

NASA GEOS Forecasting Capabilities for Air Quality

K. Emma Knowland

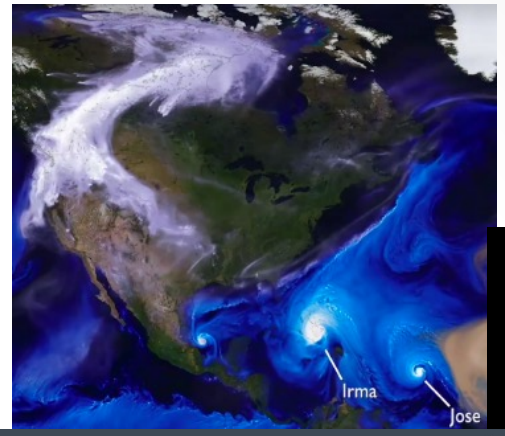
Morgan State University/GESTAR-II

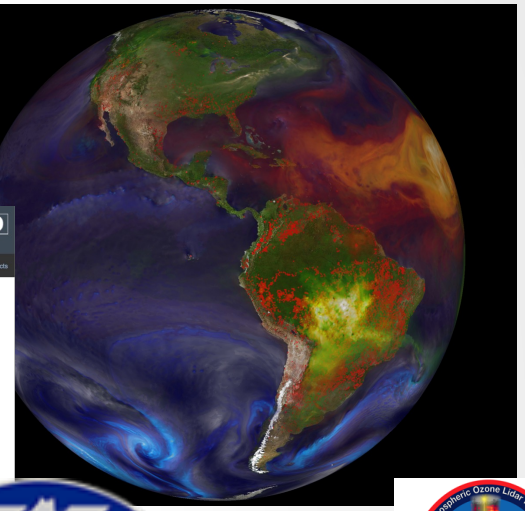
NASA Global Modeling and Assimilation Office (GMAO)

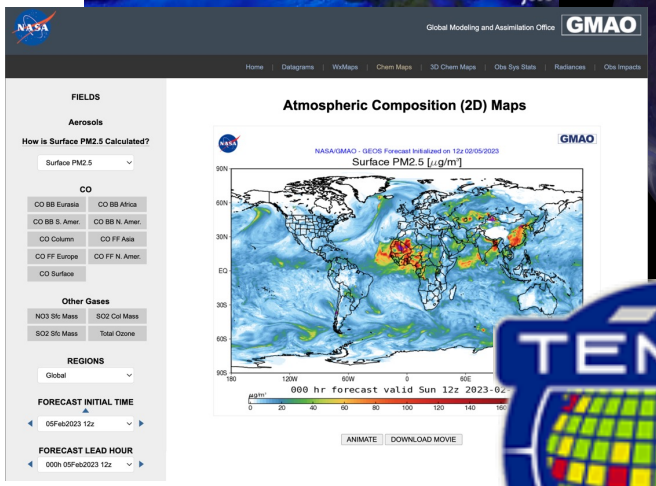
In collaboration with many scientists from GMAO and other labs at NASA Goddard Space Flight Center

OUTLINE

1. Overview of GEOS current capabilities
   - Numerical Weather Prediction
   - Composition Forecasting
2. How to access GEOS “big data” for research scientists and engaged community members
3. Bias-correcting techniques for Air Quality decision making



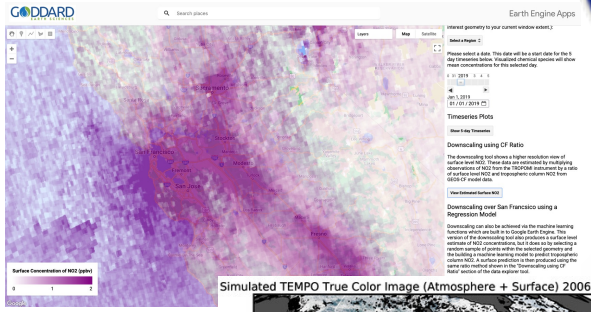


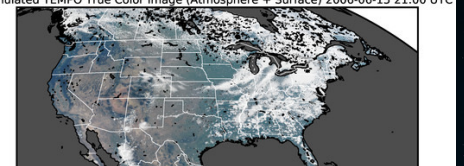














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GMAO's core mission is to enhance the value of NASA's observations to understand, analyze and predict changes in the physics, chemistry and biology of the Earth system

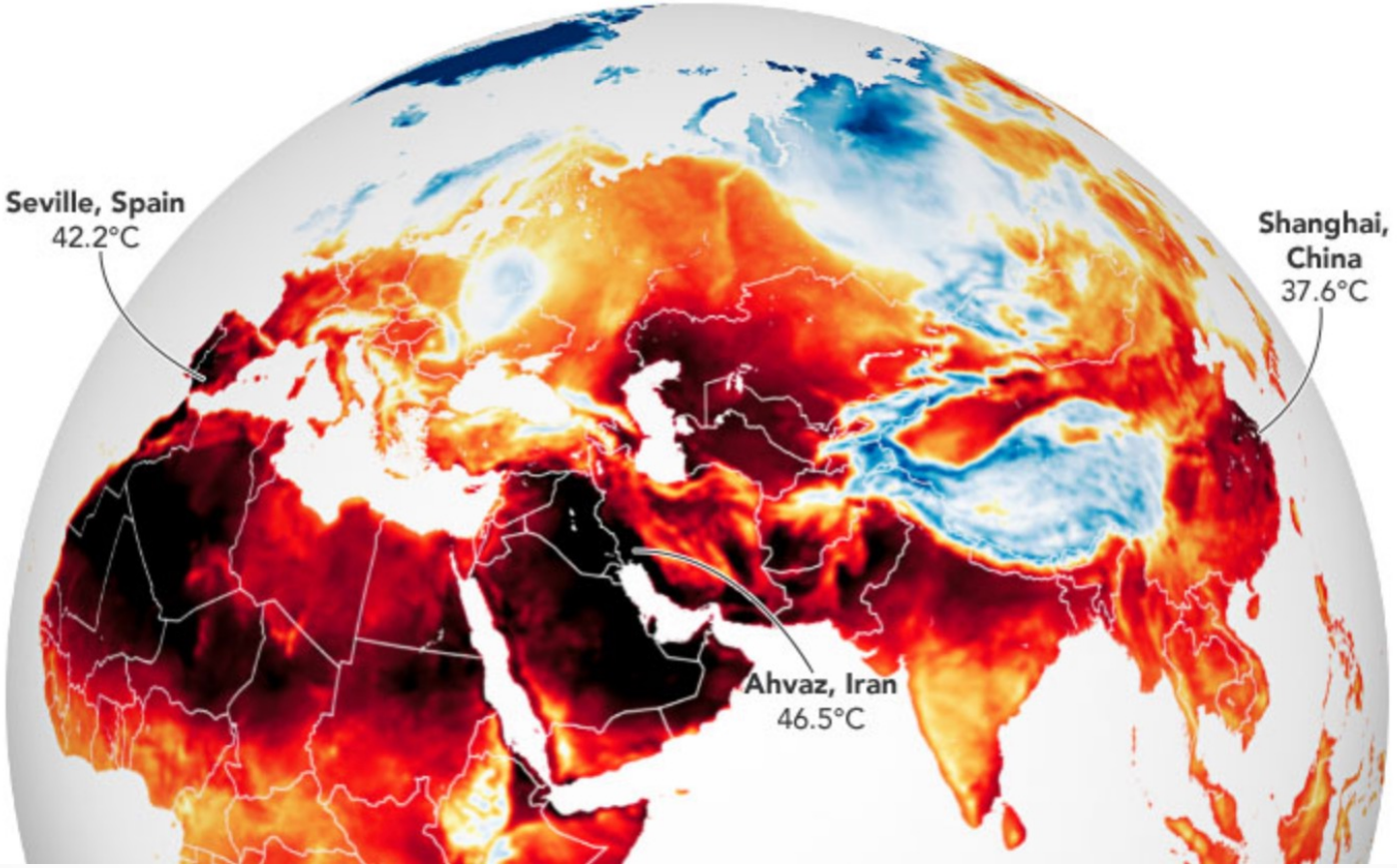
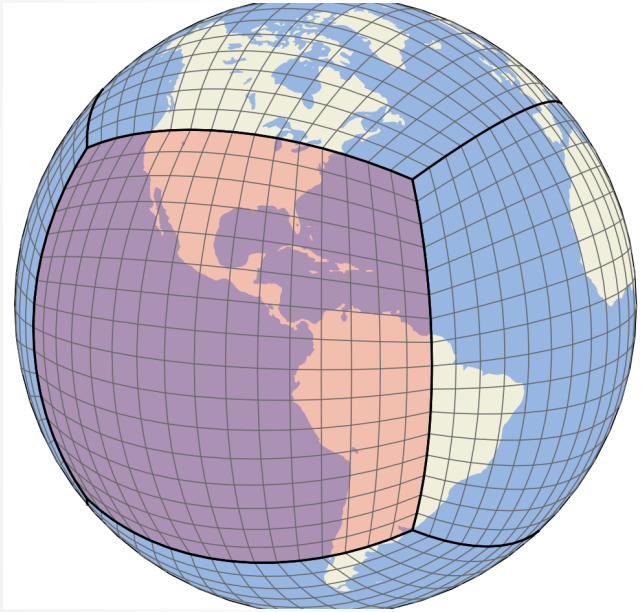


Image by Joshua Stevens,
NASA Earth Observatory
https://earthobservatory.nasa.gov/images/150083/heatwaves-and-fires-scorch-europe-africa-and-asia

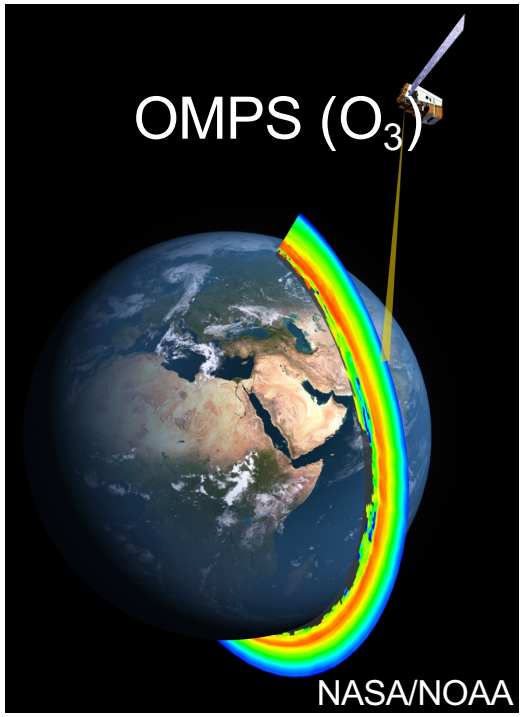
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NASA GMAO has a mature Earth System model

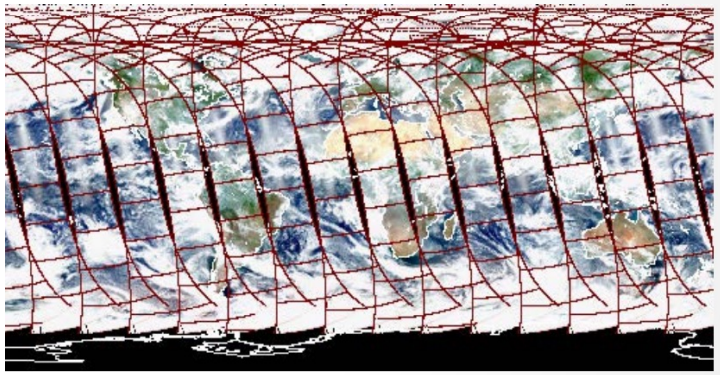
GEOS



Bindle et al., 2021 GMD



www.nasa.gov



https://modis.gsfc.nasa.gov/

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NASA GMAO global meteorology and chemistry products

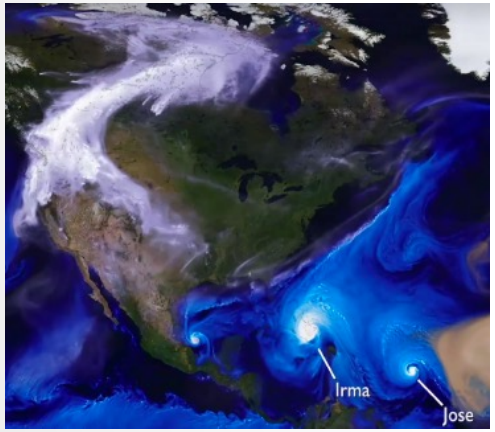
GEOS

Forecasting

Reanalysis

GEOS FP

MERRA-2

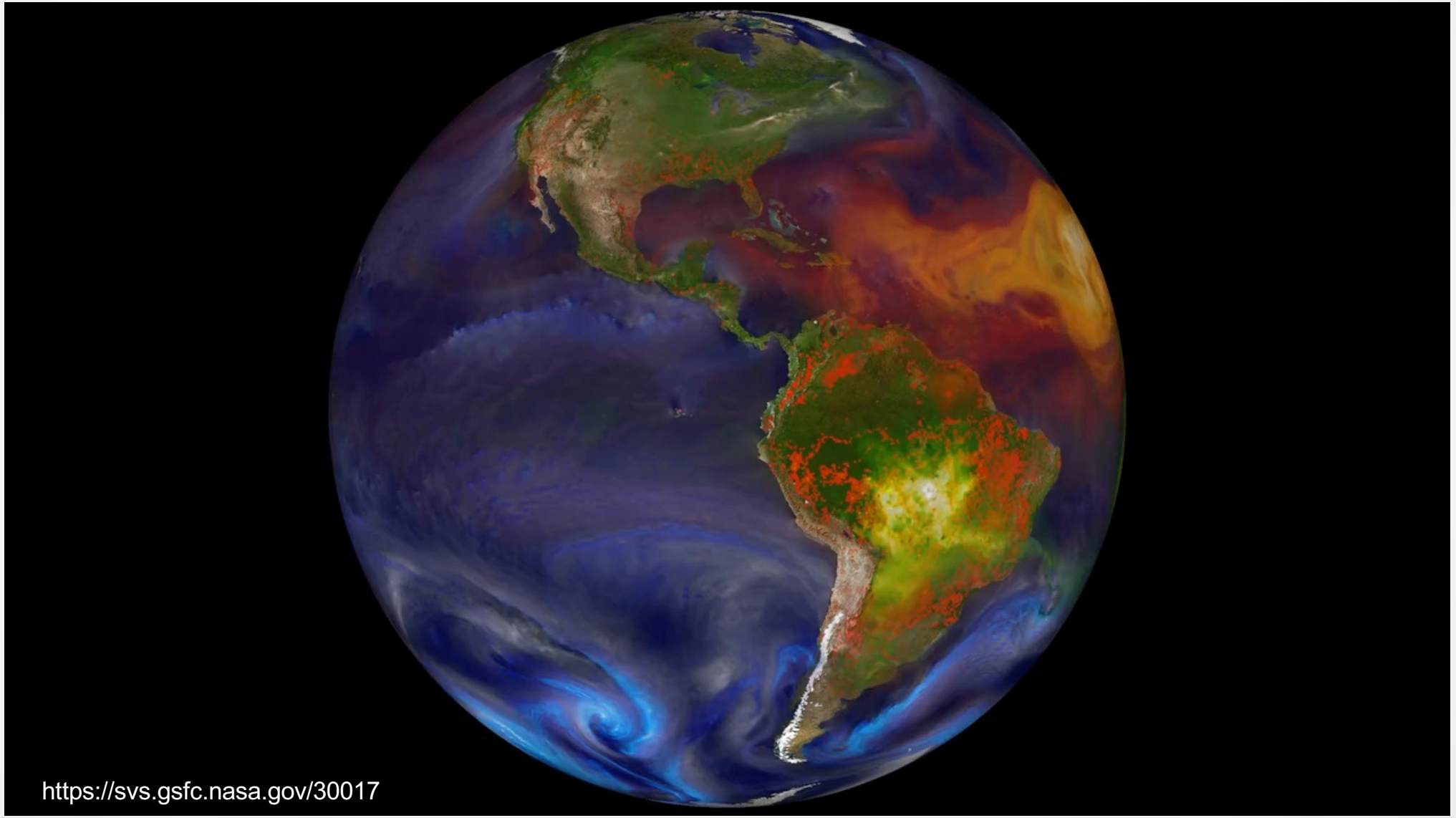


GMAO Global Modeling and Assimilation Office
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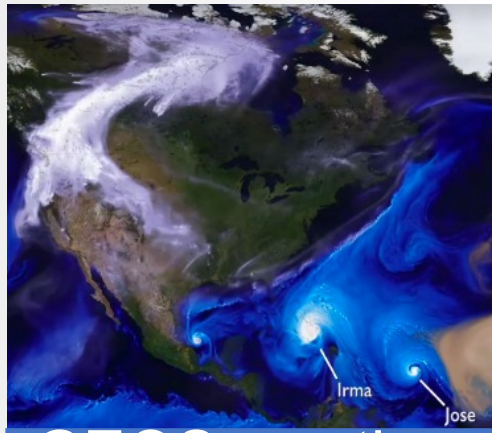
GODDARD EARTH SCIENCES

GEOS NWP capabilities

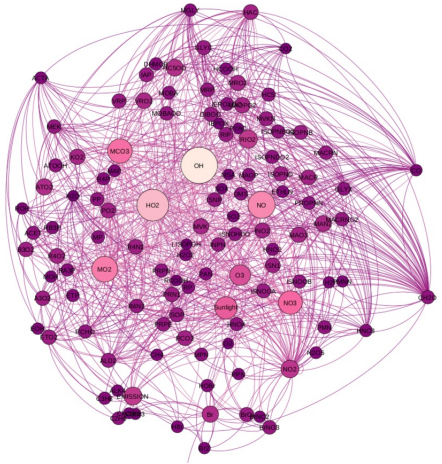


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GEOS Composition Forecast



GEOS weather forecasting



GEOS-Chem

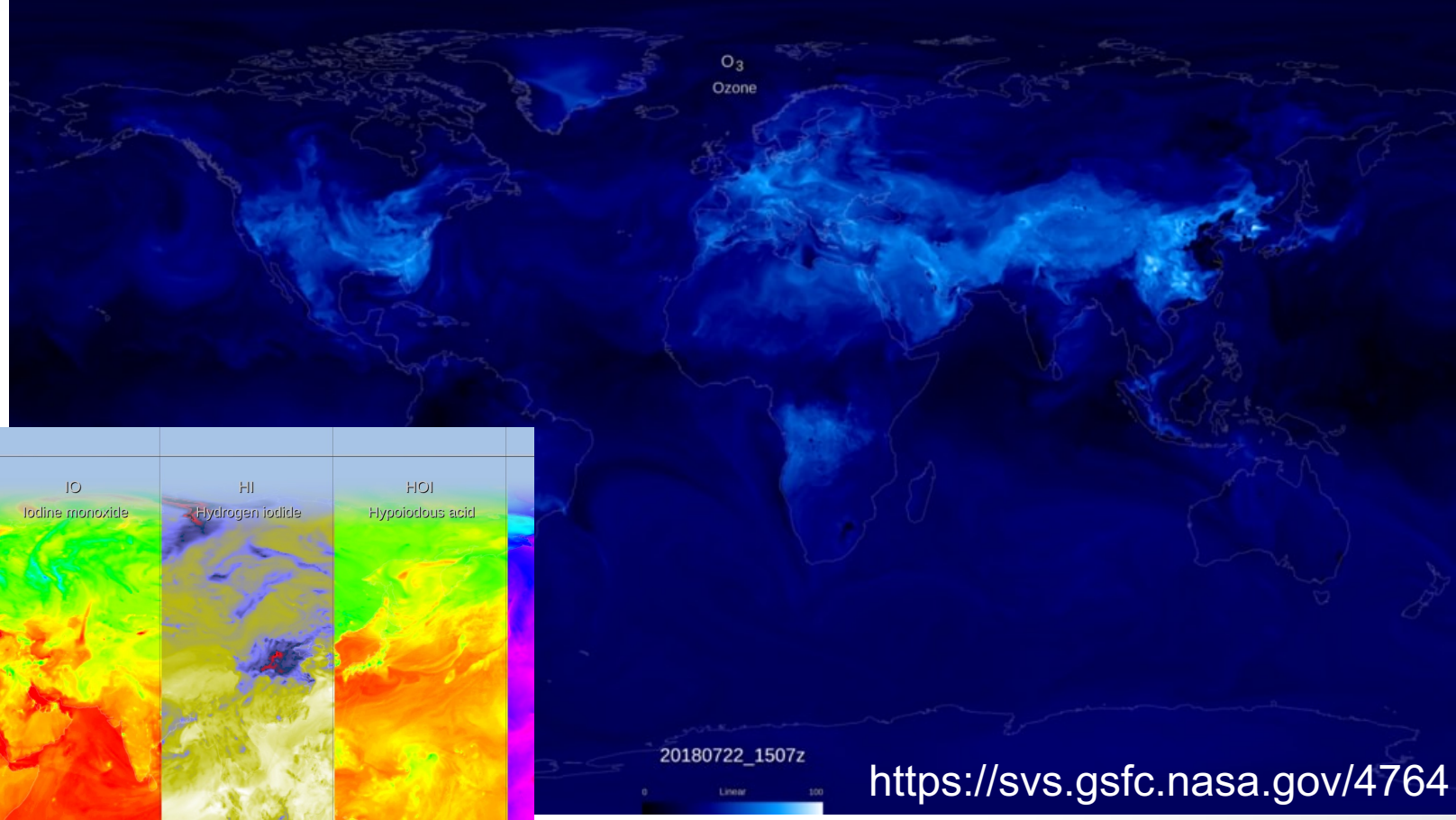
GEOS - CF

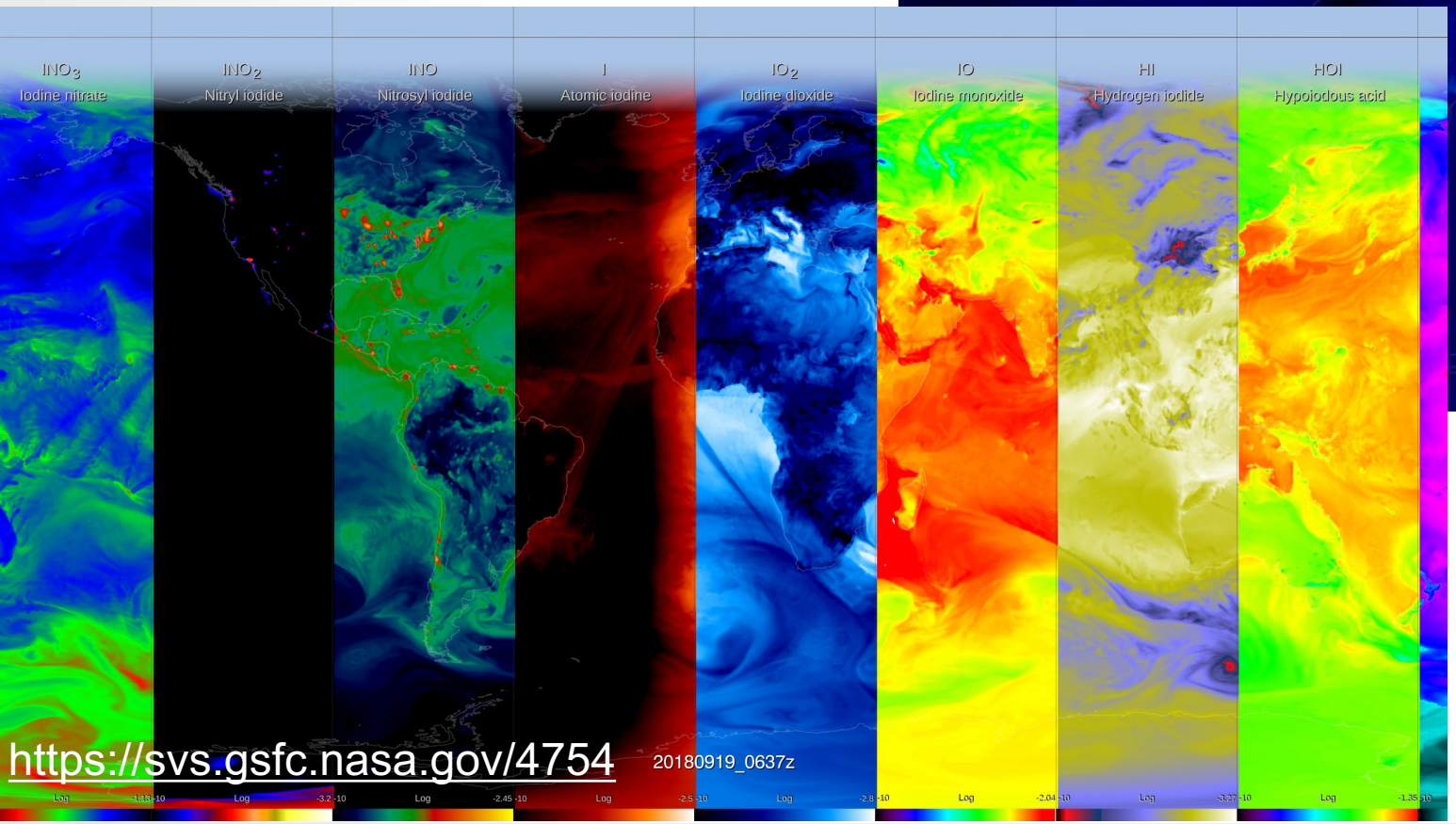
Version 12

Tropospheric and Stratospheric chemistry

- 250 Chemical Species
- 725 Chemical Reactions

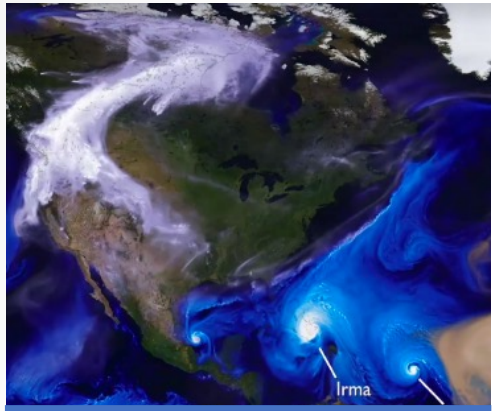
GEOS - CF



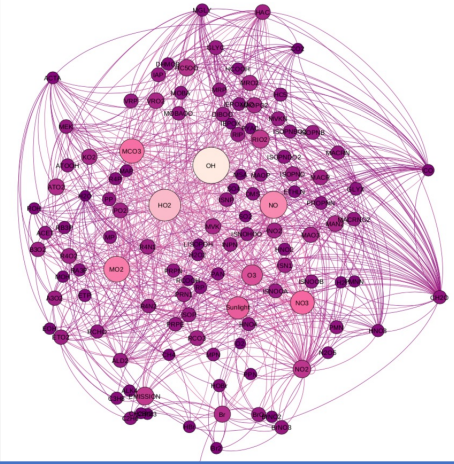


Global historical model estimates and daily 5-day forecasts of major air pollutants like Ozone & $PM_{2.5}$

Daily composition forecast



GEOS Weather



GEOS - Chem

GEOS - CF

One **5-day forecast** per day

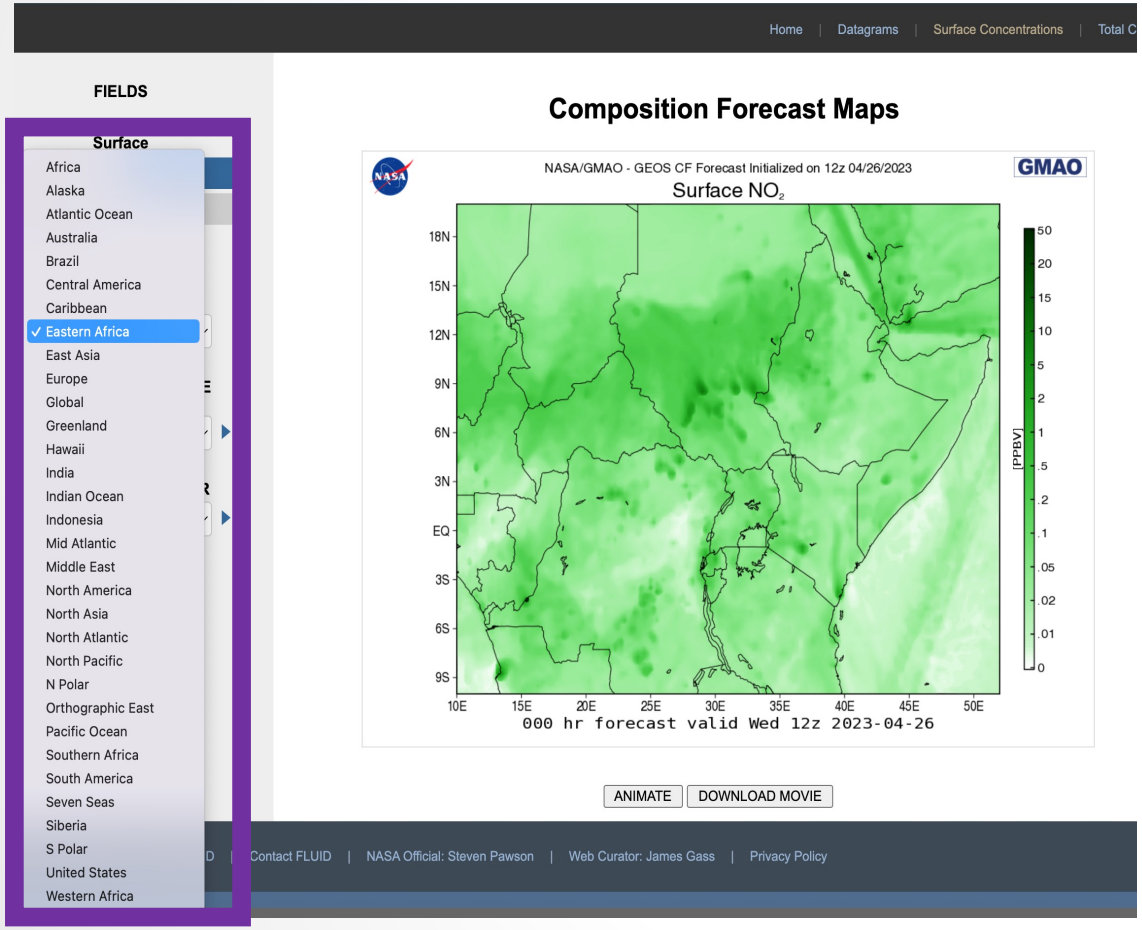
- 1-day simulation of previous 24 hours ("replay")
- 5-day forecast
- c360 (0.25°, **~25x25 km²**) resolution, 72 model layers

- **15 minute** "surface"
- **1-hour** average and instantaneous 2D & 3D
- **Available since**
  - **1 January 2018** (replay)
  - **1 January 2019** (forecast)

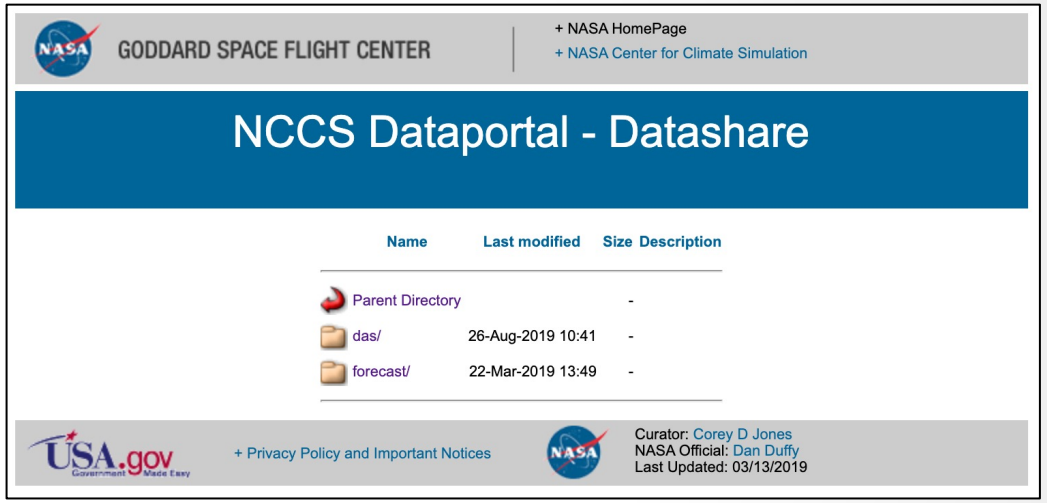
GEOS-CF output is available online in near real-time

Fluid is a mobile-friendly website

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



https://portal.nccs.nasa.gov/datashare/gmao/geos-cf/v1/



https://opendap.nccs.nasa.gov/dods/gmao/geos-cf/

GrADS Data Server - info for /gmao/geos-cf/assim/chm_tavg_1hr_g1440x721_v1 : dds das

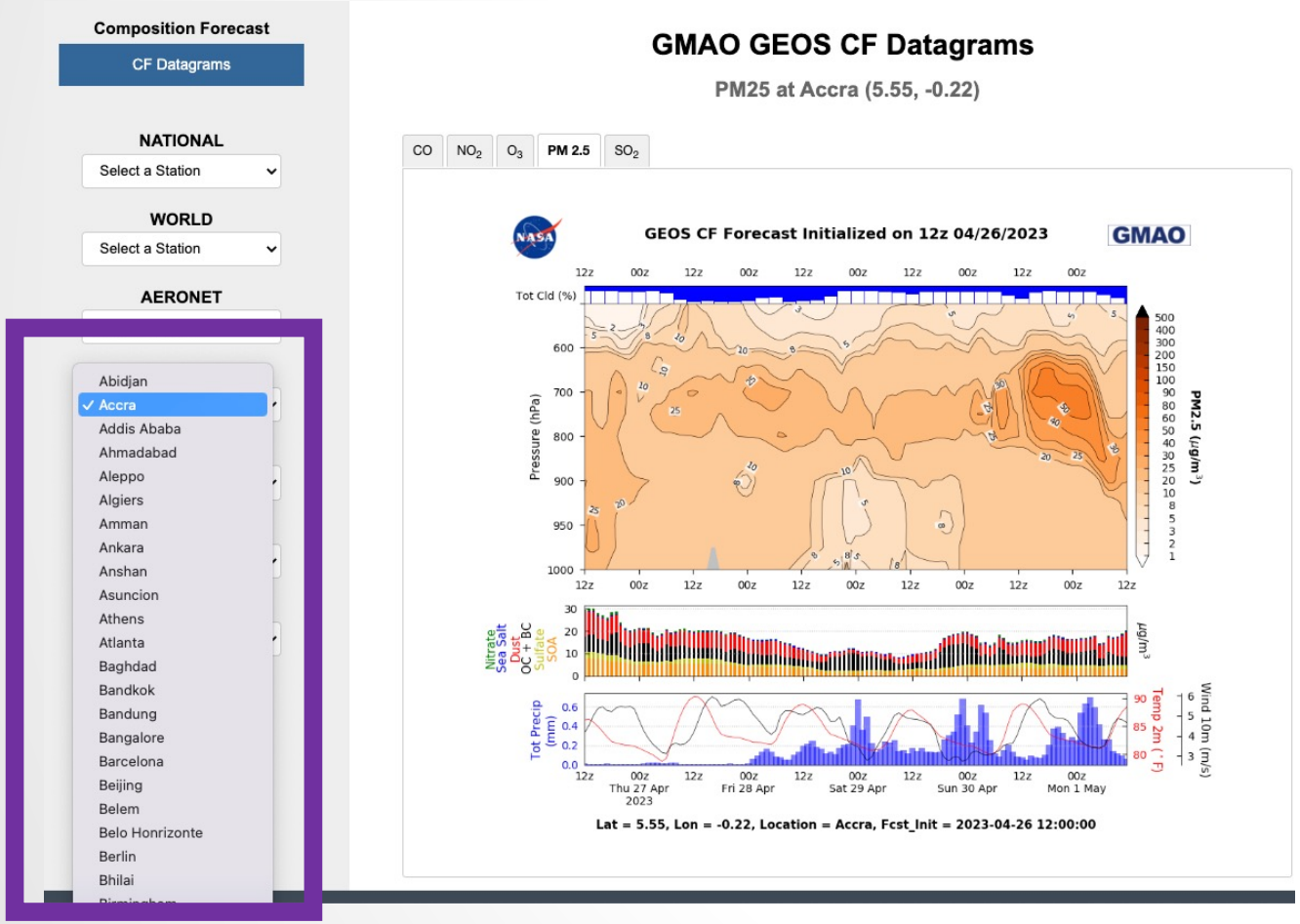
OPeNDAP/DODS Data URL: https://opendap.nccs.nasa.gov/dods/gmao/geos-cf/assim/chm_tavg_1hr_g1440x721_v1

Description:	GEOS CF (Composition Forecast)	
Documentation:	(none provided)	
Longitude:	-180.00000000000°E to 179.75000000000°E	(1440 points, avg. res. 0.25°)
Latitude:	-90.00000000000°N to 90.00000000000°N	(721 points, avg. res. 0.25°)
Altitude:	72.00000000000 to 72.00000000000	(1 points)
Time:	00:30Z01JAN2018 to 11:30Z31OCT2019	(16044 points, avg. res. 0.042 days)
Variables:	**(total of 52)**	
xyle	xylene (c8h10, mw = 106.16 g mol-1) volume mixing ratio dry air	
dst2	dust aerosol, reff = 1.4 microns (mw = 29.00 g mol-1) volume mixing ratio dry air	
hno4	peroxynitric acid (hno4, mw = 79.00 g mol-1) volume mixing ratio dry air	
pm25su_rh35_gcc	sulfate_particulate_matter_with_diameter_below_2.5_um_rh_35	

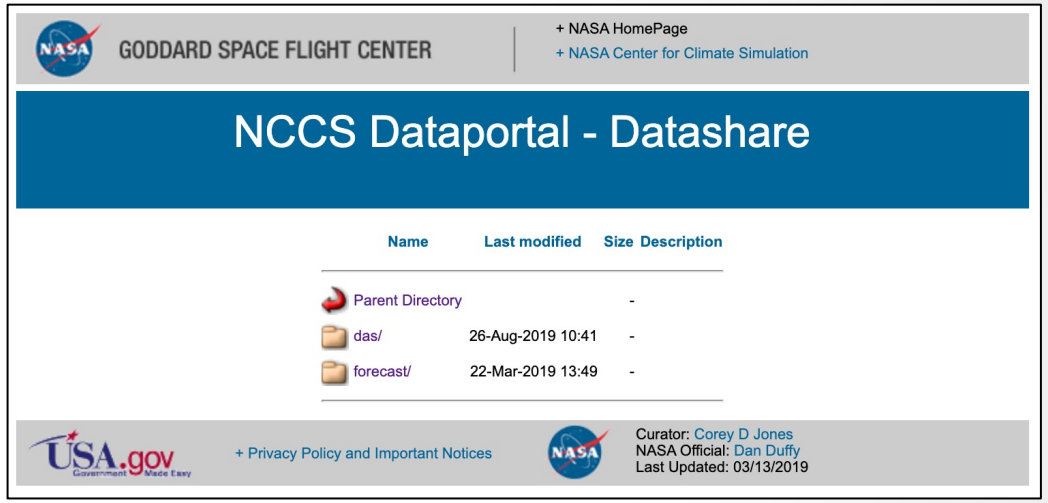
GEOS-CF output is available online in near real-time

Fluid is a mobile-friendly website

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



https://portal.nccs.nasa.gov/datashare/gmao/geos-cf/v1/



https://opendap.nccs.nasa.gov/dods/gmao/geos-cf/

GrADS Data Server - info for /gmao/geos-cf/assim/chm_tavg_1hr_g1440x721_v1 : dds das

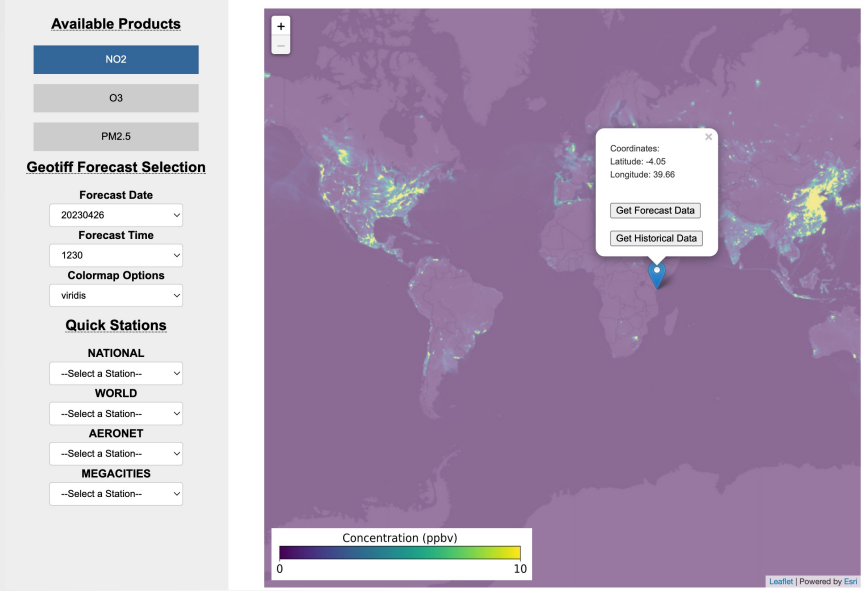
OPeNDAP/DODS Data URL: https://opendap.nccs.nasa.gov/dods/gmao/geos-cf/assim/chm_tavg_1hr_g1440x721_v1

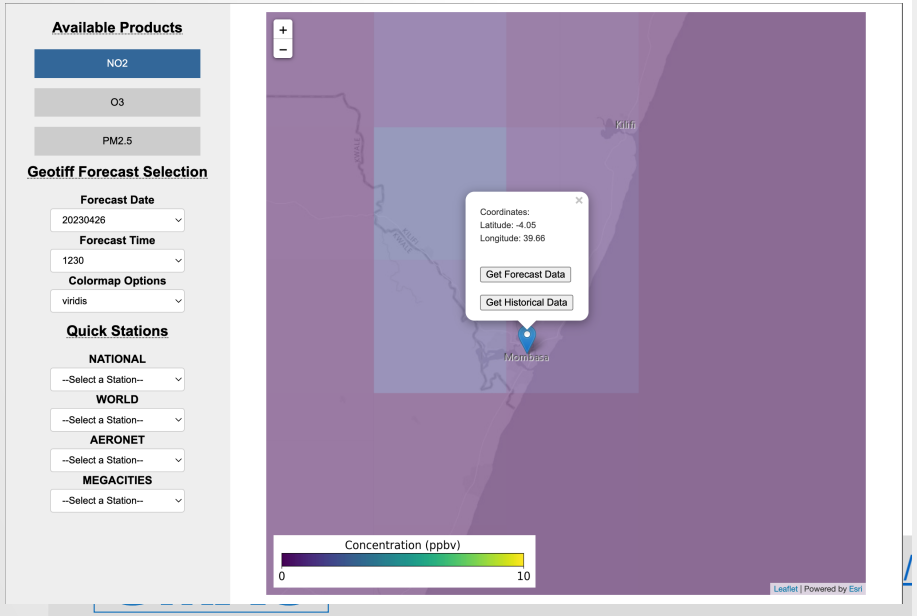
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pm25su_rh35_gcc	sulfate_particulate_matter_with_diameter_below_2.5_um_rh_35	

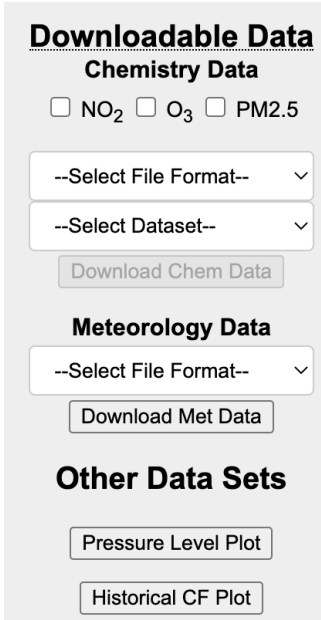
GEOS-CF forecast imagery is available on-demand

National Aeronautics and Space Administration

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







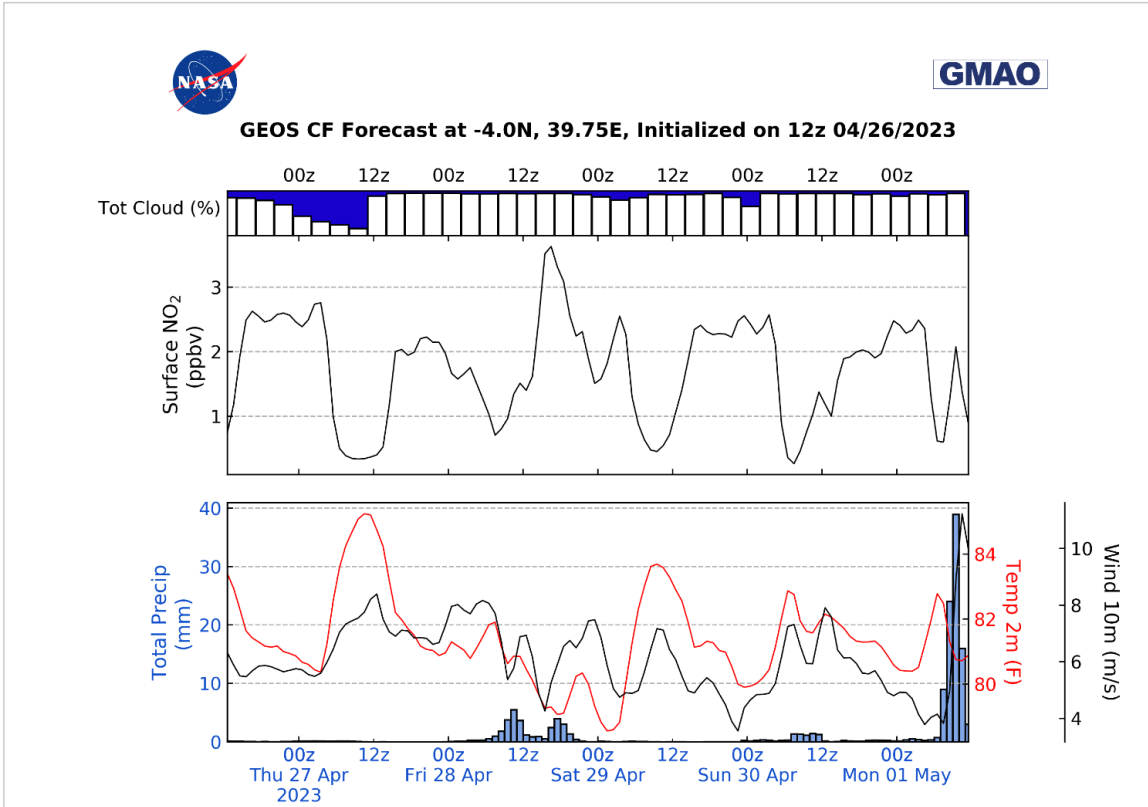
NO2

O3

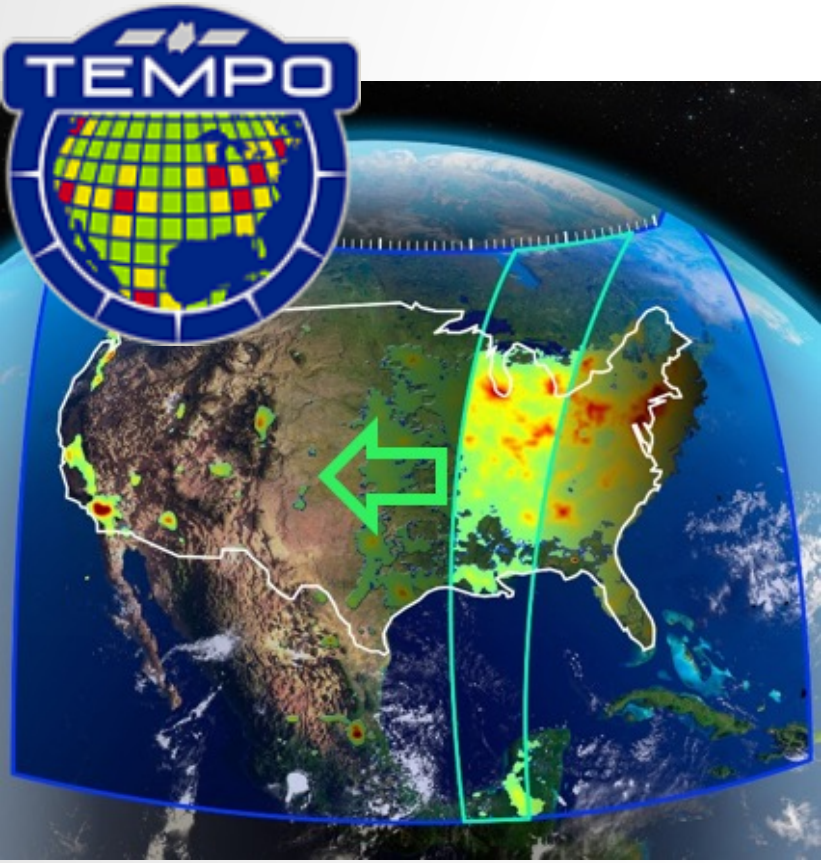
PM 2.5

GMAO GEOS CF Datagrams

NO_2 at (-4.0N, 39.75E)



Daily *atmospheric composition* forecast



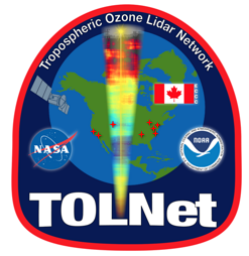


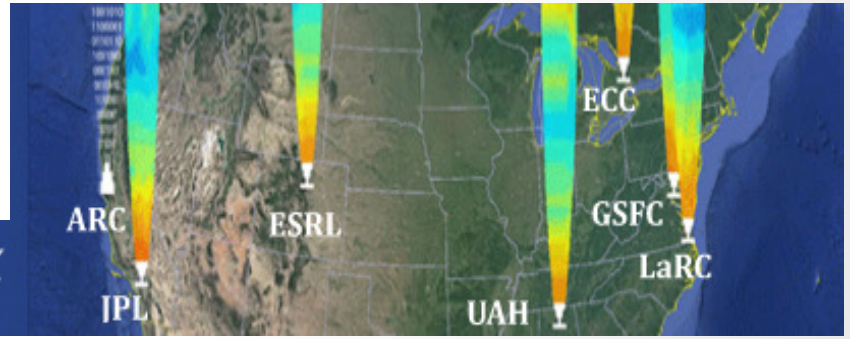
A realistic stratosphere in GEOS-CF is essential to support a broad range of NASA applications, including:

- Satellite retrievals of trace gases
- Airborne campaigns
- Stratosphere-troposphere exchange

TOLNET

Tropospheric Ozone LIDAR Network



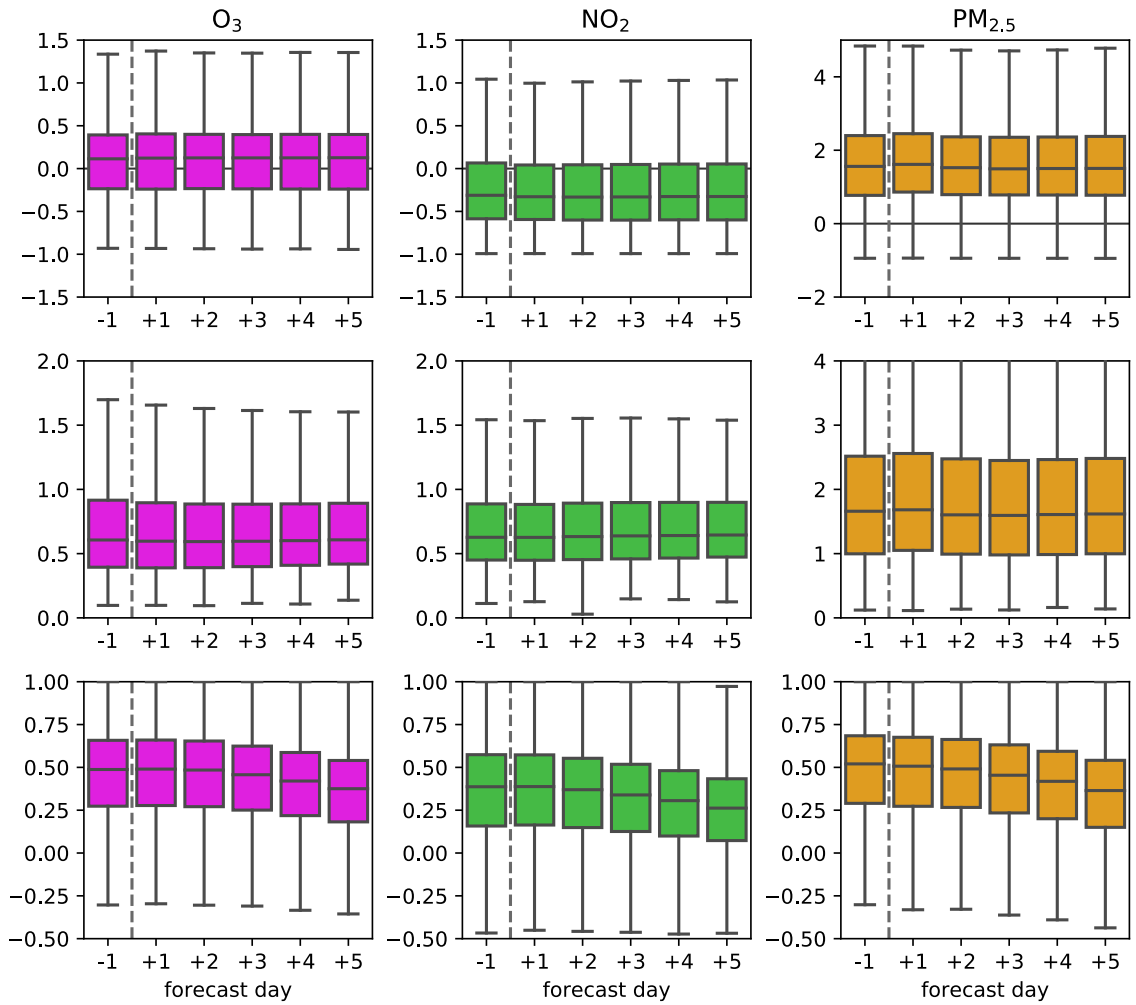


GEOS CF Forecast skill (GAW and OpenAQ)

Normalized Mean Bias (NMB)

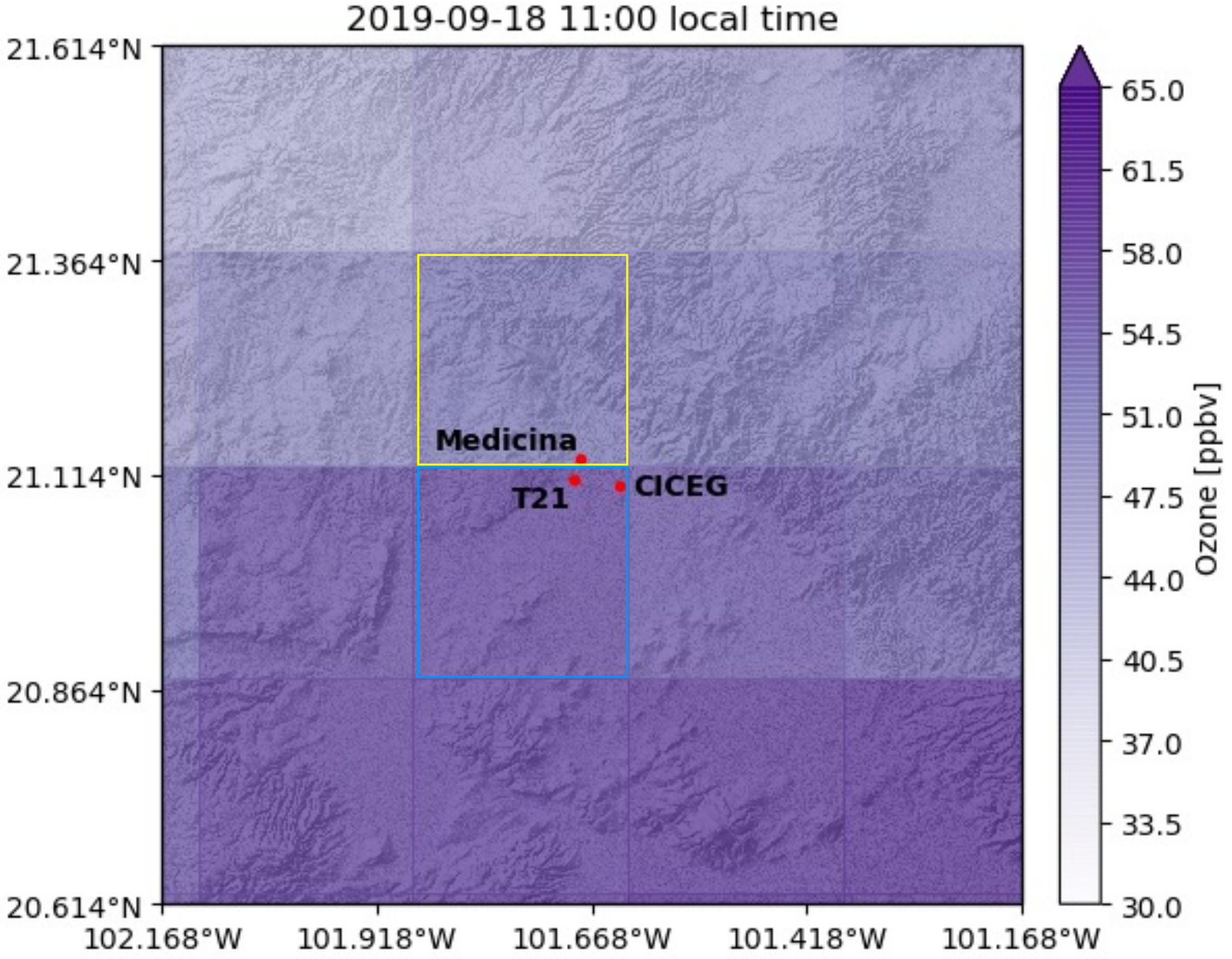
Normalized Root Mean Square Error (NRMSE)

Pearson Correlation Coefficient (R)



- Little variation in the skill scores out to 5 days
- Correlation tends to decrease after day 2 and this is likely due to changes in the meteorological forecast and biomass burning emissions.

Keller, et al. (2021). Description of the NASA GEOS composition forecast modeling system GEOS-CF v1.0. *JAMES* https://doi.org/10.1029/2020MS002413

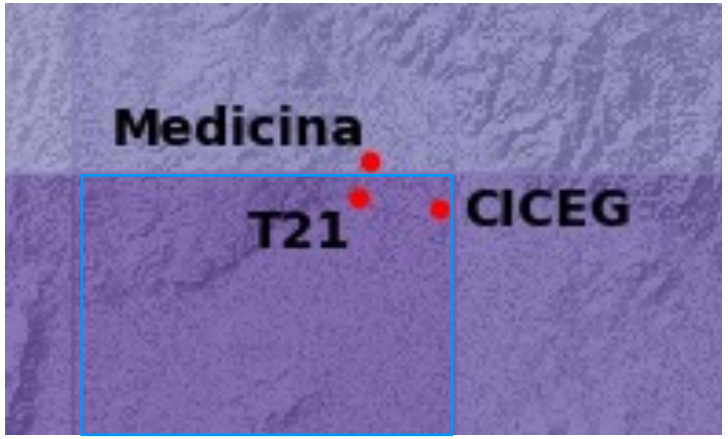


Improve local forecasts using statistical bias correction

3 monitoring stations in Leon, Mexico

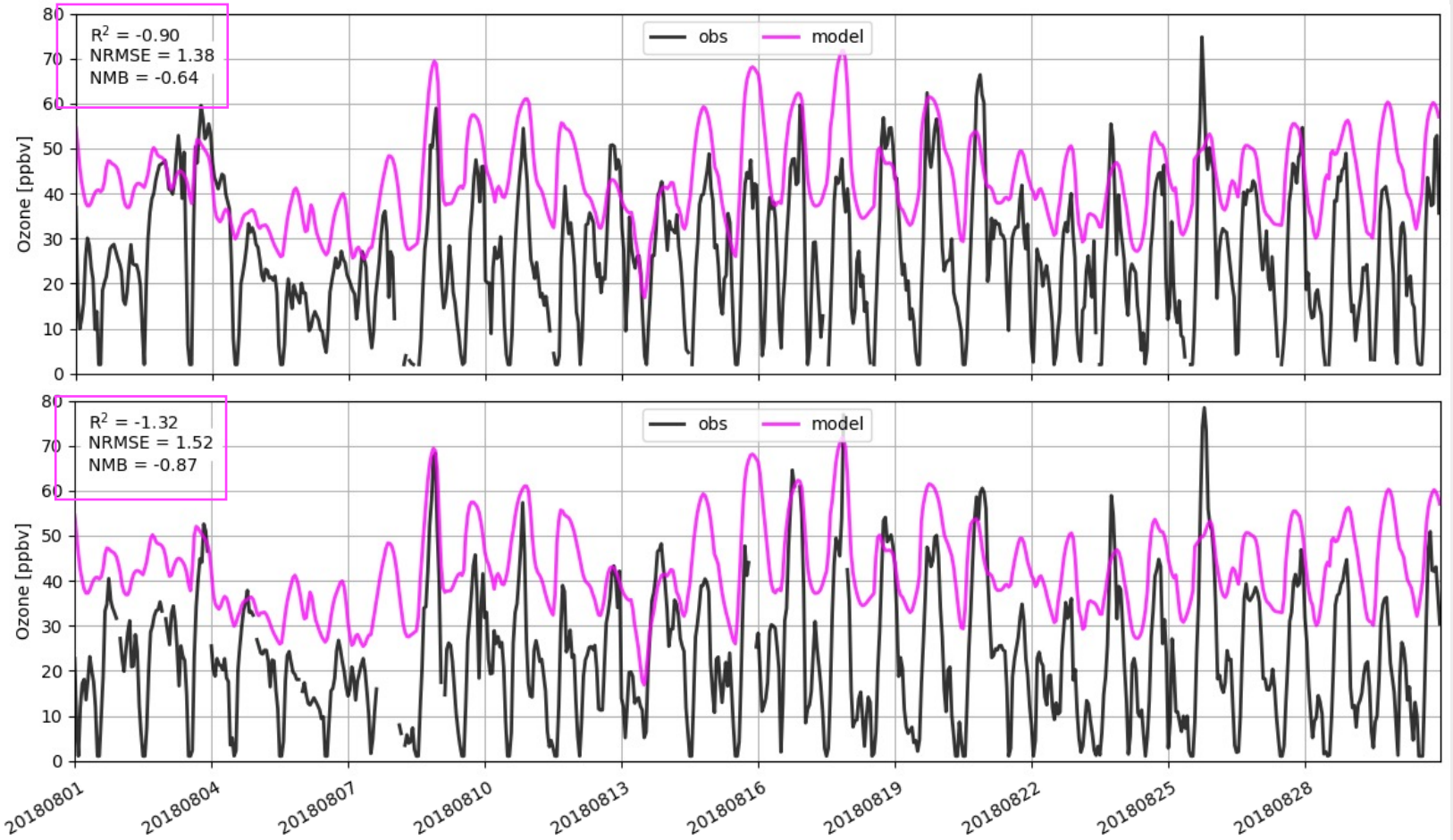
- 1 in one grid box
- 2 share a grid box
- Difficult terrain within each grid box

Improve local forecasts using statistical bias correction



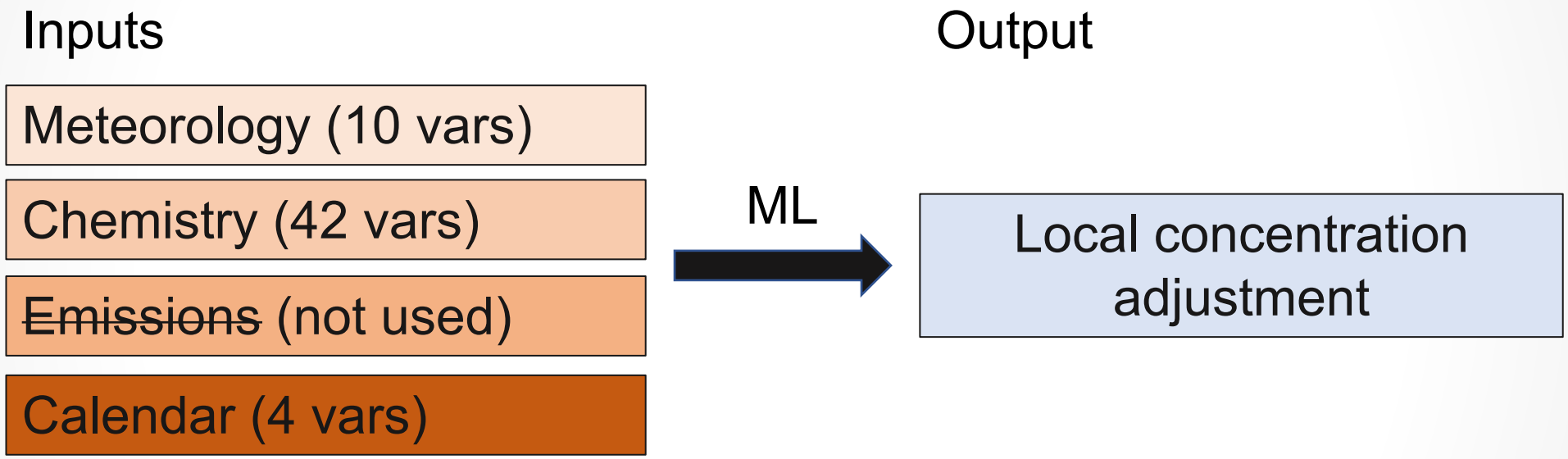
Two observation sites in the same grid box

- GEOS-CF generally over-estimates



Observations Model

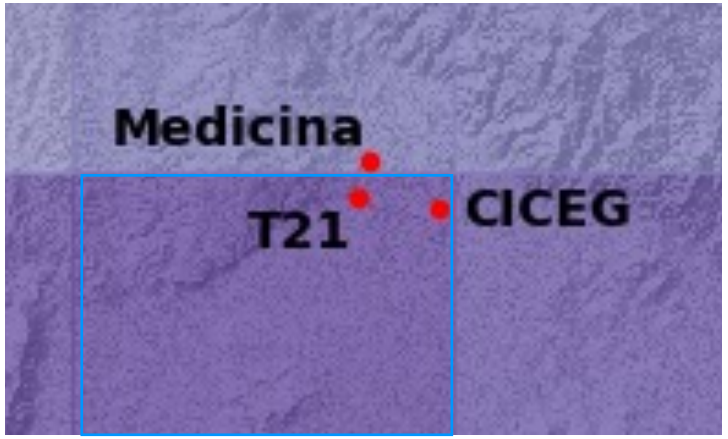
Use machine learning to correct for small scale variability and/or model biases



- Algorithm: gradient boosted decision trees (XGBoost)
- Train separate algorithm for each site

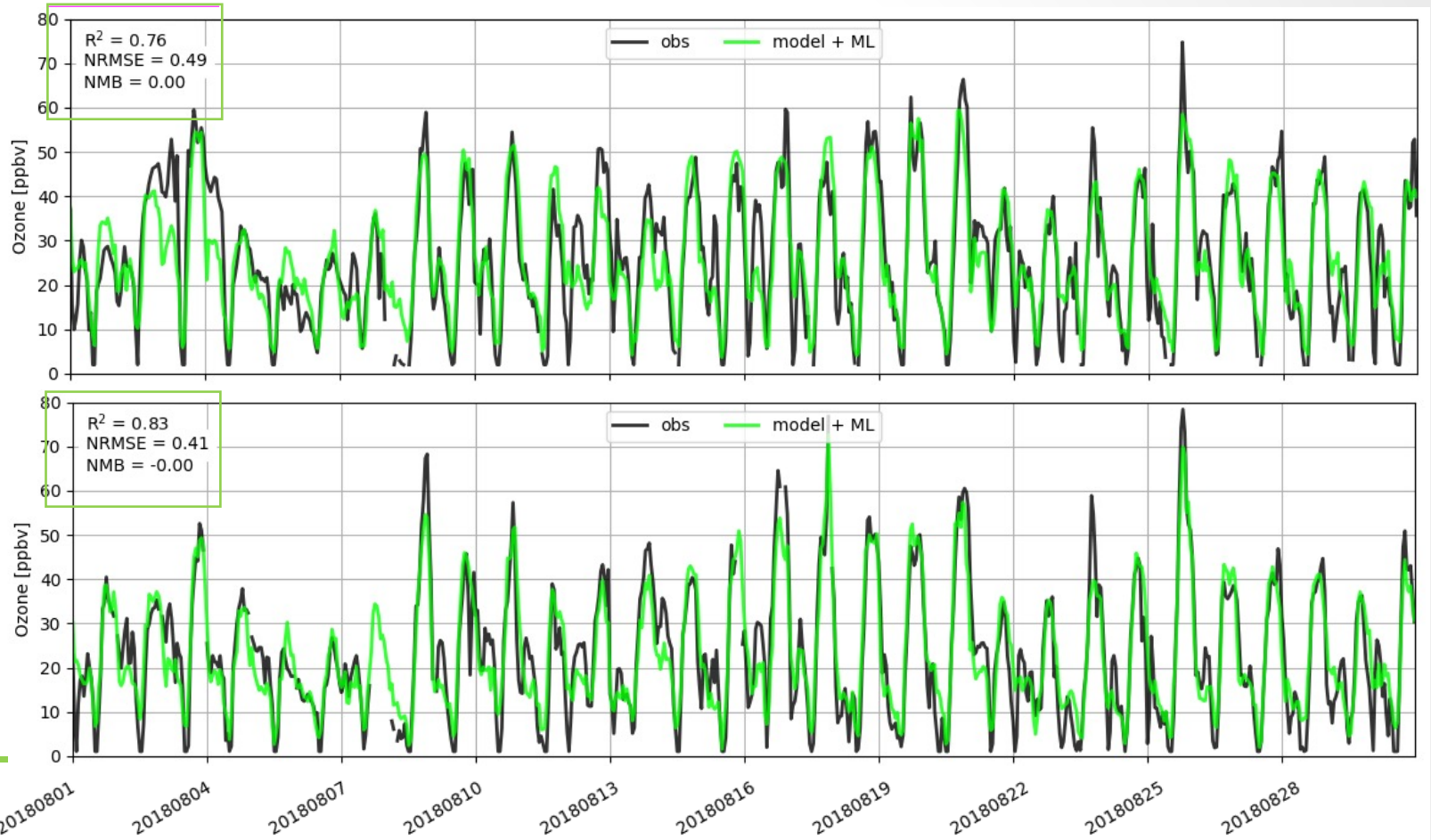
Keller et al., 2021 ACP

Improve local forecasts using statistical bias correction



Two observation sites in the same grid box

- GEOS-CF+ML captures diurnal variability at sub-grid scale



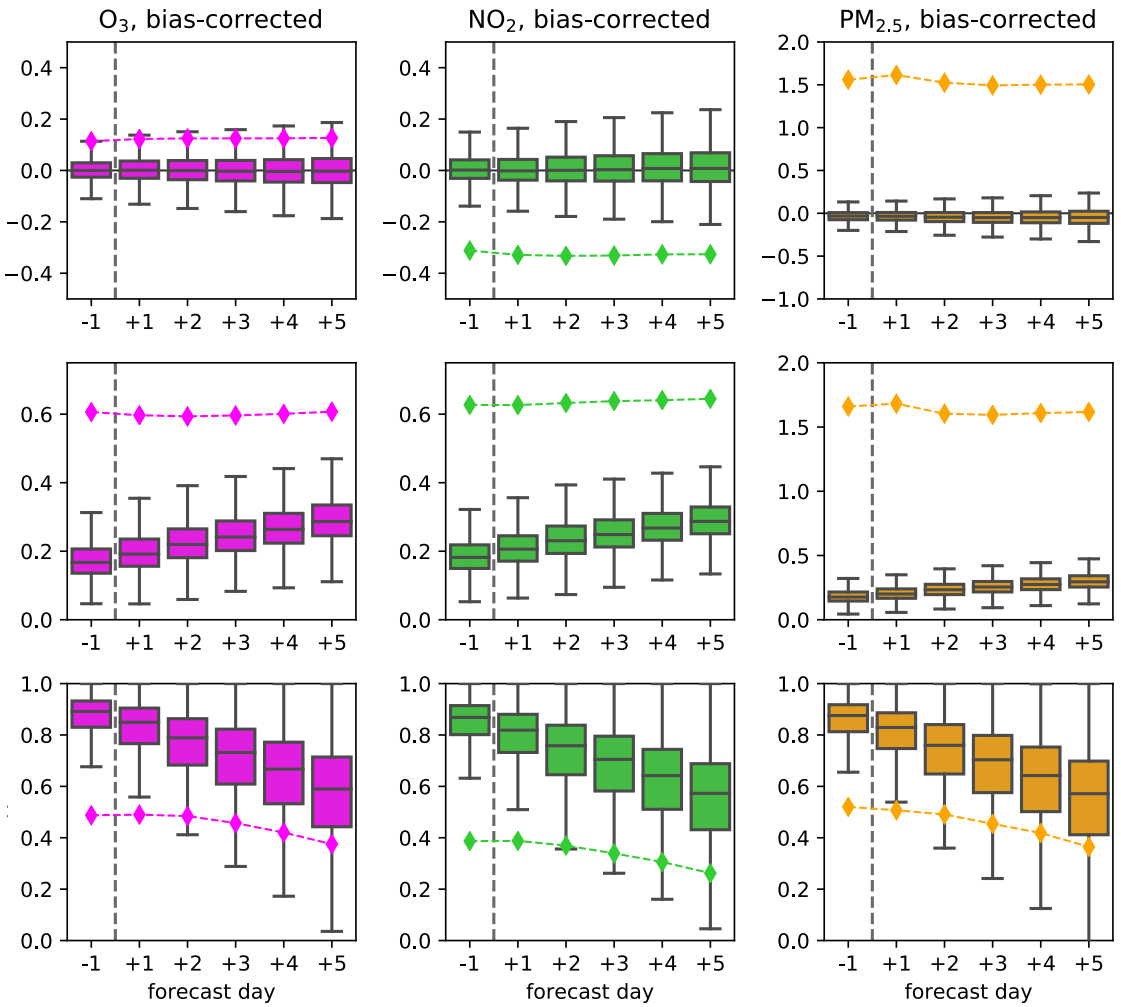
Observations Model + ML

GEOS CF Forecast skill

Normalized Mean Bias (NMB)

Normalized Root Mean Square Error (NRMSE)

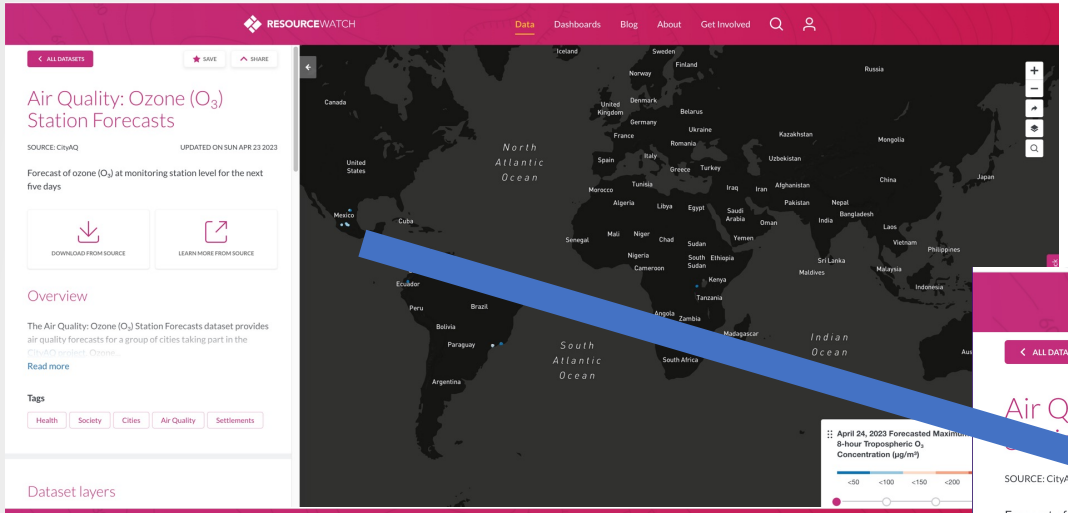
Pearson Correlation Coefficient (R)

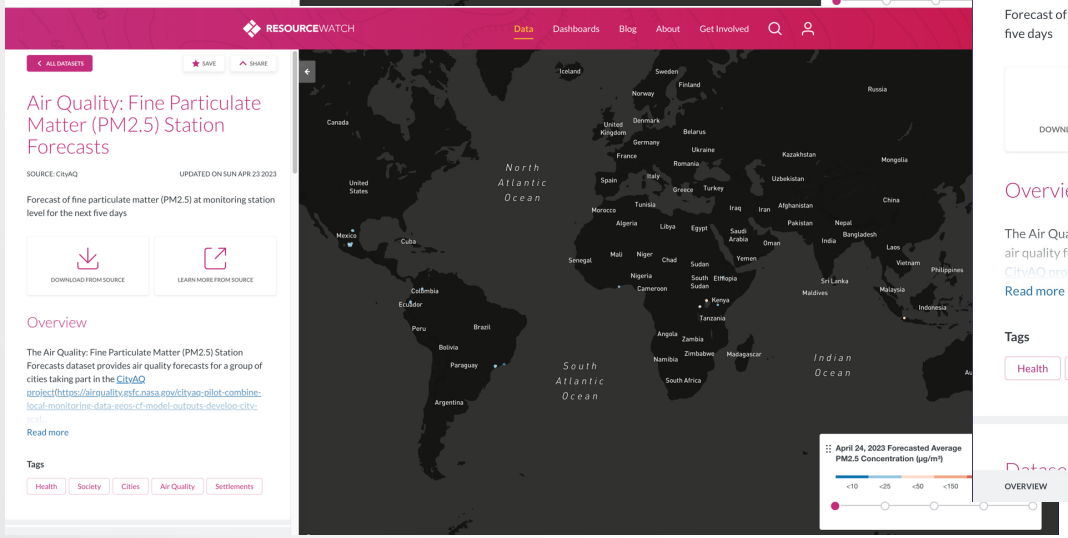


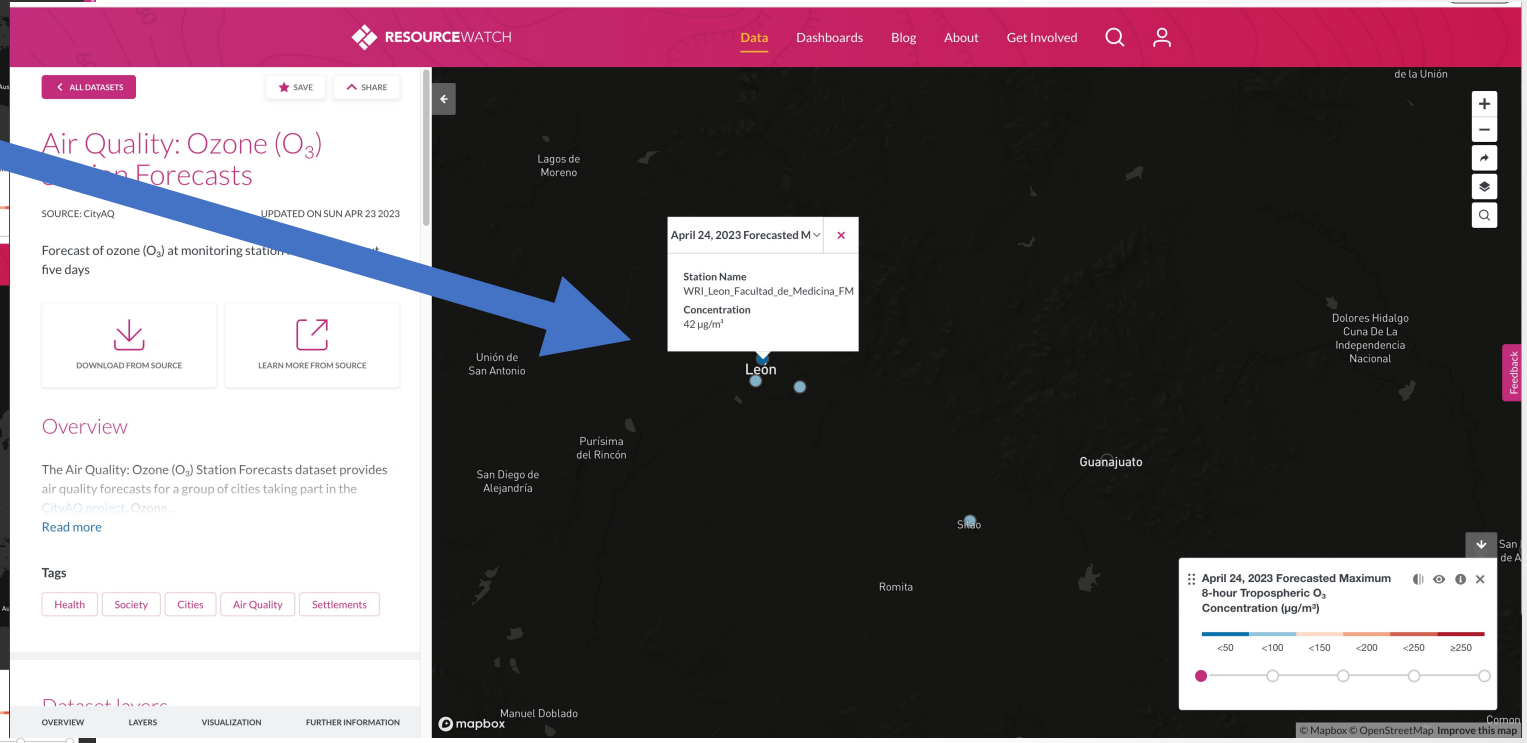
- ✓ Using a Machine Learning (ML) algorithm to calculate bias-correction term for each monitoring site can drastically improve the forecast skill at the individual locations

Keller et al., 2021 JAMES

Share and expand localized forecast capabilities and other downscaling techniques is a priority

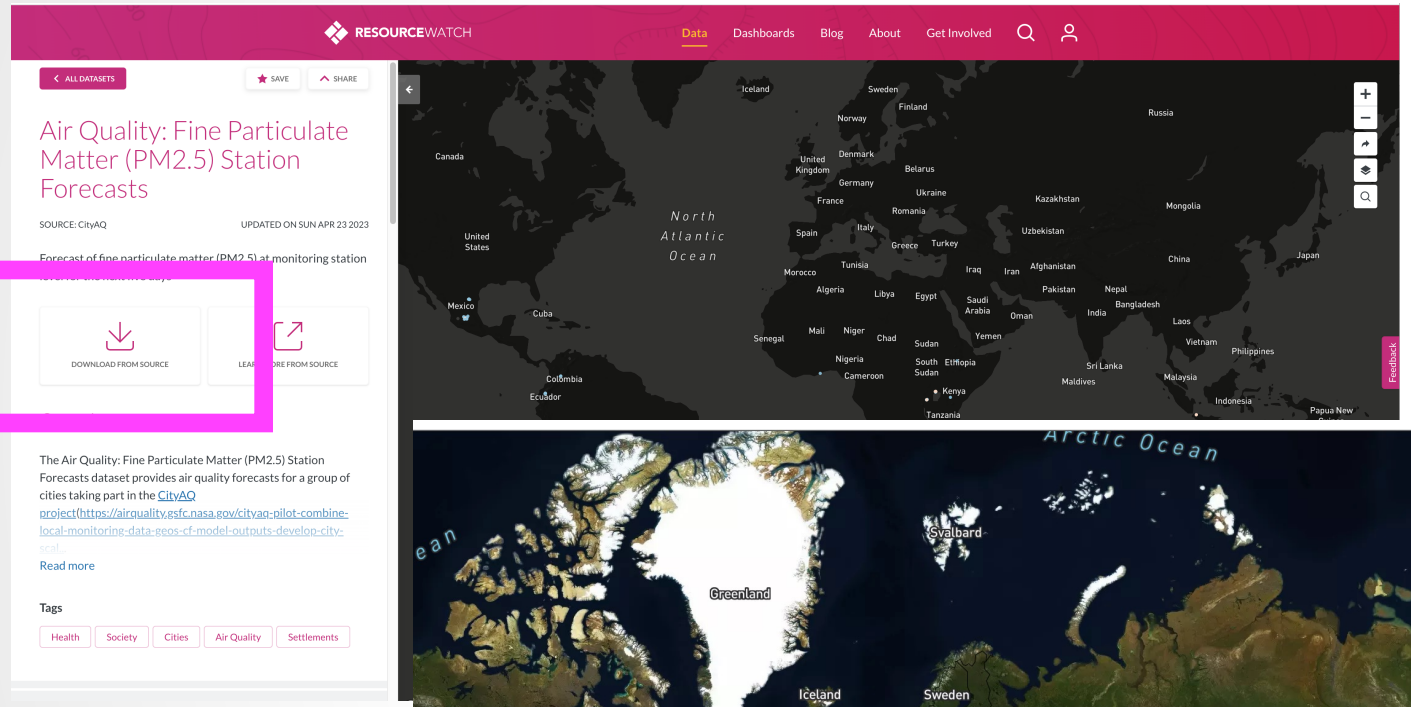


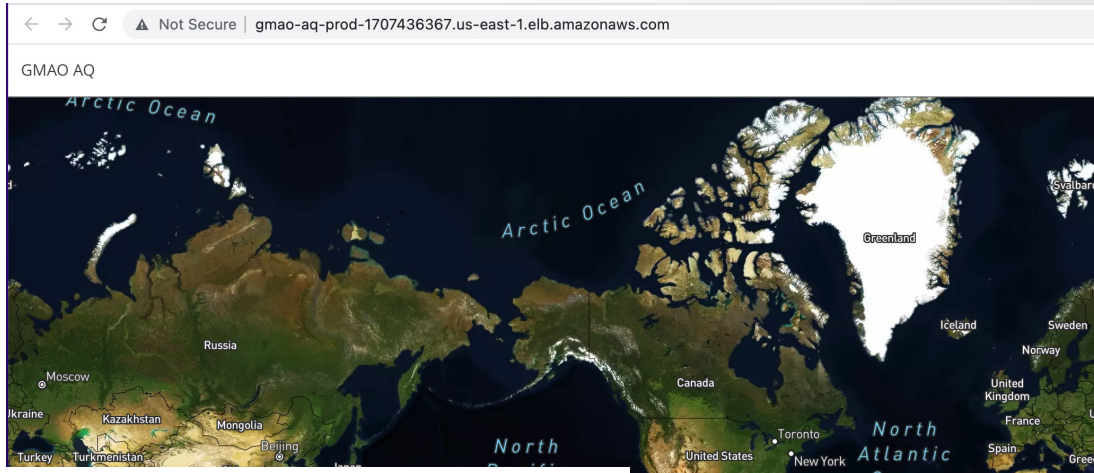


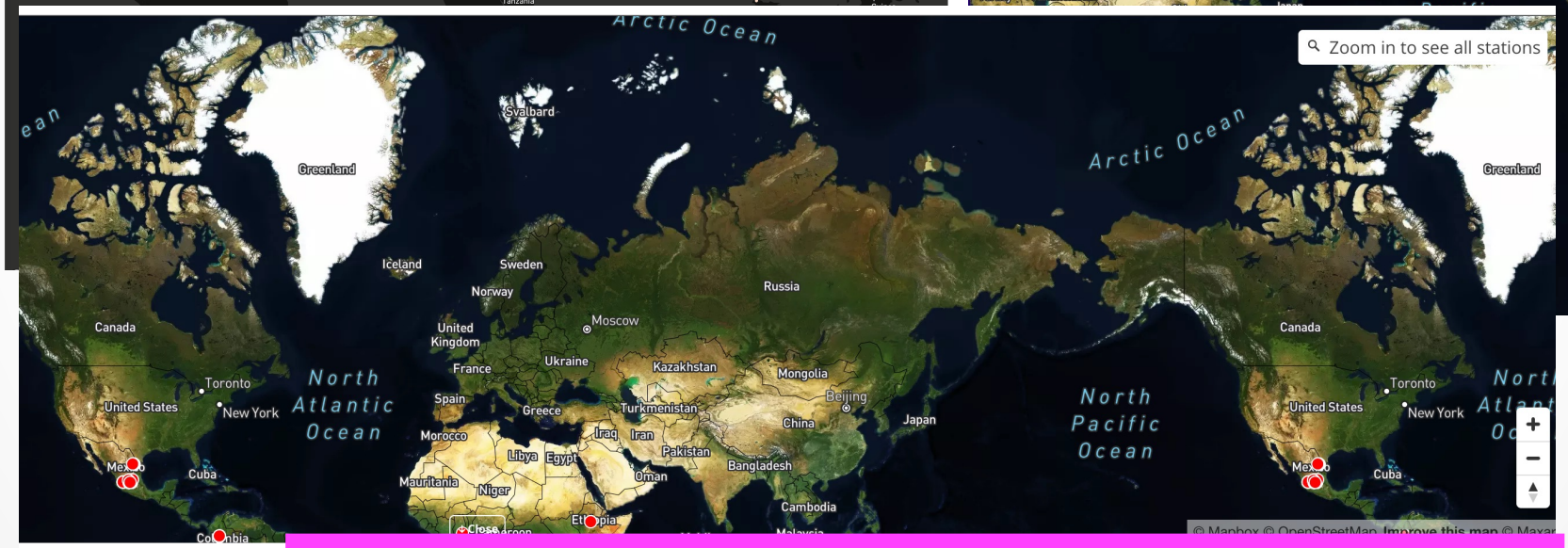


CityAQ: https://www.wri.org/initiatives/cityaq

Share and expand localized forecast capabilities and other downscaling techniques is a priority

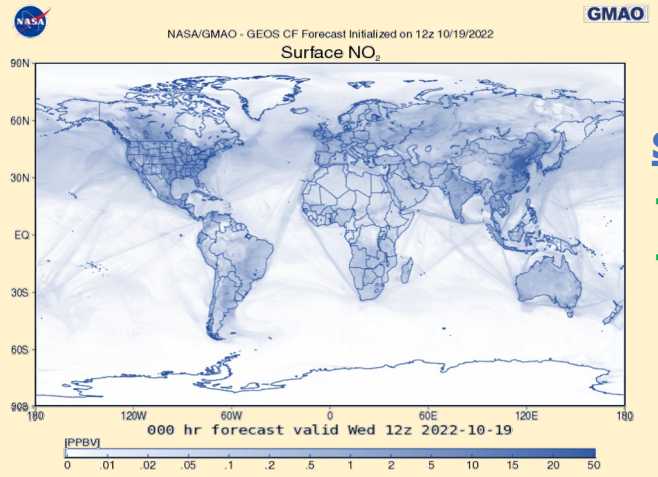








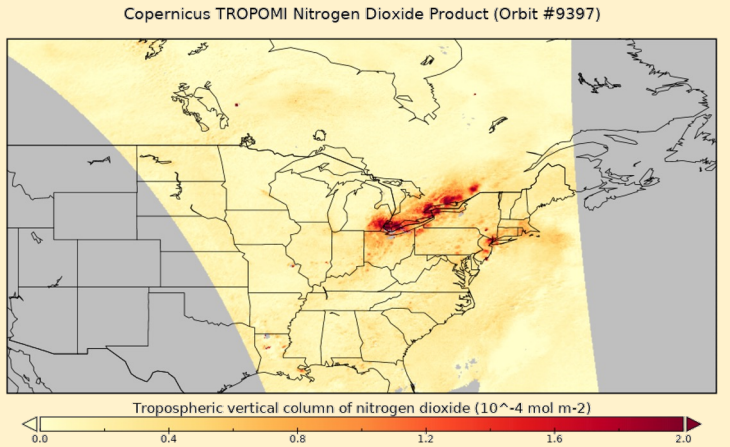
There are many different air quality data sources



Global Data Sources

simulation models
+ global coverage
+ forecasting
- limited resolution
? updated emissions

satellite retrievals
+ global coverage
- low time resolution
- column-integrated
? relevant to surface





regulatory monitoring
+ accurate
- expensive
? representative

low-cost monitoring
+ relatively inexpensive
+ dense/remote deployment
- greater noise and bias
? locally calibrated



Local Data Sources

GMAO Global Modeling and Assimilation Office
gmao.gsfc.nasa.gov
K. Emma Knowland
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GODDARD EARTH SCIENCES

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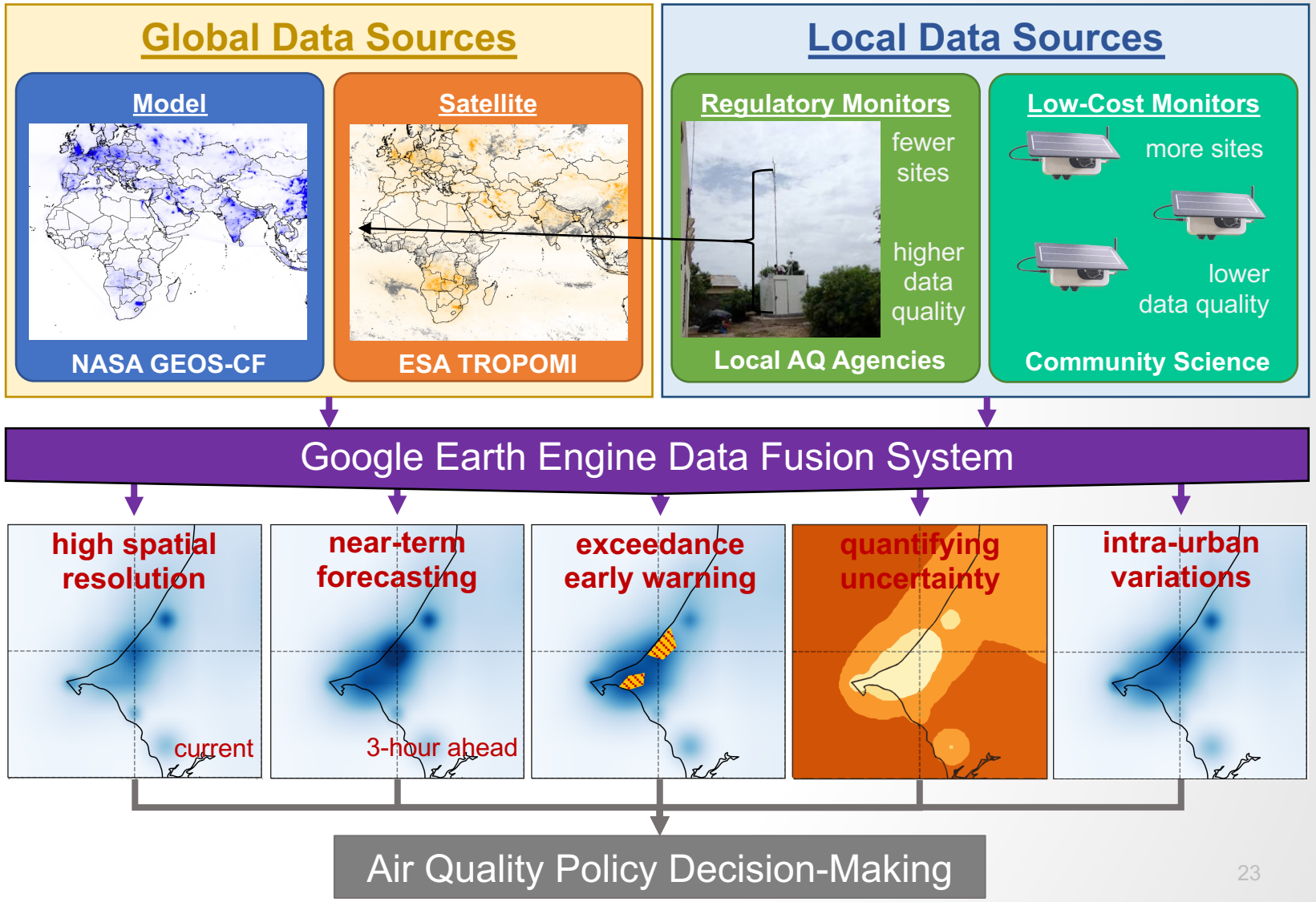
Our project's objective is to…

…integrate diverse **global** and **local** air quality data sources…

…using the cloud computing platform of **Google Earth Engine**…

…to provide synthesized **estimates** and **forecasts** of air quality at a **local scale** but with a **global scope**…

…which will be freely accessible by air quality managers worldwide, facilitating their **decision-making** processes.



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Project Scheme and Partners

NASA GMAO: basic algorithm development & refinement

Clarity: low-cost sensor integration

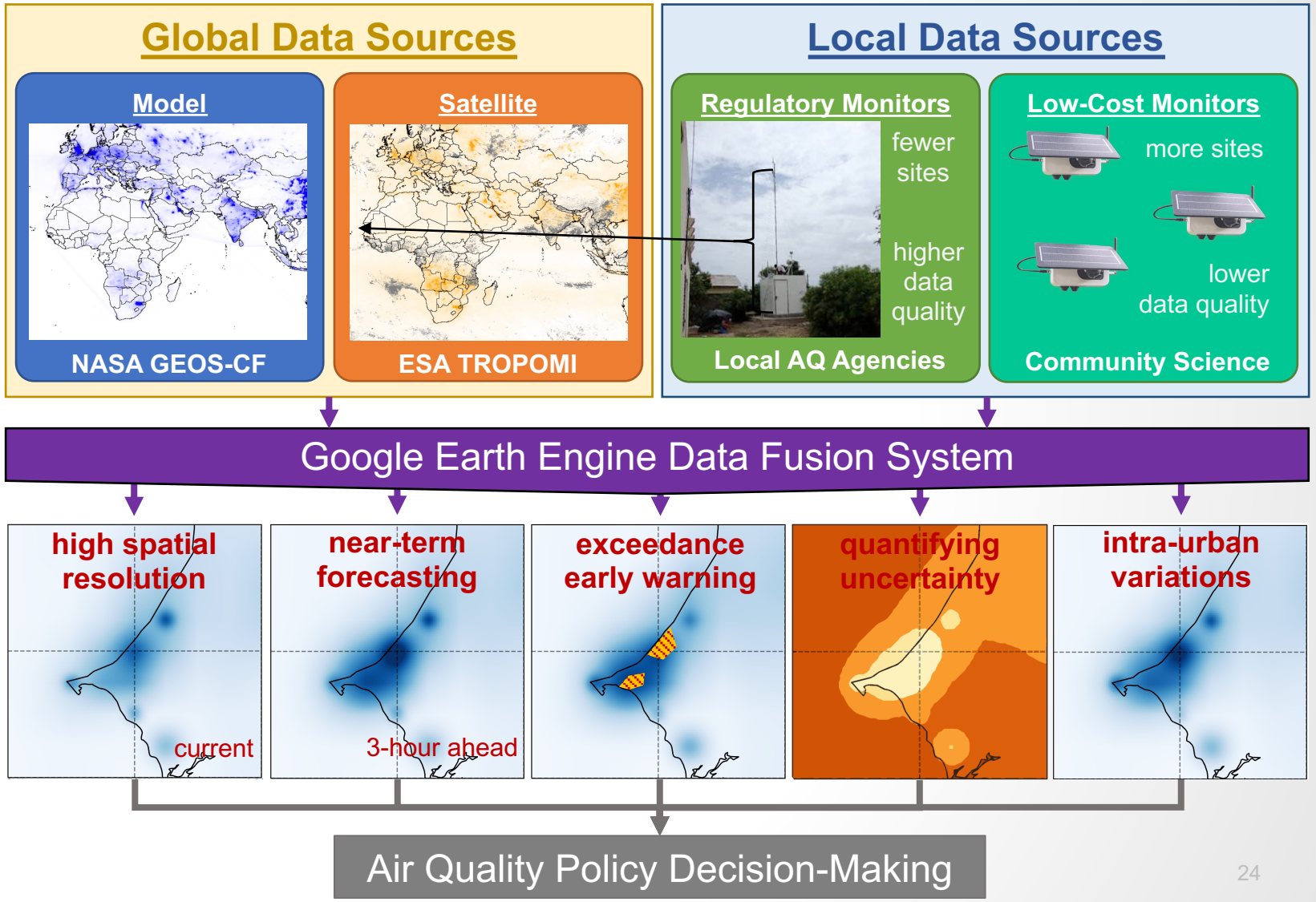
Sonoma Technologies: data fusion system implementation & user interface

WUSTL: air quality data integration expertise (monthly/annual timescales)

Columbia LDEO: experience training end-users in AQ data interpretation

UNEP: integration with global end-users
- Dakar, Senegal
- Rio de Janeiro, Brazil

US EPA: integration with US end-users
- Portland, OR
- Denver & Boulder, CO
- Gulfport, MS
- Charleston, WV

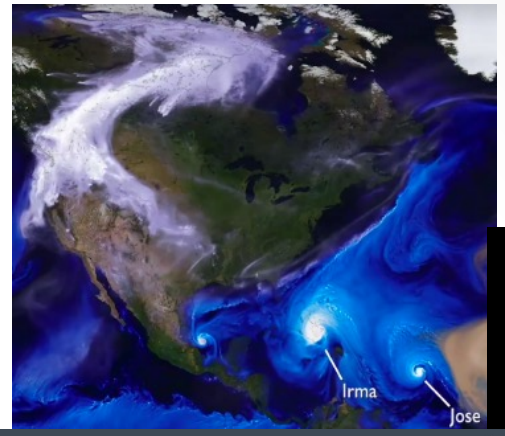


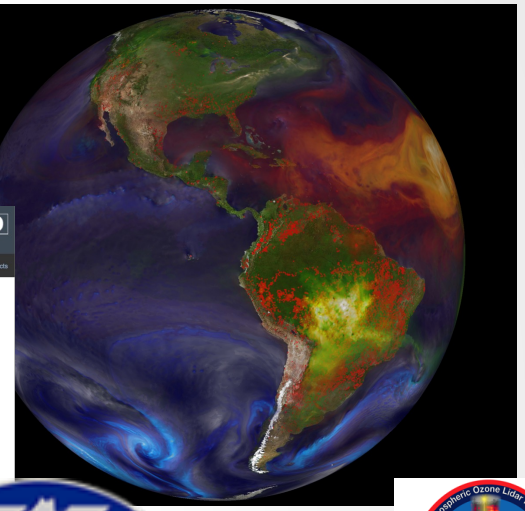
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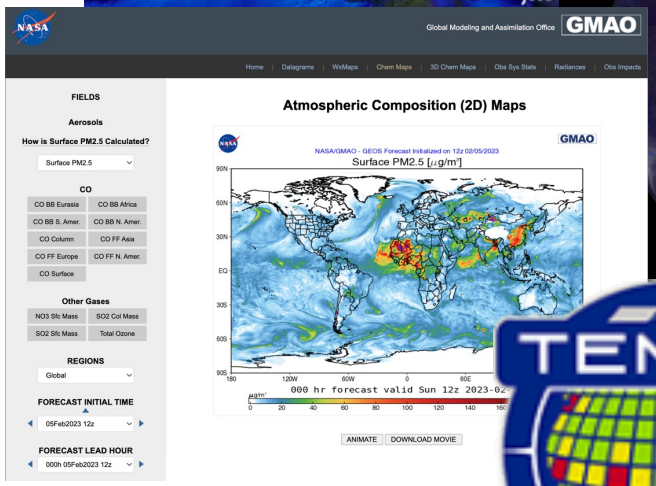
Summary

- GMAO has a state-of-the-science Earth System model and data assimilation system
- GMAO products are available to the public with file formats for both scientists and air quality managers to use.
- NASA products are research products
- Expanding our capability to provide downscaled bias-corrected and data-constrained forecasts is a priority
- We want to hear from you so we can make our products as useful as possible!

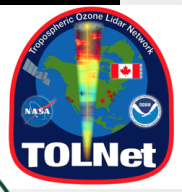
Thank you for listening!



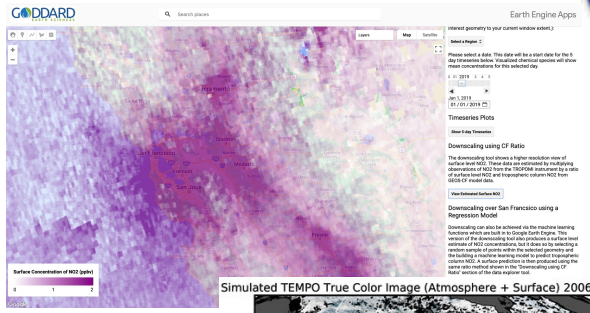


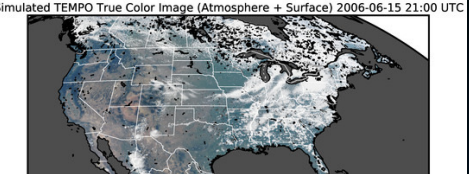


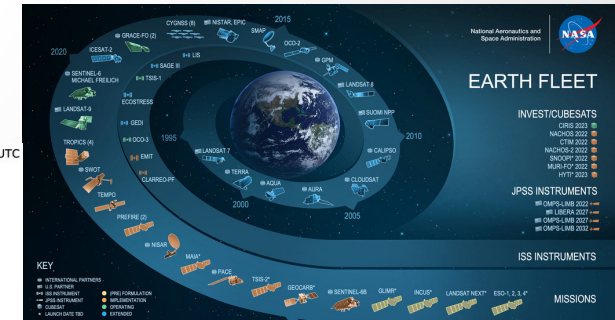












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