOAA)
Suomi NPP
(NOAA)
Terra
Landsat 8
(USGS)
Aqua
CloudSat
CALIPSO
GPM
Aura
GRACE
(2)
OSTM/Jason 2
(NOAA)
OCO-2
05.17.17

Potentially Useful Space-based Observations for the Air Quality Community

- Aerosols (AOD, fire detection) **MODIS, VIIRS** → can be used to infer "nose-level" $PM_{2.5}$ with atmospheric models
- Nitrogen dioxide (NO_2) **OMI, TROPOMI** → most straightforward to observe & excellent tracer of combustion
- Carbon monoxide (CO) **MOPITT** → another tracer of combustion
- Ozone (O_3) OMI, MLS, AIRS, OMPS → no information on "nose-level" concentrations
- Sulfur dioxide (SO_2) OMI, Ammonia (NH_3) TES, CrIS, AIRS, Formaldehyde (HCHO) **OMI**, OMPS, TROPOMI

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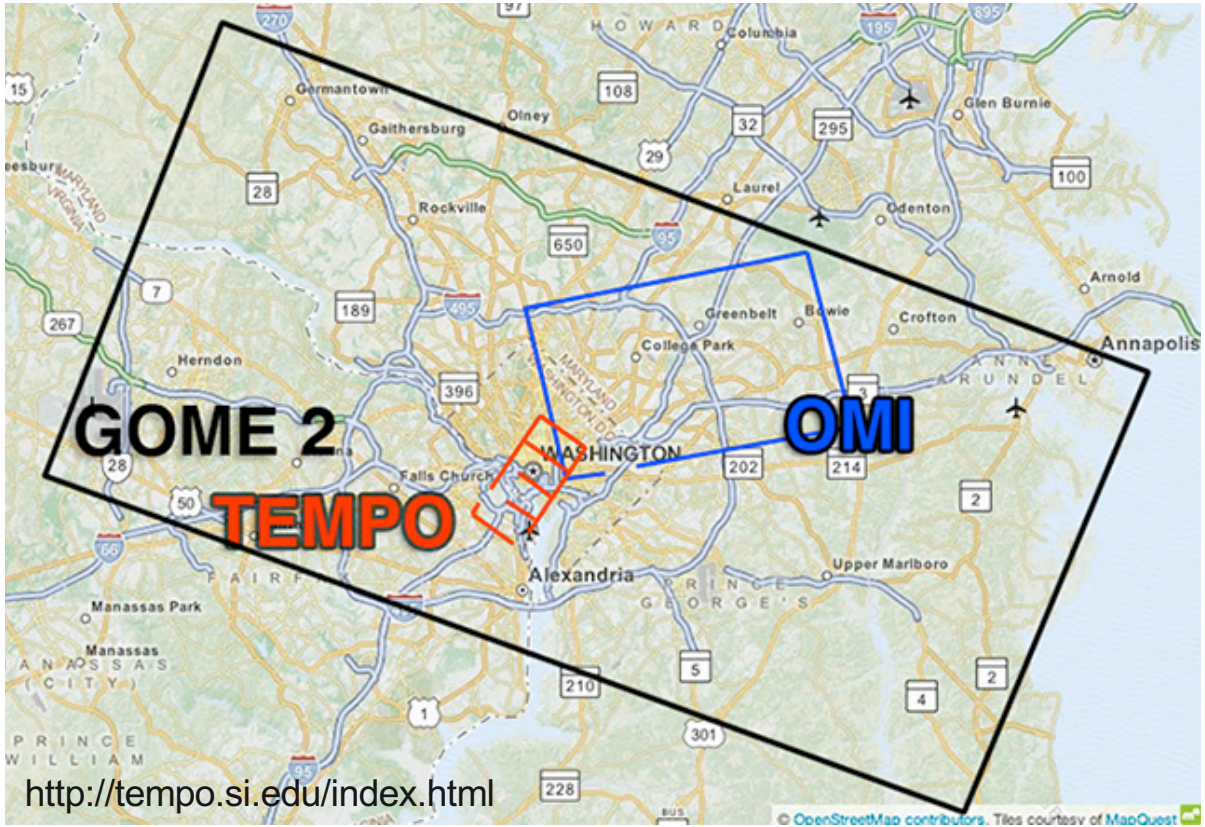
Evolving and Improving Spatial Resolution



GOME (1996)
Daily
40 x 40 km^2 & greater

↓

OMI (2004)
Daily
13 x 24 km^2 & greater

↓

TROPOMI (2017)
Daily
~3.5 x 7 km^2

↓

TEMPO (202x)
Hourly
2 x 5 km^2

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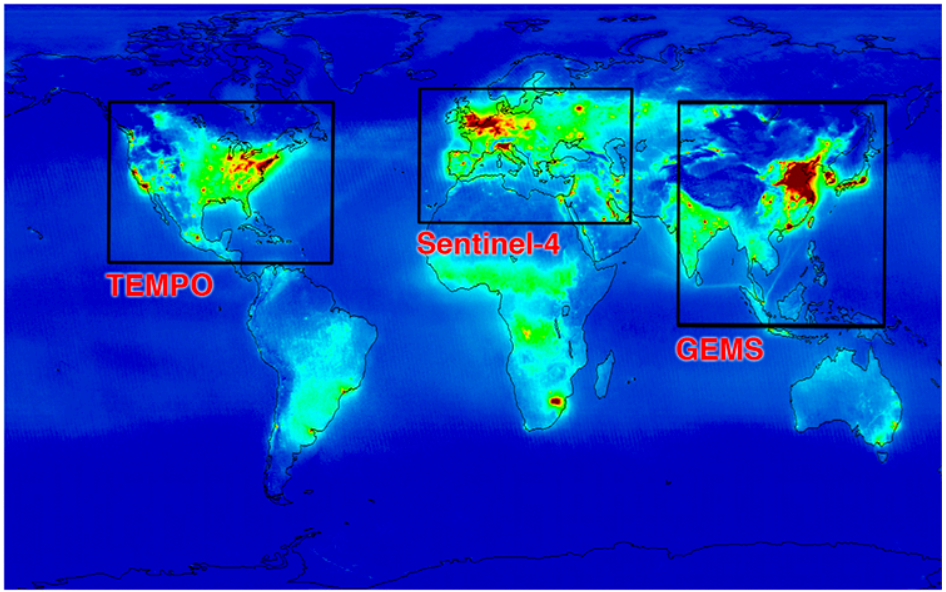
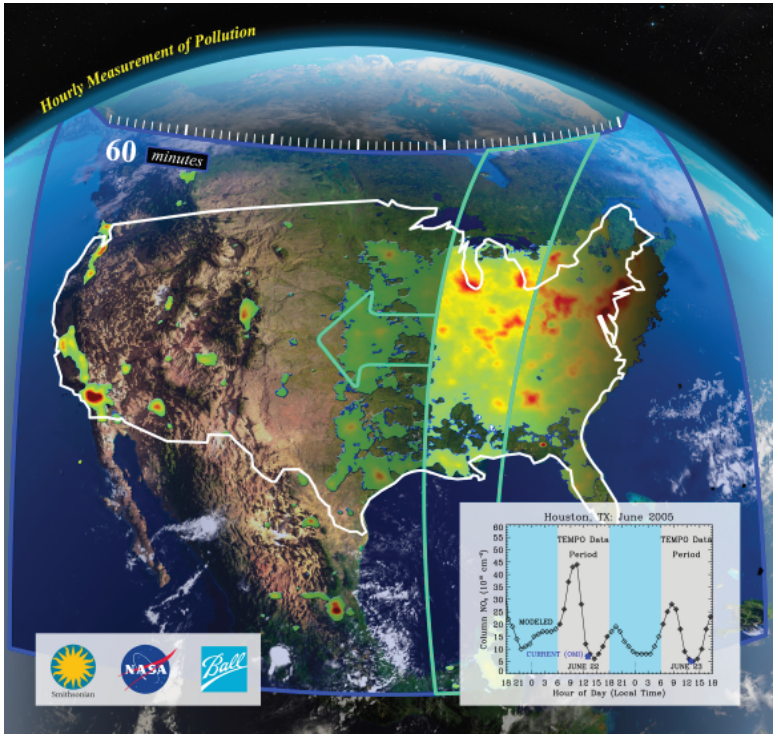
Upcoming NASA TEMPO - Geostationary

Tropospheric Emissions: Monitoring Pollution (TEMPO)





http://tempo.si.edu

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NASA Programs

HAQAST – NASA Health and Air Quality Applied Science Team

"Connecting NASA Data and Tools with Health and Air Quality Stakeholders"
HAQAST6 will take place July 10-12, 2019 in Pasadena, California

https://haqast.org/nasa-tools/

ARSET – NASA Applied Remote Sensing Training

"The ARSET program offers satellite remote sensing training that builds the skills to integrate NASA Earth Science data into an agency's decision-making activities."

https://arset.gsfc.nasa.gov/

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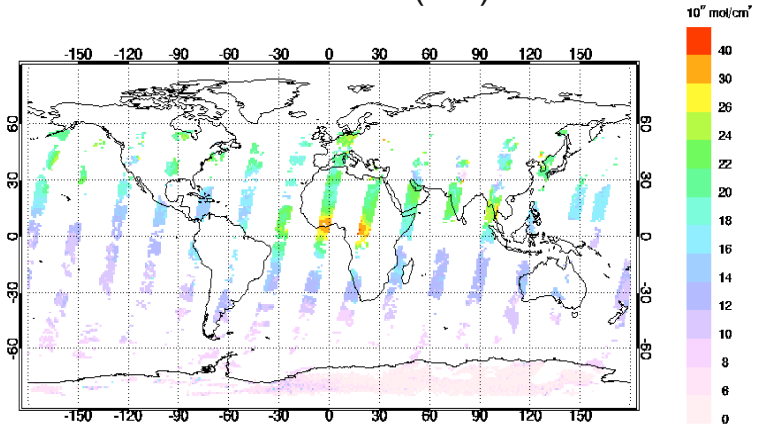
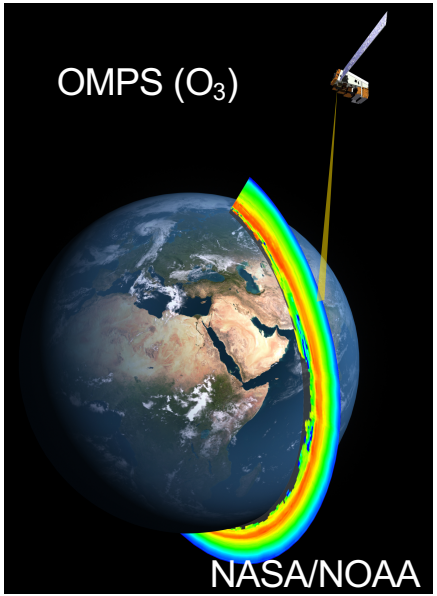
Earth Observing Satellites

Terra MOPITT (CO)

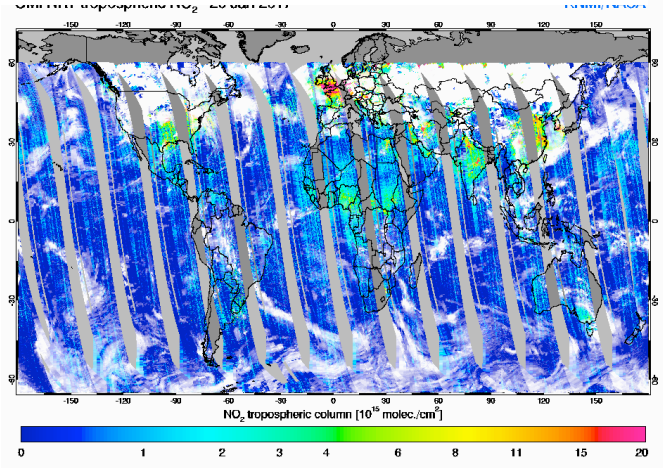


www.acom.ucar.edu



www.nasa.gov

Aura OMI (NO_2, O_3)



www.temis.nl

Global coverage from space but temporal frequency may be on the order of days not hours

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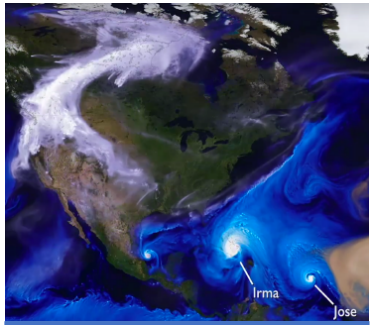
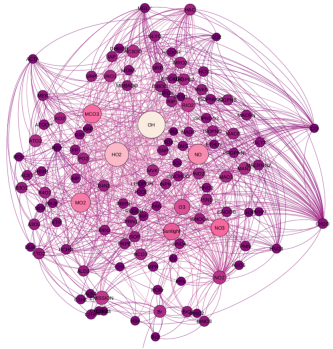
NASA GMAO's Composition Forecast



GEOS NWP

+



GEOS - Chem

Research product

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GEOS-Chem is a state-of-the science chemistry transport model

Tropospheric and Stratospheric full chemistry

- 250 reactive species, 725 reactions
- 100+ user/developer groups worldwide
- Updated version is released about every year

GEOS-Chem

Harvard University
Atmospheric Chemistry Modeling Group

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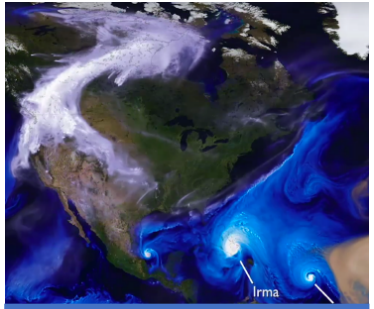
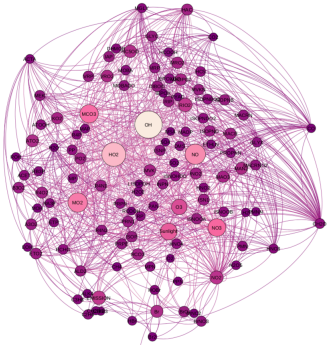
Daily composition forecast



GEOS NWP



GEOS - Chem

GEOS - CF

One **5-day forecast** per day

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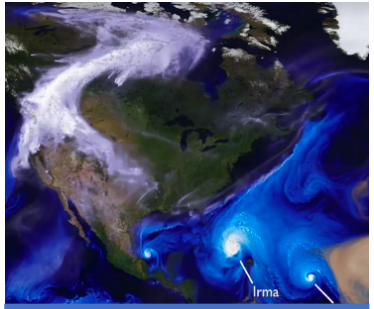
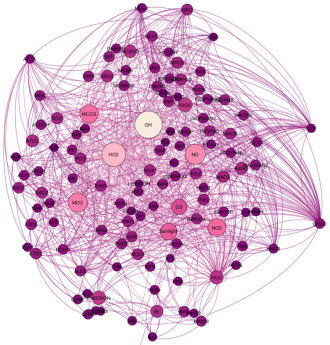
Daily composition forecast



GEOS NWP



GEOS - Chem

GEOS - CF

One **5-day forecast** per day

- 1-day hindcast “analysis”
- 5-day forecast

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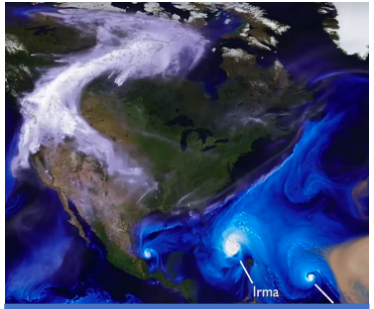
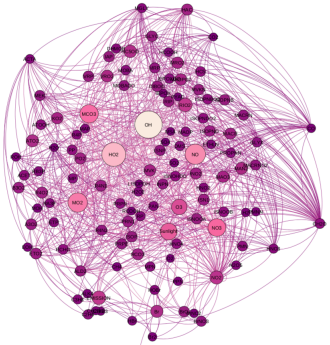
Daily composition forecast



GEOS NWP



GEOS - Chem

GEOS - CF

One **5-day forecast** per day

- 1-day hindcast
- 5-day forecast
- c360 (0.25°, **~25x25 km²**) resolution, 72 model layers

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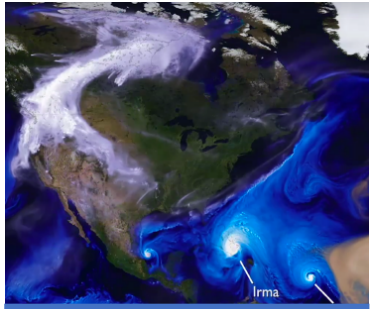
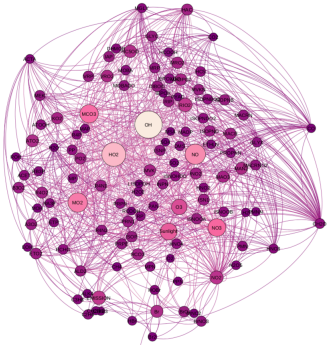
Daily composition forecast



GEOS NWP



GEOS - Chem

GEOS - CF

One **5-day forecast** per day

- 1-day hindcast
- 5-day forecast
- c360 (0.25°, **~25x25 km²**) resolution, 72 model layers
- O_3, NO_x, VOCs, PM ...

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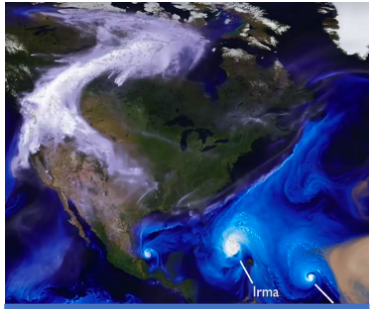
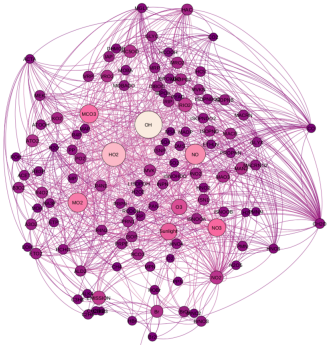
Daily composition forecast



GEOS NWP



GEOS - Chem

GEOS - CF

One **5-day forecast** per day

- 1-day hindcast
- 5-day forecast
- c360 (0.25°, ~25x25 km^2)
- **15 minute** "surface"
- **1-hour** average and instantaneous 2D & 3D

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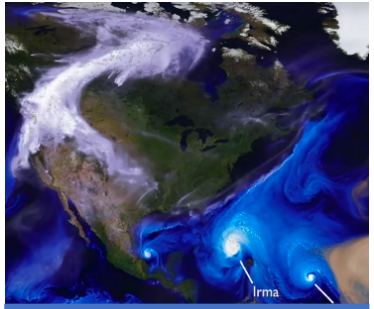
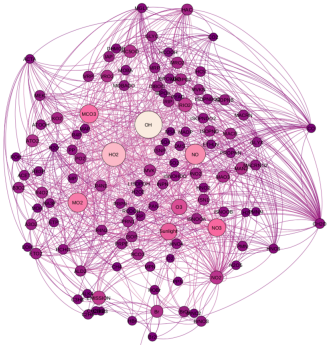
Daily composition forecast



GEOS NWP



GEOS - Chem

GEOS - CF

One **5-day forecast** per day

- 1-day hindcast
- 5-day forecast
- c360 (0.25°, ~25x25 km^2)

- **1 January 2018 - NRT**

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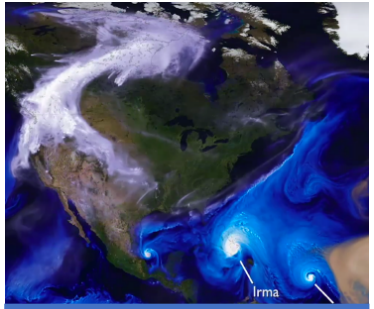
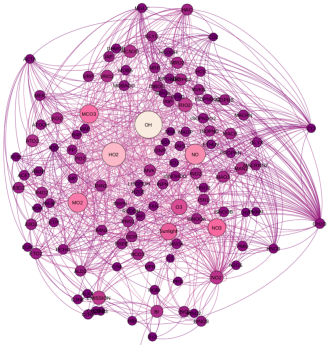
Chemistry is not cheap!



GEOS NWP



GEOS - Chem

GEOS - CF

Run on **NASA's** Center for Climate Simulation **supercomputer**

- using the computing power equivalent to **3500** personal **computers**.

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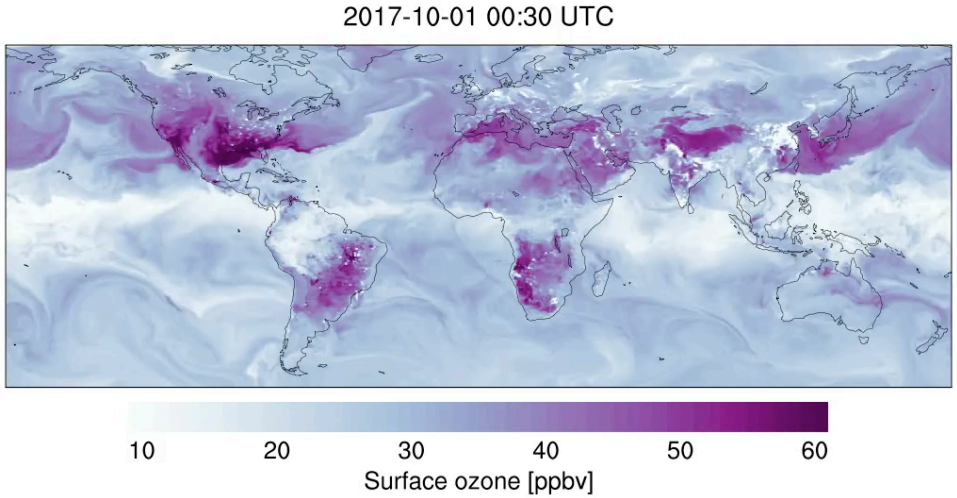
High-Resolution Global Simulation

GEOS - CF



25 km x 25 km (16 miles)

- **Highest** horizontal resolution of a global atmospheric composition forecast
- **10 x higher** than conventional global atmospheric chemistry simulations.

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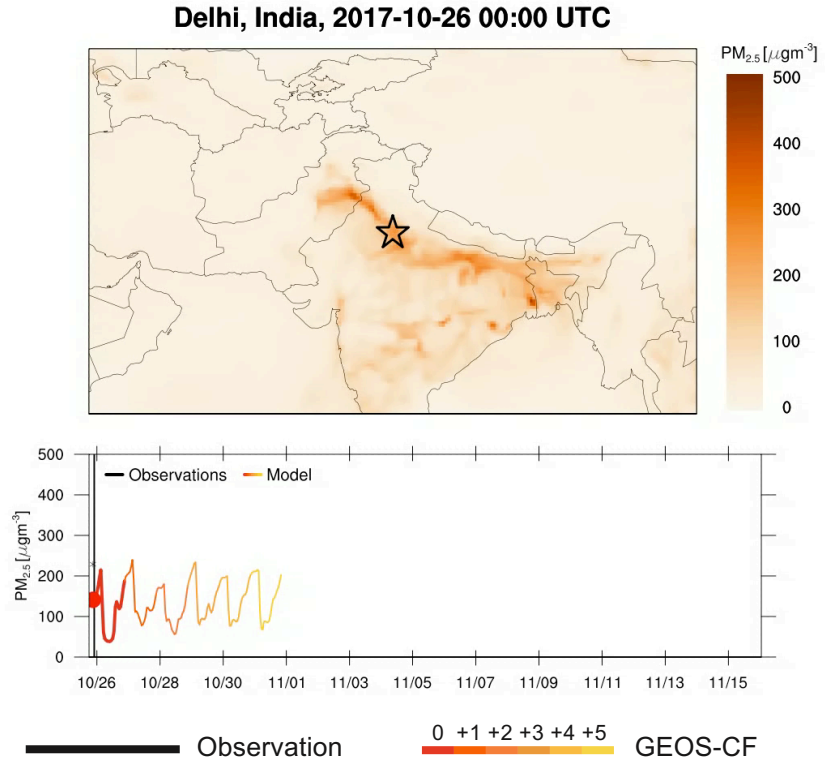
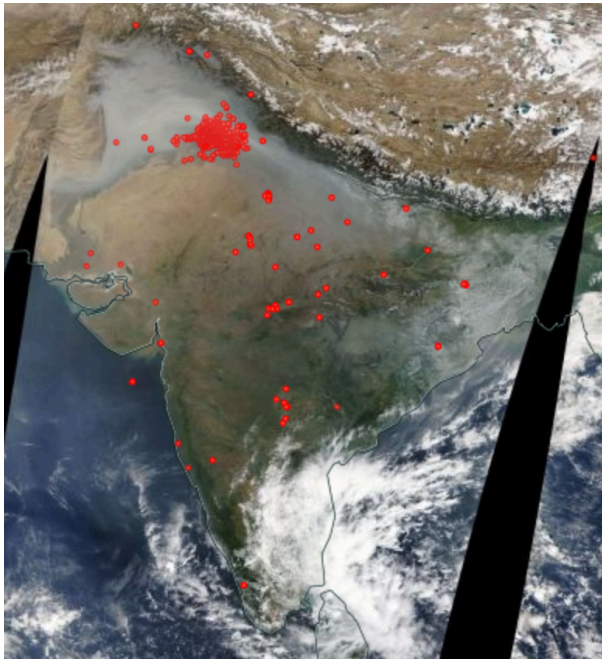
Case study: agricultural fires in India



MODIS fires Nov 01, 2017



openaq

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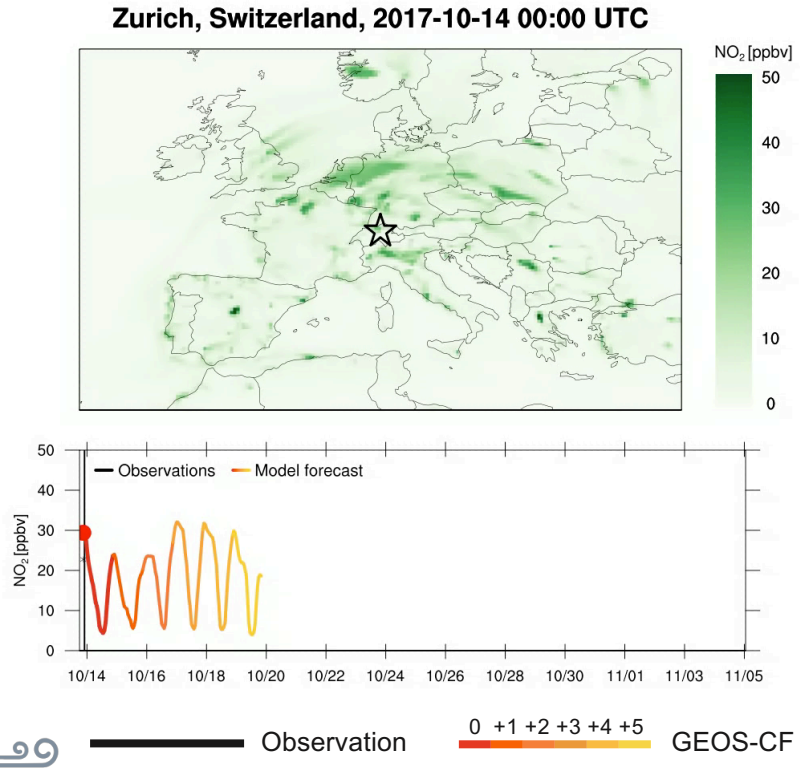
Daily composition forecast

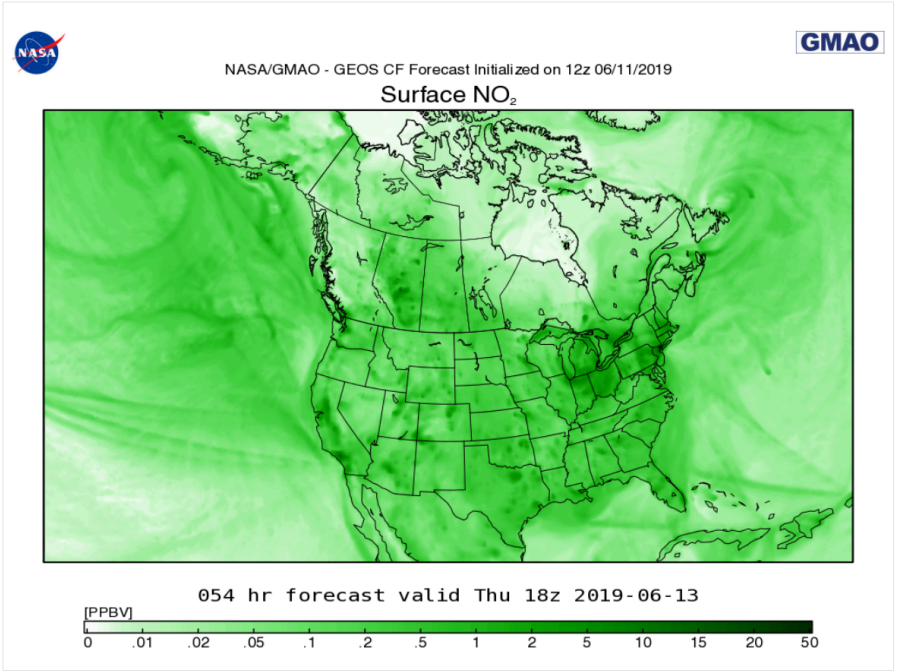


GEOS - CF

- Annual emission scale factors based on satellite
- Scale factors applied to emissions for diurnal and weekly variations

Where to find GEOS-CF

Output available at fluid.nccs.nasa.gov/cf



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Composition Forecast Maps

FIELDS

CO Sfc | NO2 Sfc | O3 Sfc | PM2.5 Sfc | SO2 Sfc

REGIONS

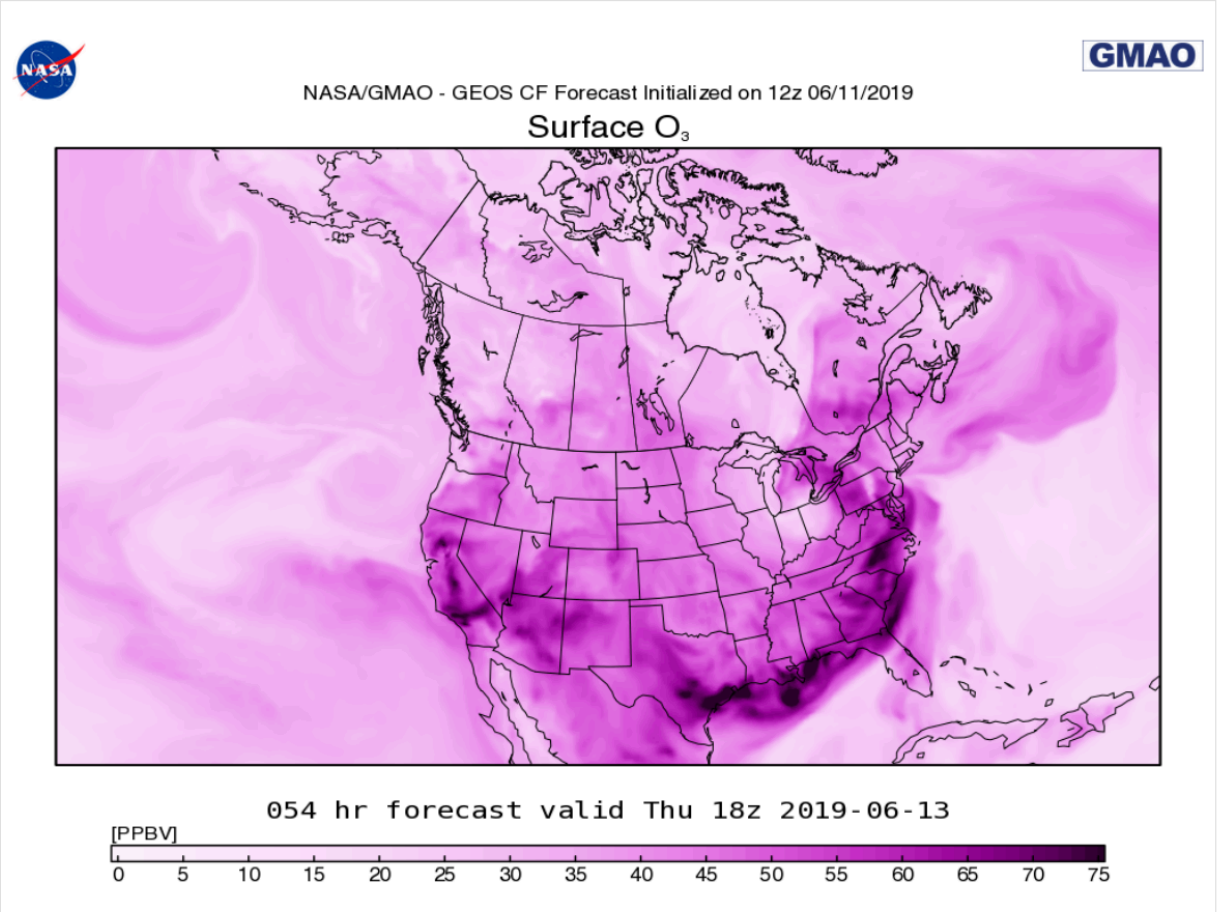
North America

FORECAST INITIAL TIME

11Jun2019 12z

FORECAST LEAD HOUR

054h 13Jun2019 18z



Model forecast O_3

https:/fluid.nccs.nasa.gov/cf

Model forecast O_3 at Raleigh

Composition Forecast

CF Datagrams

NATIONAL

Raleigh

WORLD

Select a Station

AERONET

Select a Station

MEGACITIES

Select a Station

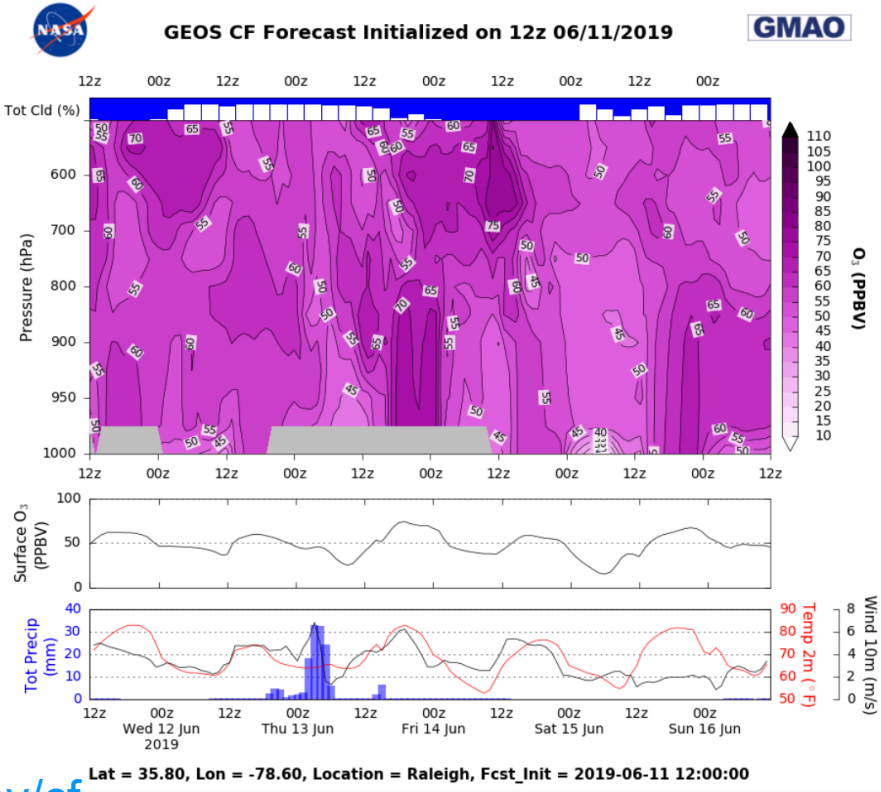
ACTIVE CAMPAIGNS

Select a Station

GMAO GEOS CF Datagrams

O3 at Raleigh (35.80, -78.60)

CO | NO_2 | **O_3** | PM 2.5 | SO_2



Vertical O_3

Surface O_3

Meteorology

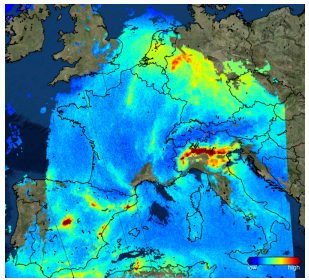
https:/fluid.nccs.nasa.gov/cf

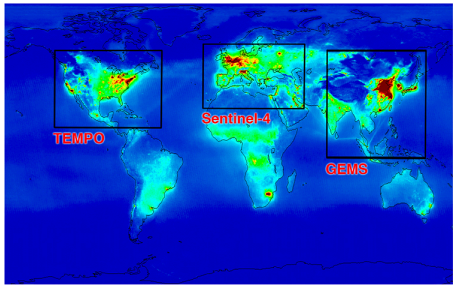
Summary

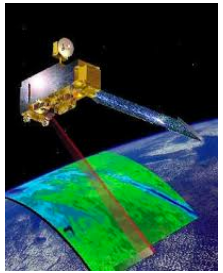
- GEOS-CF produces daily global air quality forecasts at 25km (16 miles) horizontal resolution
- Output available at fluid.nccs.nasa.gov/cf

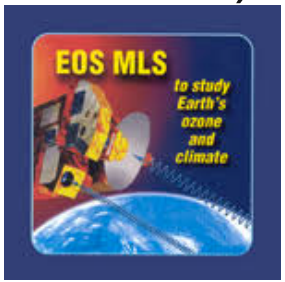
Under development:

- Assimilation system for trace gases (O_3, NO_x, CO, & others)









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of York

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America

IIEC
International Institute for Energy Conservation

HAQAST

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NYU

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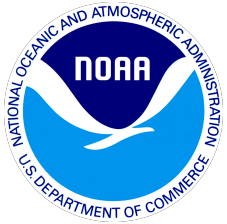
VE RI TAS
HARVARD

FOREST SERVICE
US
DEPARTMENT OF AGRICULTURE

openaq

unicef

QUITO
ALCALDÍA

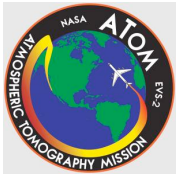

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

JAYA RAYA

BMKG

C40
CITIES
CLIMATE LEADERSHIP GROUP


NASA
ATOM
ATMOSPHERIC TOMOGRAPHY MISSION

CLIMATE &
CLEAN AIR
COALITION
TO REDUCE SHORT-LIVED
CLIMATE POLLUTANTS

HawaDawa

APHC
ARMY PUBLIC HEALTH CENTER

BOEM & NASA
SATELLITE COASTAL AND OCEANIC ATMOSPHERIC POLLUTION EXPERIMENT
SCOAPE

KNMI

JOHNS HOPKINS
BLOOMBERG SCHOOL
of PUBLIC HEALTH

ECMWF

UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY

GOVERNO DO
Rio de
Janeiro

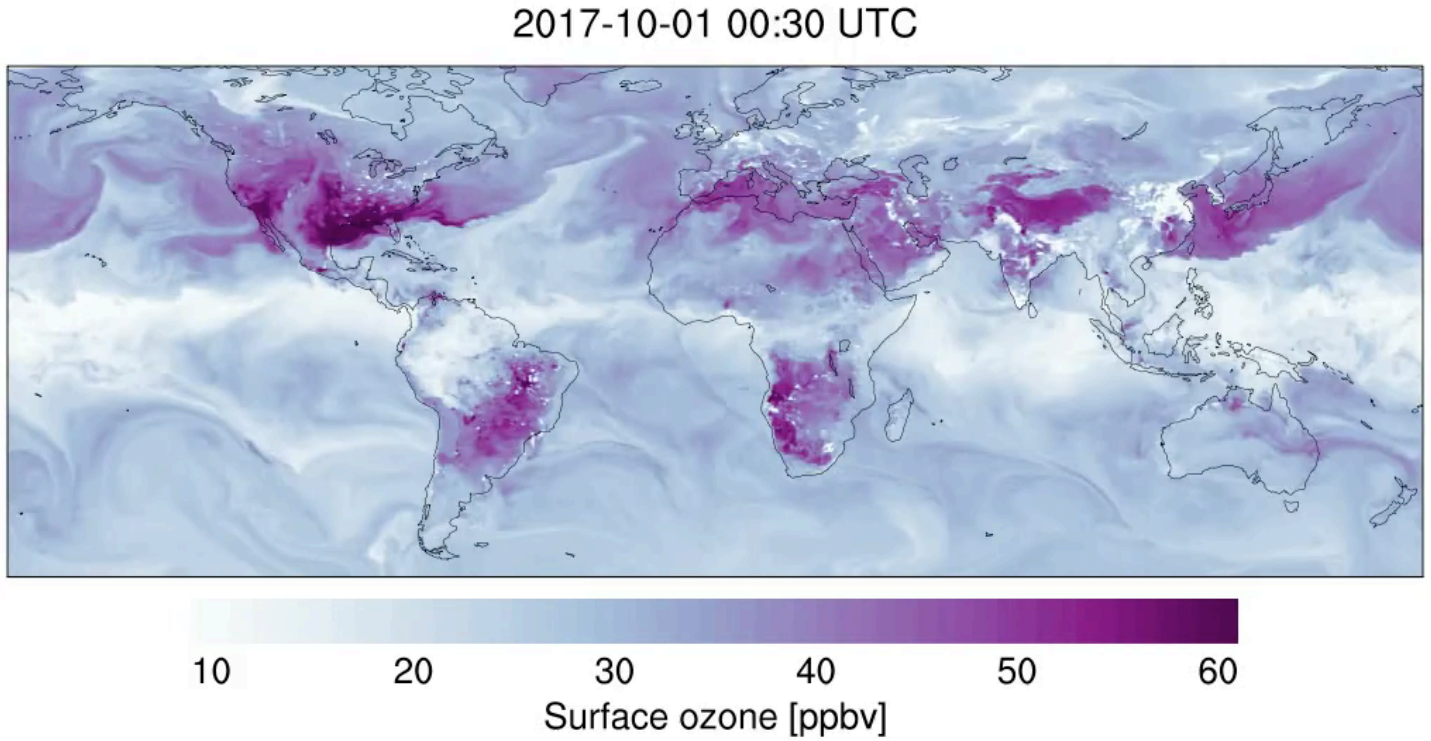
IBM

Swiss Re

DEPARTMENT OF STATE
UNITED STATES OF AMERICA

WORLD
RESOURCES
INSTITUTE

Thank you!



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