National Aeronautics and Space Administration

NASA GEOS model and data assimilation system for atmospheric composition

K. Emma Knowland

Morgan State University/GESTAR-II

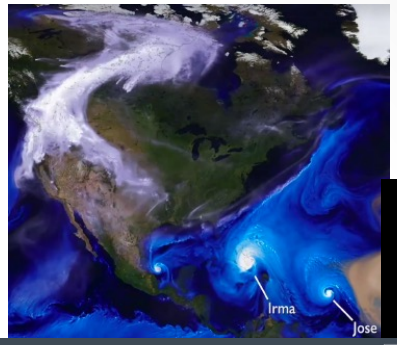
NASA Global Modeling and Assimilation Office (GMAO)

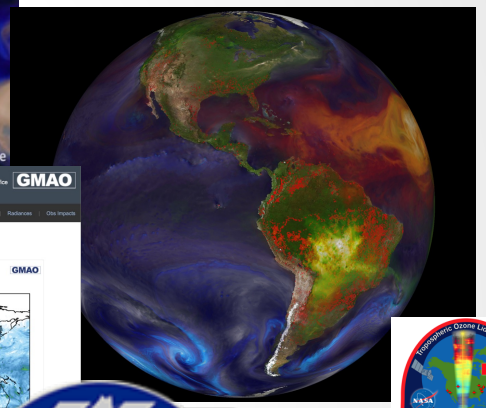
In collaboration with many scientists from GMAO and other labs at NASA Goddard Space Flight Center

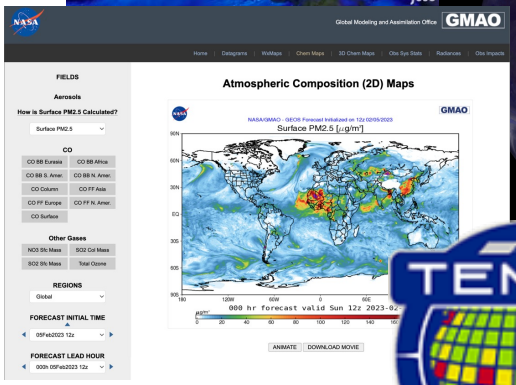
National Aeronautics and Space Administration

OUTLINE

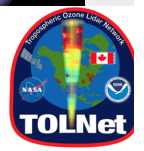
1. Overview of GEOS current capabilities
   - Numerical Weather Prediction
   - Aerosol and Constituent data assimilation systems
   - Composition Forecasting
2. How to access GEOS “big data” for research scientists and engaged community members
3. Applications
4. Updates to the GEOS Composition Forecast
5. Future Direction

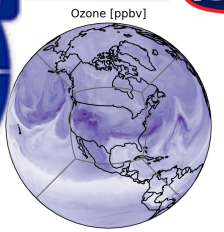


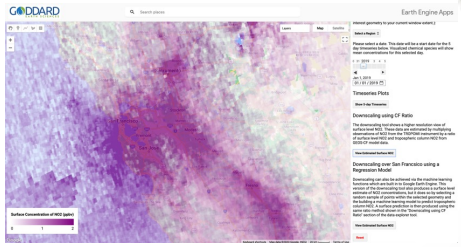


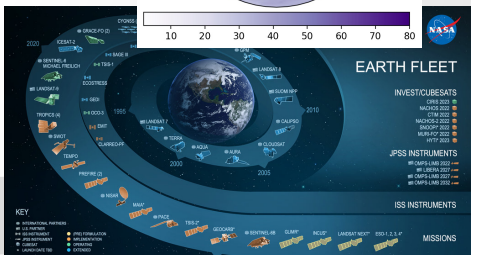












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GMAO's core mission is to enhance the value of NASA's observations to understand, analyze and predict changes in the physics, chemistry and biology of the Earth system

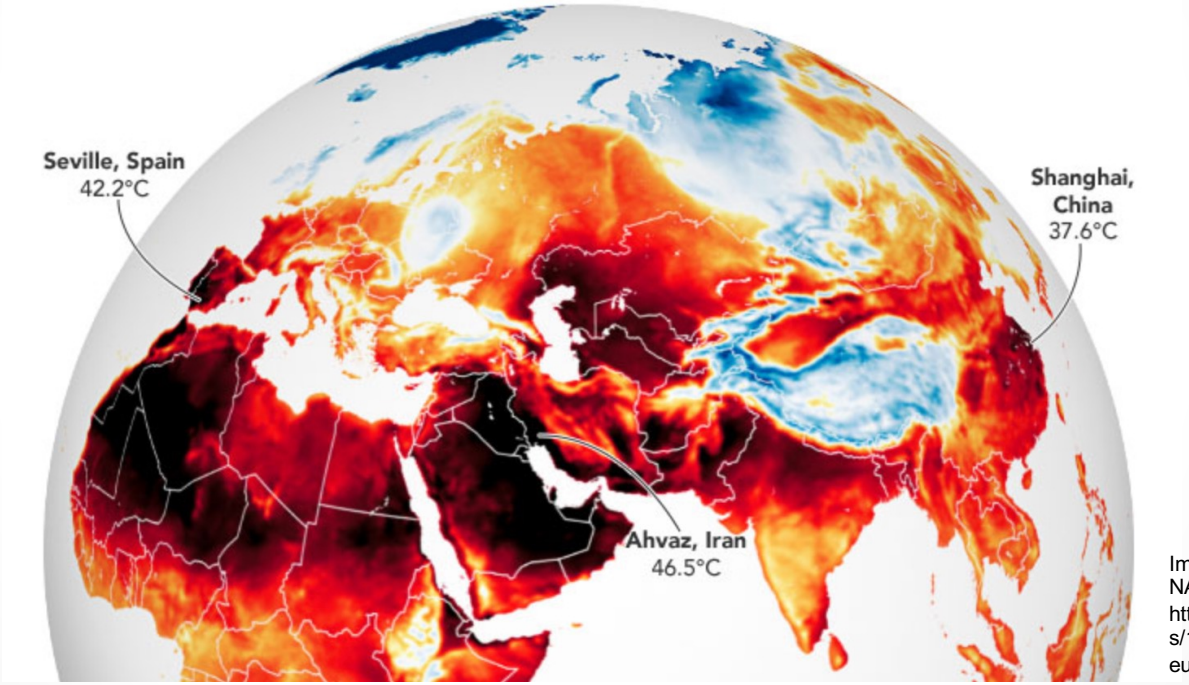
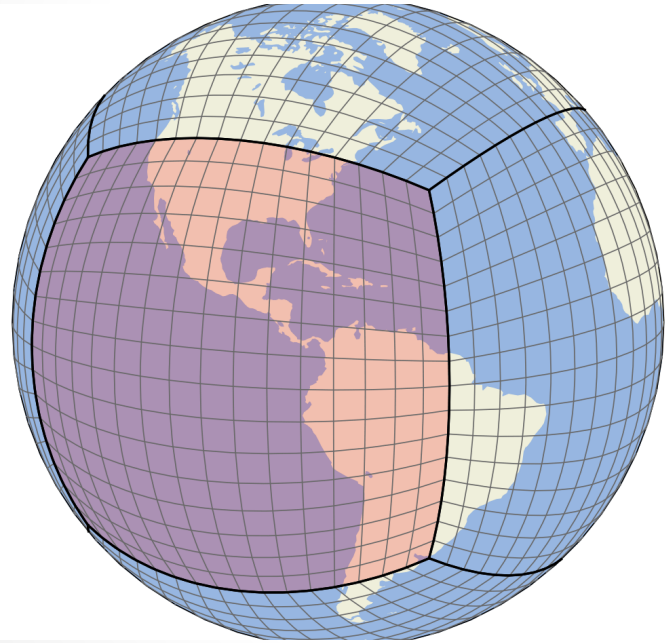


Image by Joshua Stevens,
NASA Earth Observatory
https://earthobservatory.nasa.gov/images/150083/heatwaves-and-fires-scorch-europe-africa-and-asia

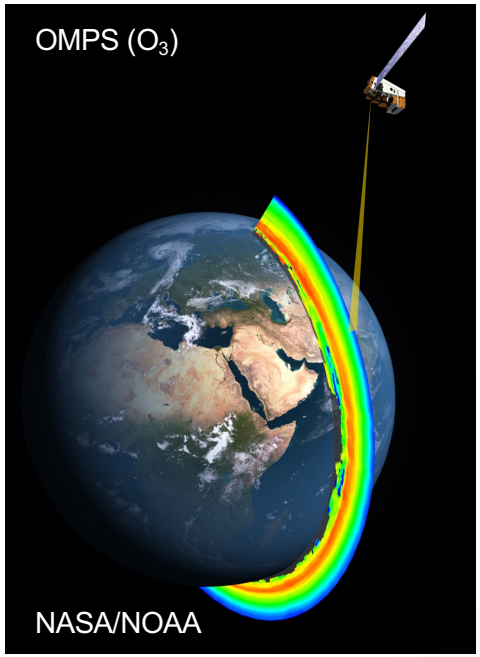
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NASA GMAO global meteorology and chemistry products

GEOS



Bindle et al., 2021 GMD



www.nasa.gov

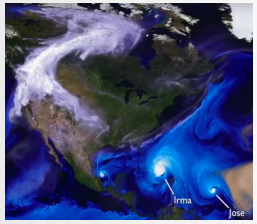
NASA GMAO global meteorology and chemistry products

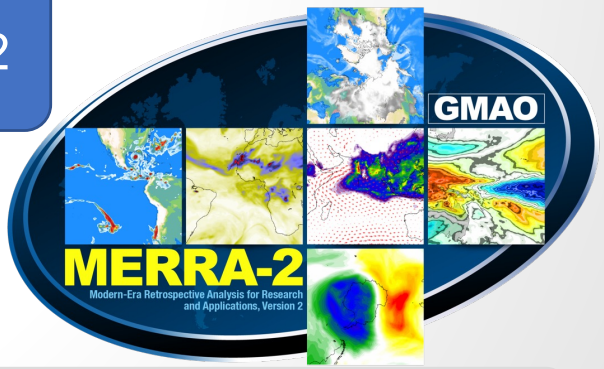
GEOS

Forecasting

Reanalysis

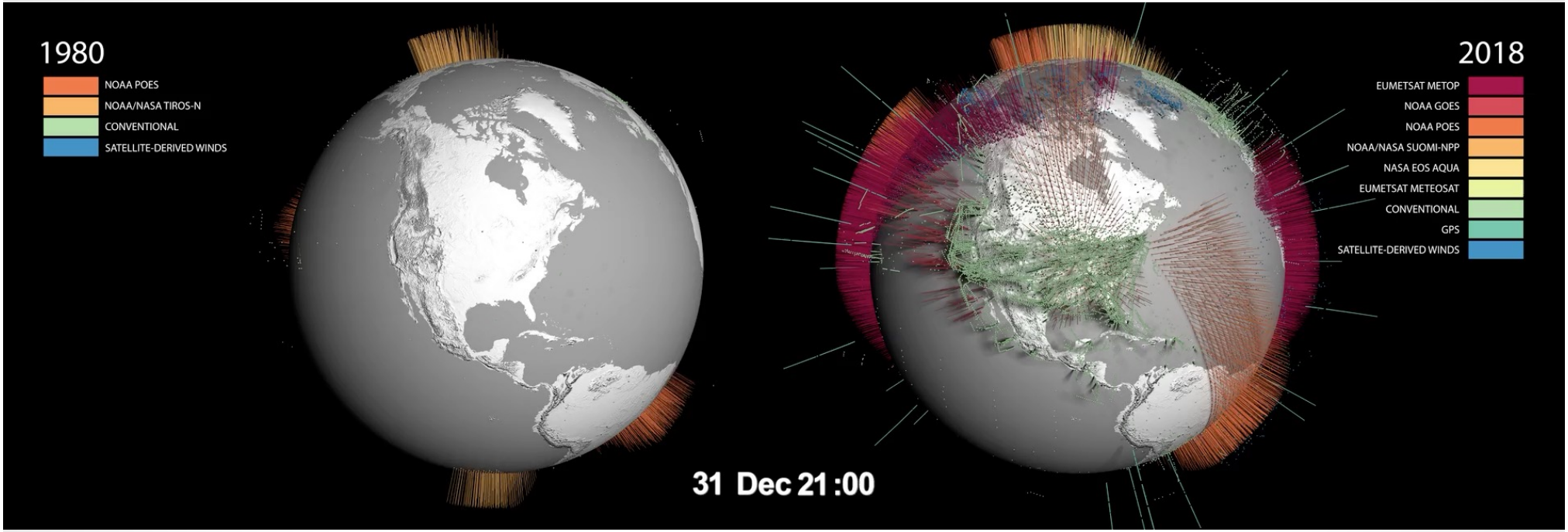
MERRA-2





National Aeronautics and Space Administration

Changes to the observing system



https://svs.gsfc.nasa.gov/4654

NASA GMAO global meteorology and chemistry products

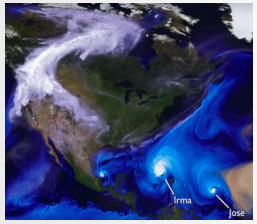
GEOS

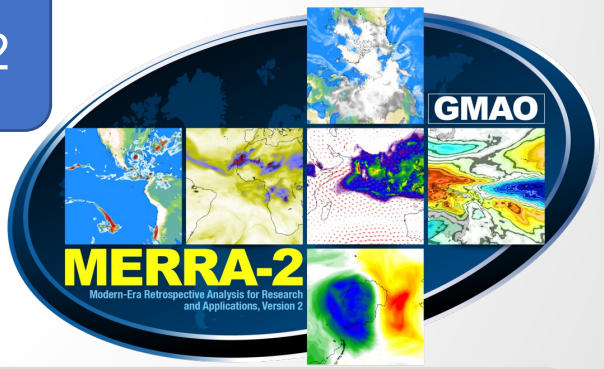
Forecasting

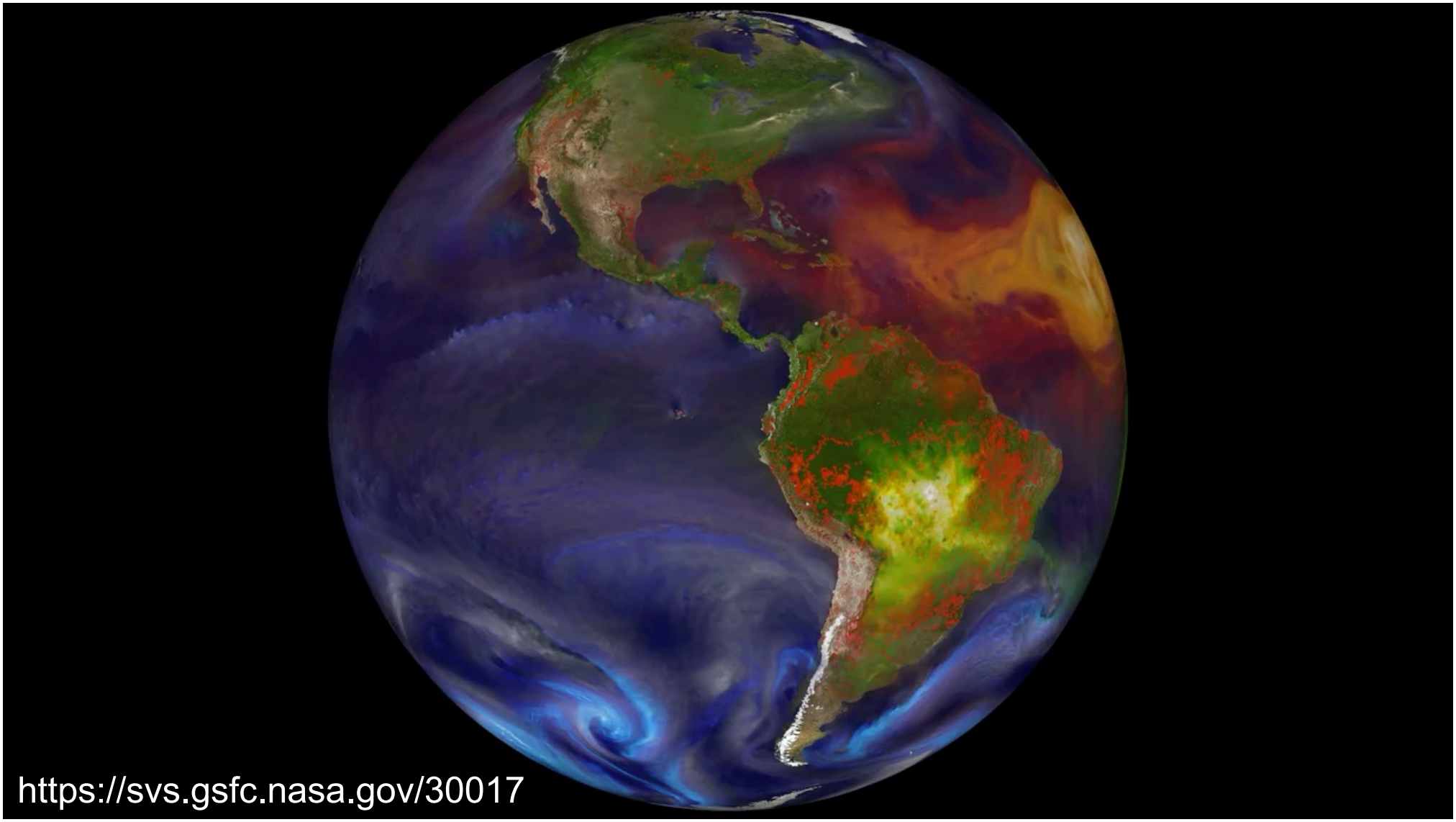
Reanalysis

GEOS FP

MERRA-2






https://svs.gsfc.nasa.gov/30017

NASA GMAO global meteorology and chemistry products

GEOS

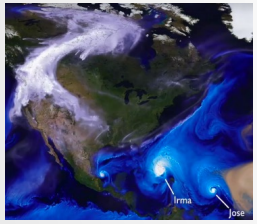
Forecasting

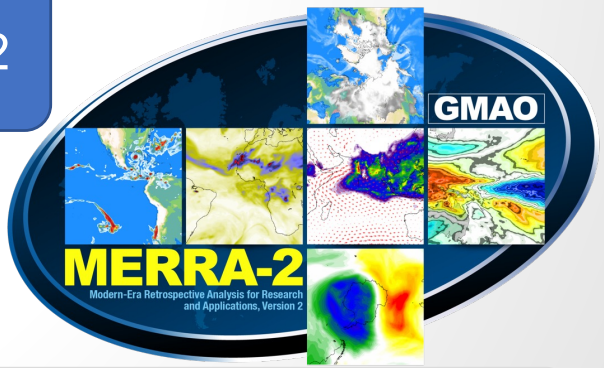
Reanalysis

GEOS FP

GEOS-CF

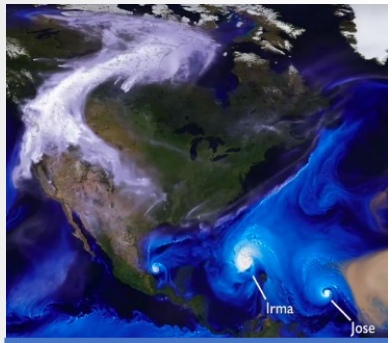
MERRA-2



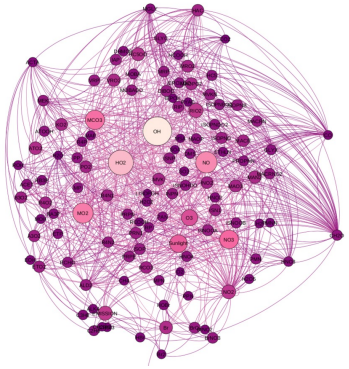


GEOS-CF produces daily global forecasts of atmospheric composition at 0.25° resolution

National Aeronautics and Space Administration

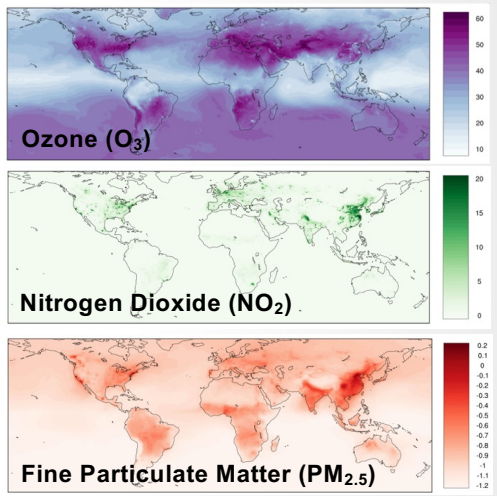


GEOS NWP



GEOS-Chem

GEOS - CF



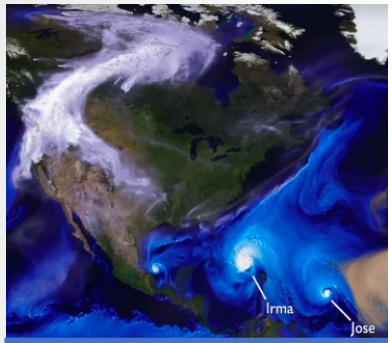
Version 12

Tropospheric and Stratospheric chemistry

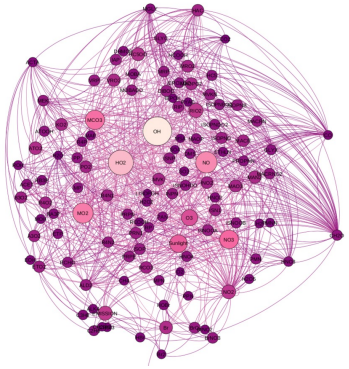
- 250 Chemical Species
- 725 Chemical Reactions

GEOS-CF produces daily global forecasts of atmospheric composition at 0.25° resolution

National Aeronautics and Space Administration

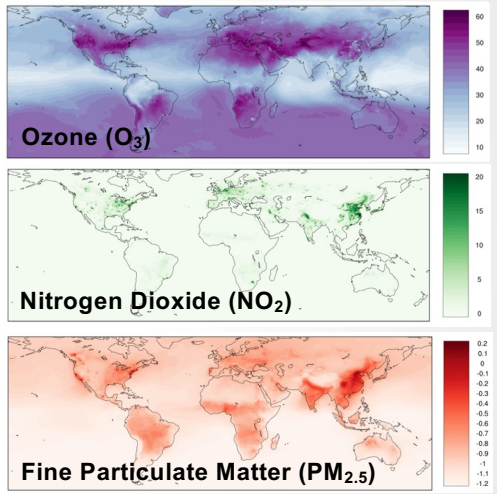


GEOS NWP



GEOS-Chem

GEOS - CF

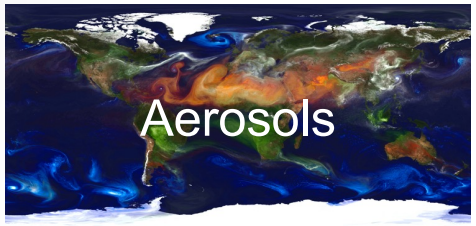


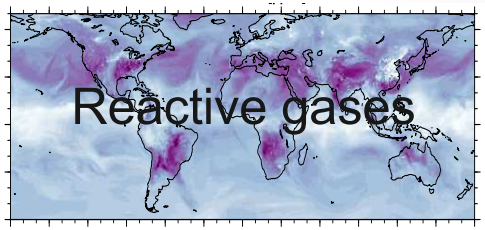
Daily GEOS-CF global 5-day composition forecasts at 0.25° (25km) resolution are generated in near-real time available since January 2018

Keller, C. A., et al. (2021). **Description of the NASA GEOS composition forecast modeling system GEOS-CF v1.0**. *Journal of Advances in Modeling Earth Systems*, 13, e2020MS002413. https://doi.org/10.1029/2020MS002413

Knowland, K. E., et al. (2022). **NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0: Stratospheric Composition.** *JAMES* https://doi.org/10.1029/2021MS002852

Aerosol and Gas Phase Chemistry



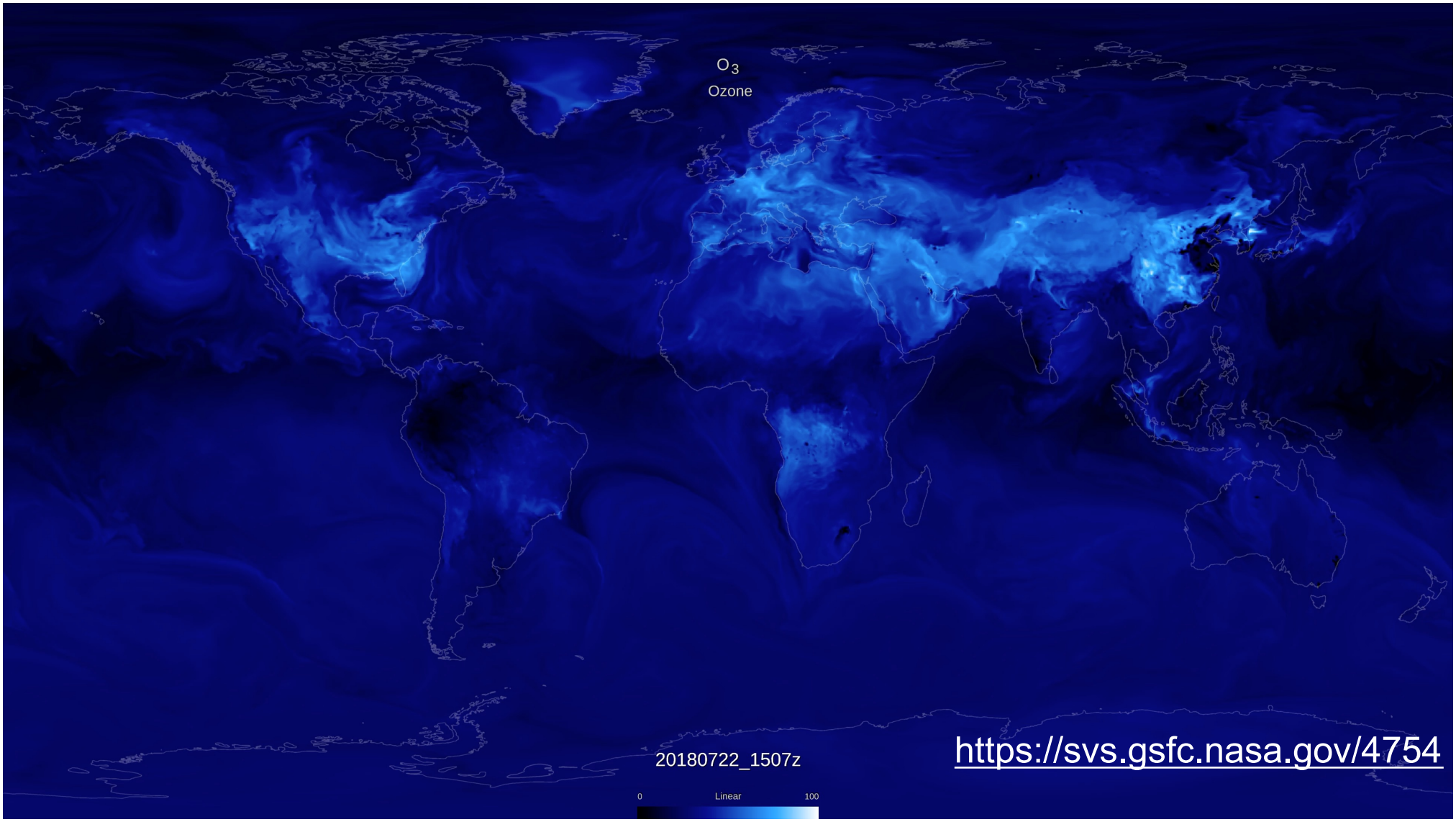


- Particulate matter:
  - Carbon
  - Sea salt
  - Dust
  - Sulfate
  - Nitrates
  - (Secondary Organics)

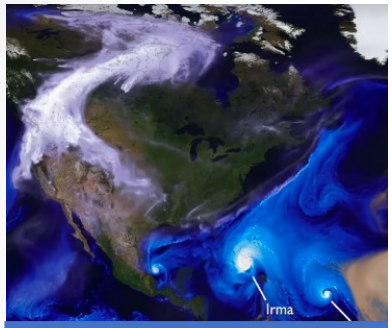
- Ozone (O_3)
- Nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Volatile organic compounds (VOCs):
  - Formaldehyde
  - Benzene / Toluene
  - And many more!

GOCART

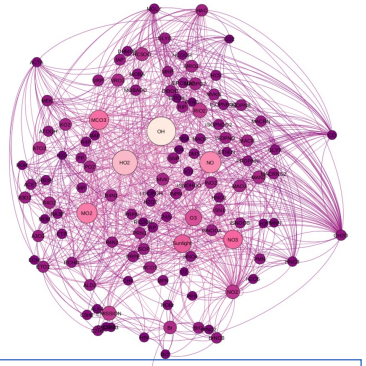
GEOS-Chem


O_3
Ozone
20180722_1507z
0
Linear
100
https://svs.gsfc.nasa.gov/4754

Daily composition forecast



GEOS NWP

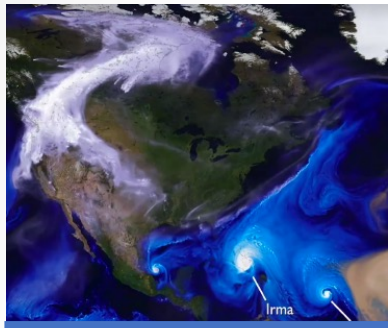


GEOS-Chem

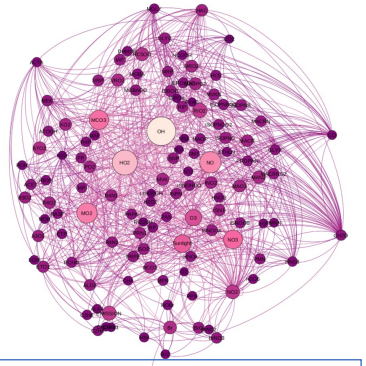
GEOS - CF

One **5-day forecast** per day

Daily composition forecast



GEOS NWP



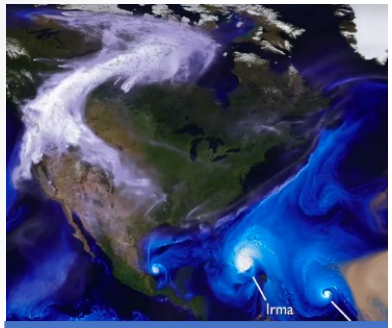
GEOS-Chem

GEOS - CF

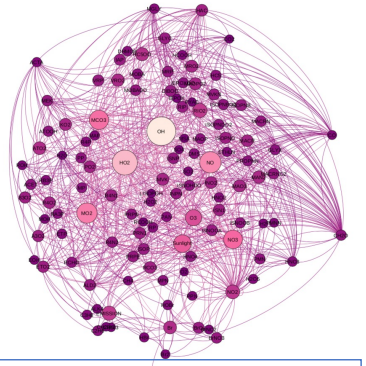
One **5-day forecast** per day

- 1-day meteorological replay "analysis"
- 5-day forecast

Daily composition forecast



GEOS NWP



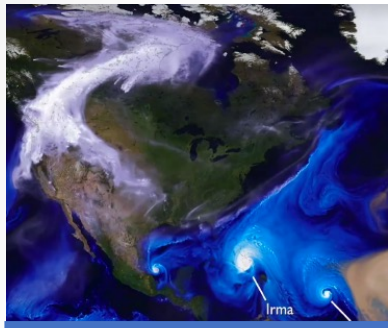
GEOS-Chem

GEOS - CF

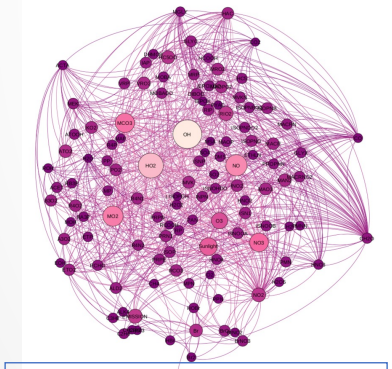
One **5-day forecast** per day

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

Daily composition forecast



GEOS NWP



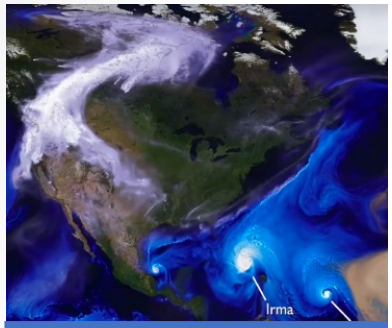
GEOS-Chem

GEOS - CF

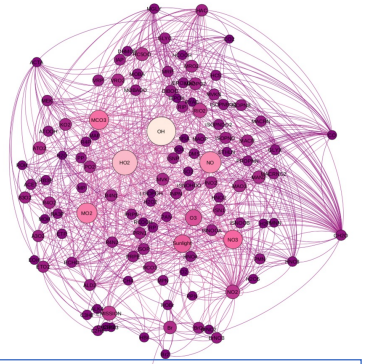
One **5-day forecast** per day

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

Daily composition forecast



GEOS NWP



GEOS-Chem

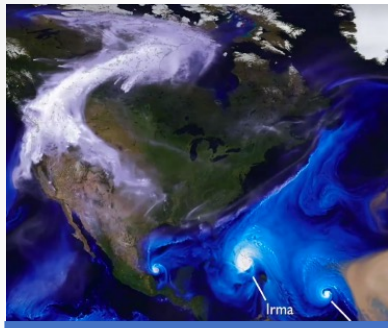
GEOS - CF

One **5-day forecast** per day

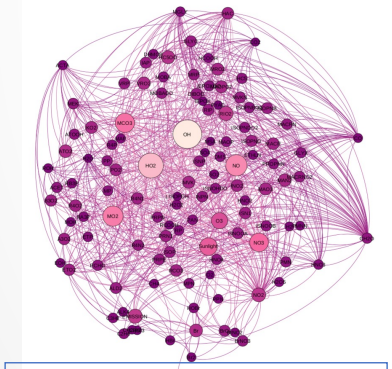
- 1-day replay
- 5-day forecast
- c360 (0.25°, ~25x25 km^2)
- **15 minute** "surface"
- **1-hour** average and instantaneous 2D & 3D

Daily composition forecast

National Aeronautics and Space Administration



GEOS NWP



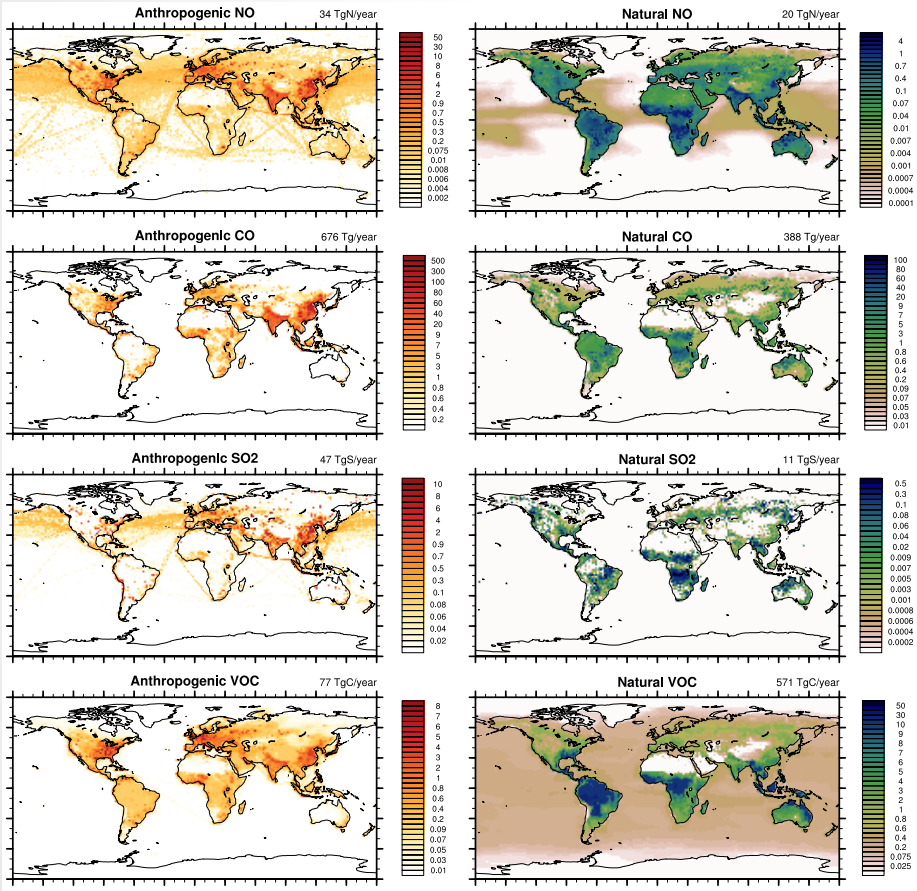
GEOS-Chem

GEOS - CF

One **5-day forecast** per day

- 1-day replay
- 5-day forecast
- c360 (0.25°, ~25x25 km^2)
- **Available since**
  - **1 January 2018** (replay)
  - **1 January 2019** (forecast)

GEOS-Chem emissions



Anthropogenic: HTAP, RETRO, DICE (Africa), AEIC (aircraft)

Biomass burning: QFED NRT

Biogenic: Megan 2.1

Lightning: online (Murray et al., 2012)

Soil NOx: online (Hudman et al. 2012)

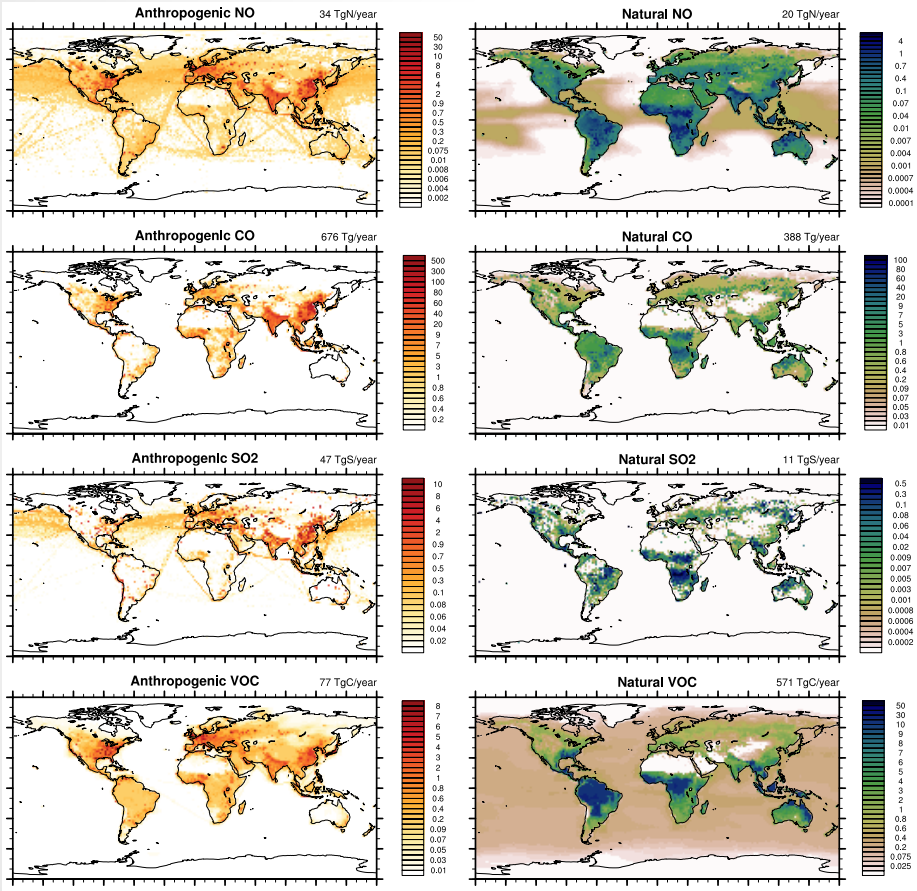
Dust: online (Zender et al. 2003)

Sea salt: online (Jaegle et al., 2011)

Ocean: online: sea salt, DMS, acetone, acetaldehyde, HOI, I_2

Prescribed: CFCs, VSLS, CH_4, CO_2

GEOS-Chem emissions

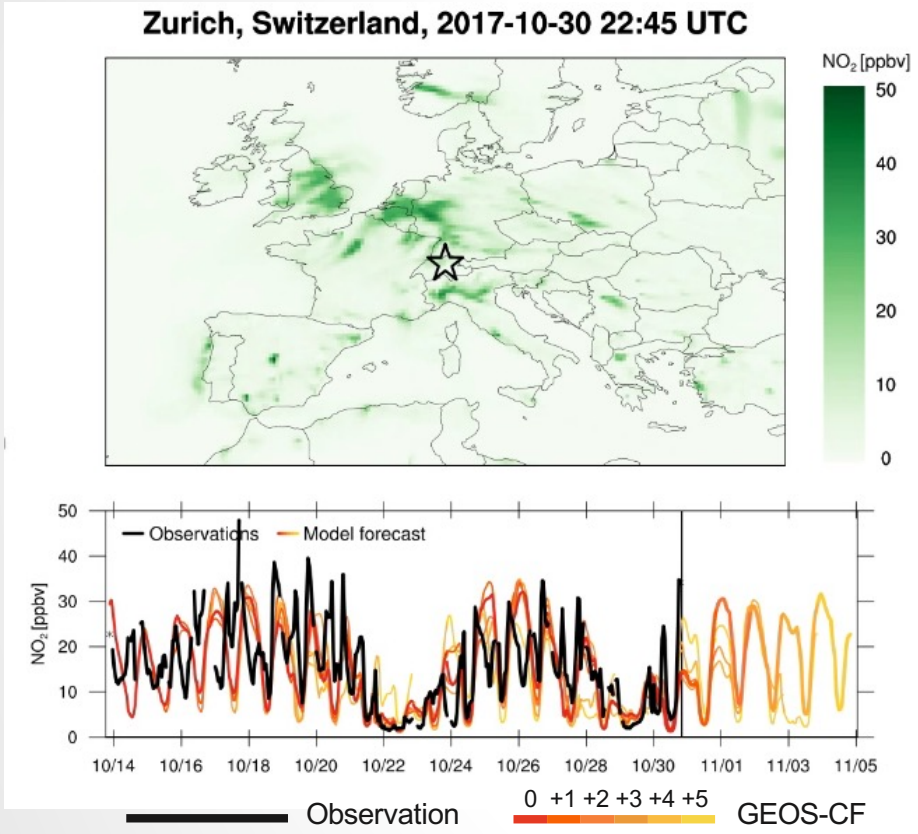


Anthropogenic: HTAP, RETRO, DICE (Africa), AEIC (aircraft)

Biomass burning: QFED NRT

- Annual gridded scale factors based on satellite data are applied to the emissions of CO (Oda et al., 2017) and SO_2 (Liu et al., 2018).
- "Business-as-usual" assumed for 2020 (and other pandemic years)
- 35% of fire emissions emitted above boundary layer (Fischer et al., 2014)

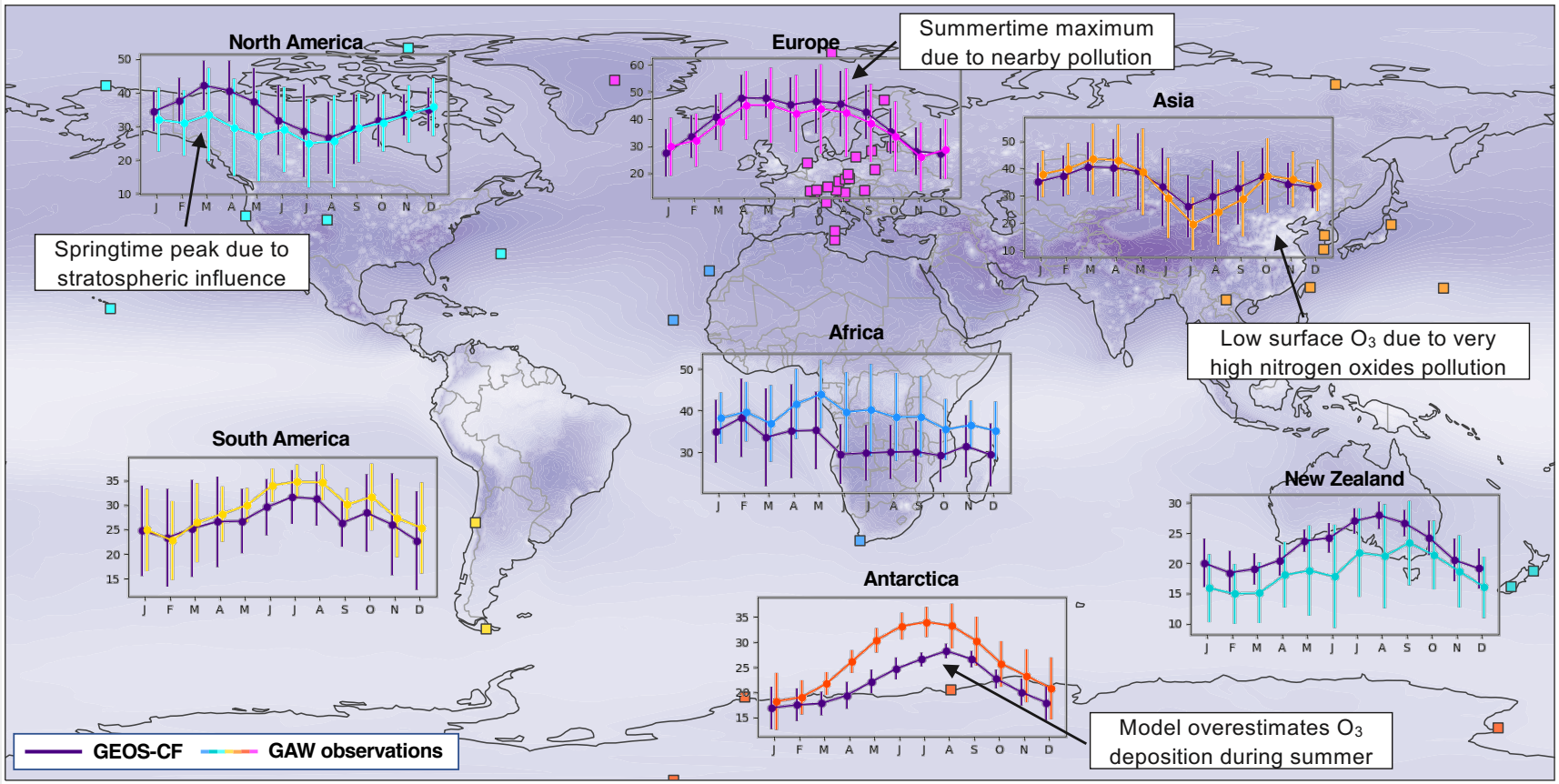
Daily variations of emissions



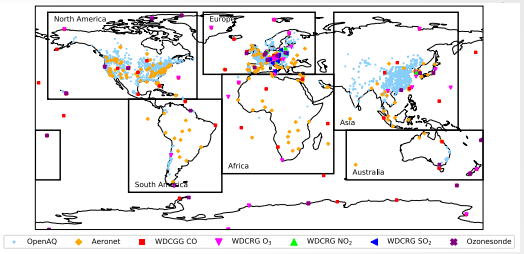
Scale factors applied to emissions for diurnal and weekly variations

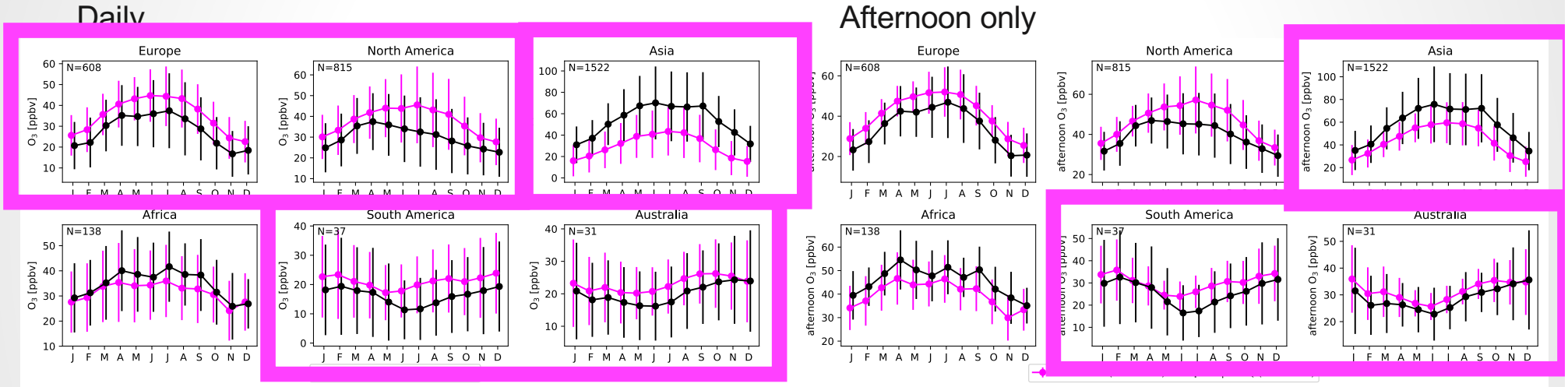
- These are clearly beneficial for surface NO_2 analyses and forecasts
- Shown for Zurich - weather and diurnal/weekly signals are prominent
- Surface observations obtained from OpenAQ (openaq.org)

GEOS-CF surface ozone compares well against background observations from the Global Atmospheric Watch (GAW) network



Surface O_3 (OpenAQ sites only)





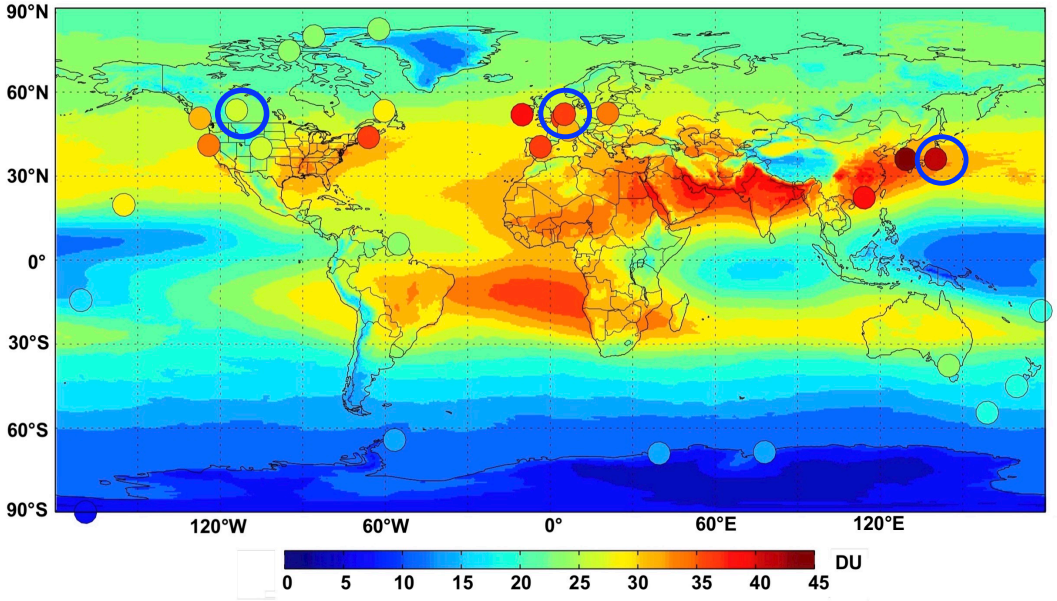
- GEOS-CF captures the overall seasonal cycle in the six regions, but generally overestimates in Europe, North & South America and Australia, while underestimating in Asia and Africa.
- In polluted regions, such as Asia, the bias is reduced when focusing on peak photochemical production period. GEOS-CF still has a bias over US during summer and fall, a known GEOS-Chem issue (Travis et al., 2016;2019; Hu et al., 2018).

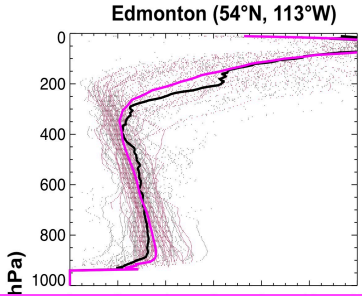
Observations GEOS-CF

Keller et al., 2021 JAMES

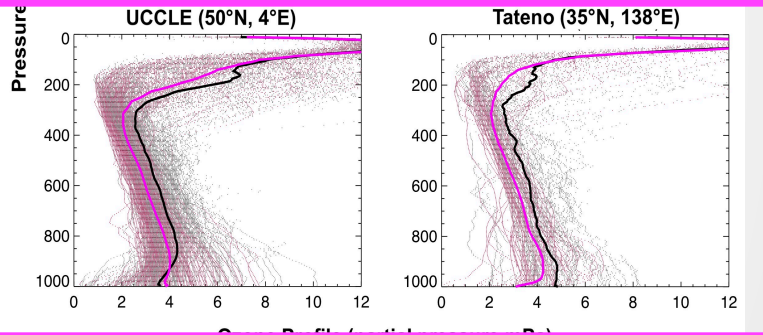
GEOS-CF captures the observed ozone spatial distribution and profile shapes shown by ozonesondes

2018 Tropospheric O_3 column (TOC): GEOS-CF and sondes





GEOS-CF in general captures the observed ozonesonde profile shapes, as seen at these three stations.



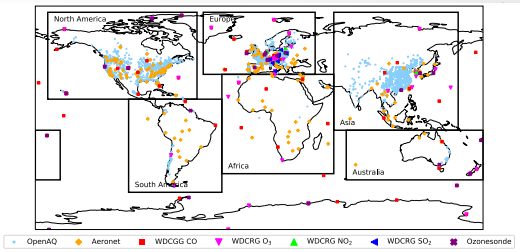
- GEOS-CF captures the overall spatial distribution of ozonesonde TOC, but with *underestimates* over polluted regions (e.g. sites over eastern US, Europe, east Asia).

Sondes GEOS-CF

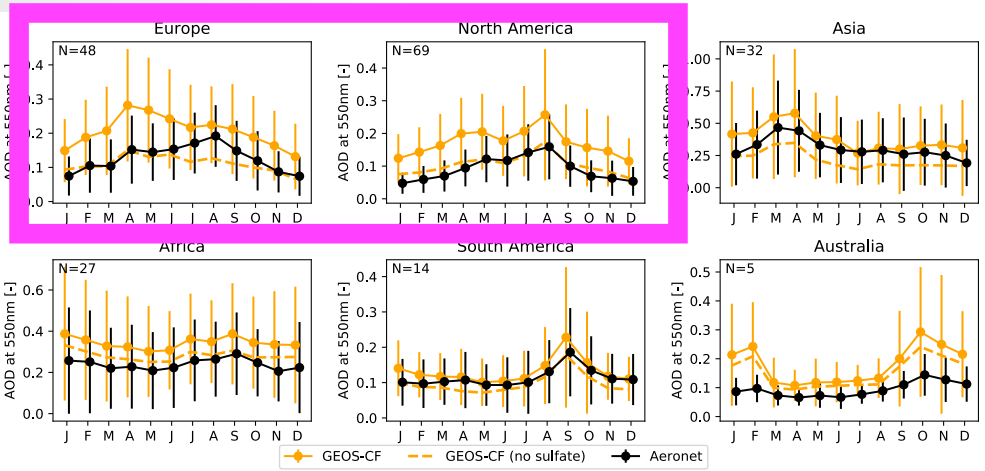
Thin lines: daily profiles in 2018
Thick lines: annual means

Figures courtesy of Junhua Liu

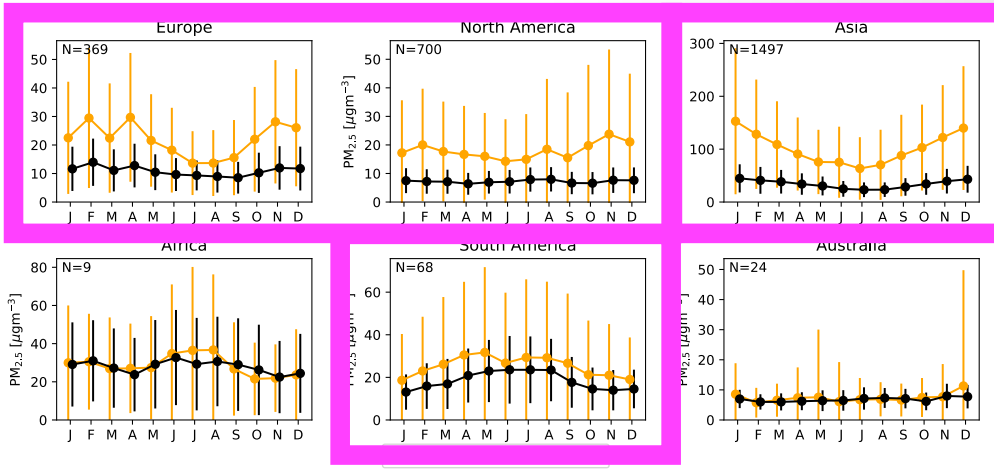
GEOS-CF generally overestimates aerosols (AOD and $PM_{2.5}$)



AOD from Aeronet network



PM2.5 from OpenAQ database

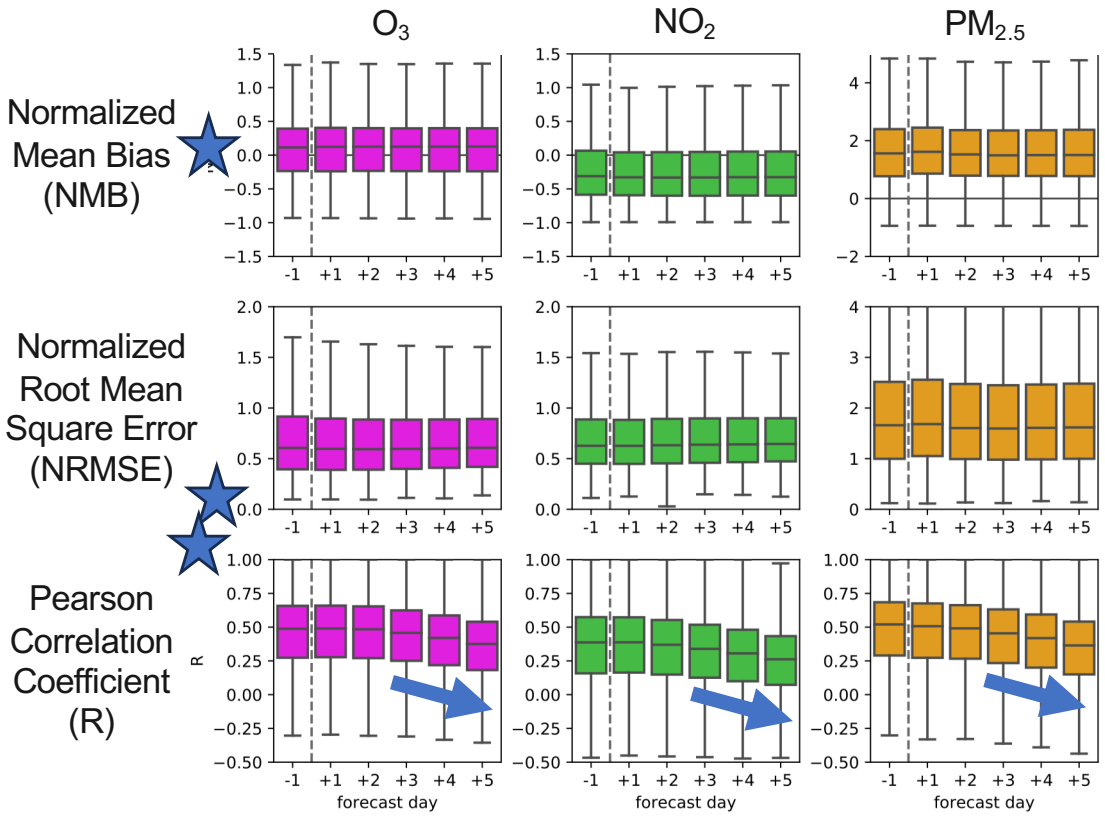


- GEOS-CF overestimates AOD 550 nm at most Aeronet sites. This is likely due to the overestimation of sulfates in the model.
- Similarly, GEOS-CF $PM_{2.5}$ is overestimated in Europe, North America, Asia and South America.

Observations GEOS-CF

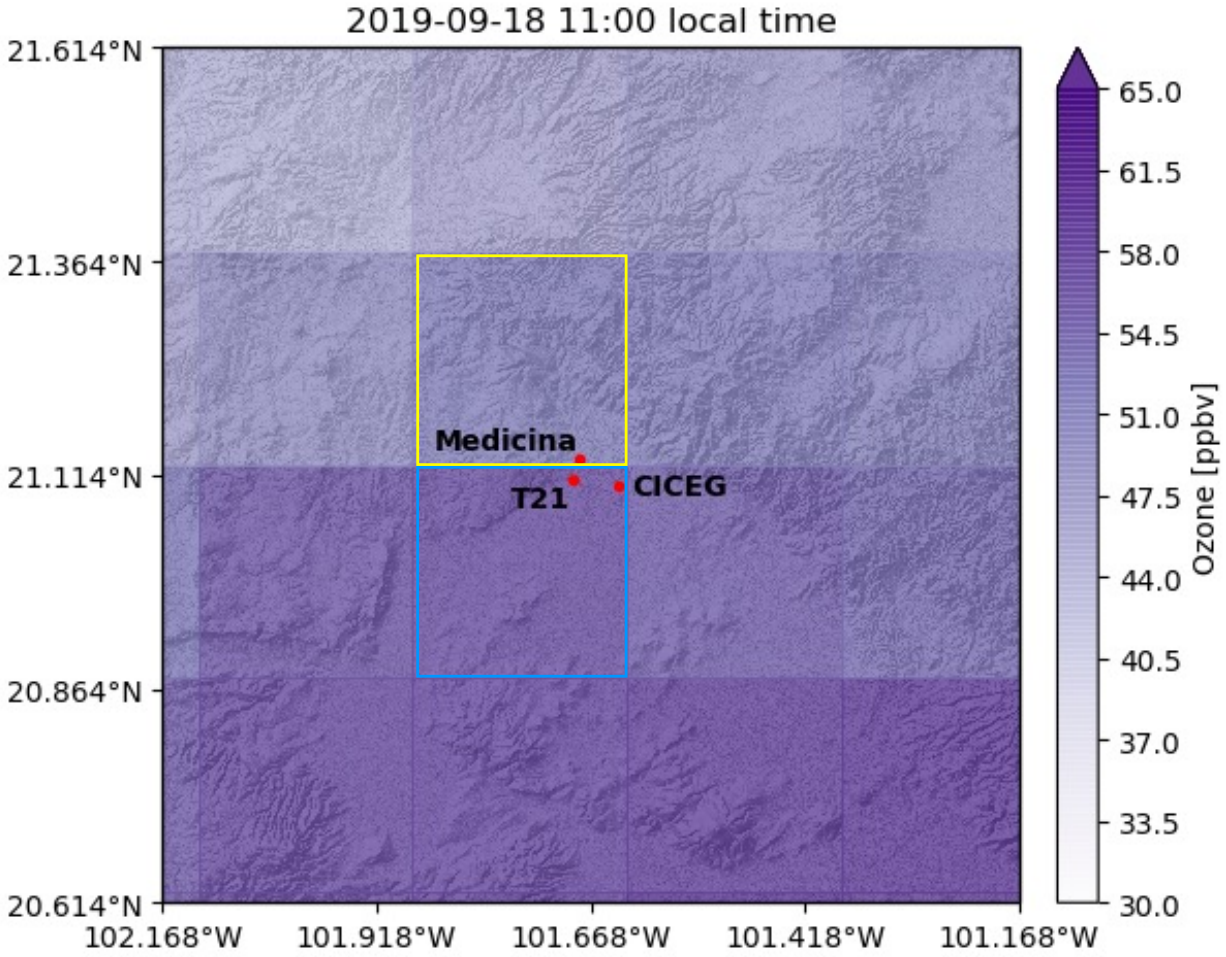
Keller et al., 2021 JAMES

GEOS-CF "Air Quality" Forecast skill (GAW and OpenAQ)



- Little variation in the skill scores (NMB and NRMSE) 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 JAMES

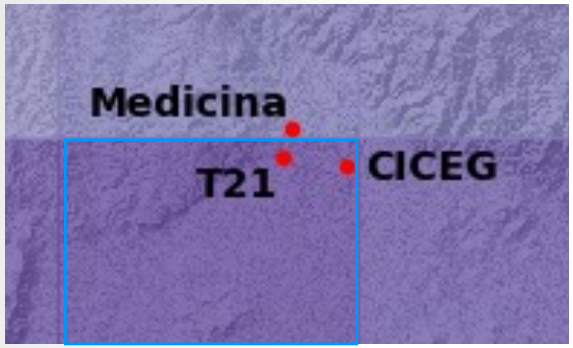


Improve local forecasts using statistical bias correction

3 monitoring stations in Leon, Mexico

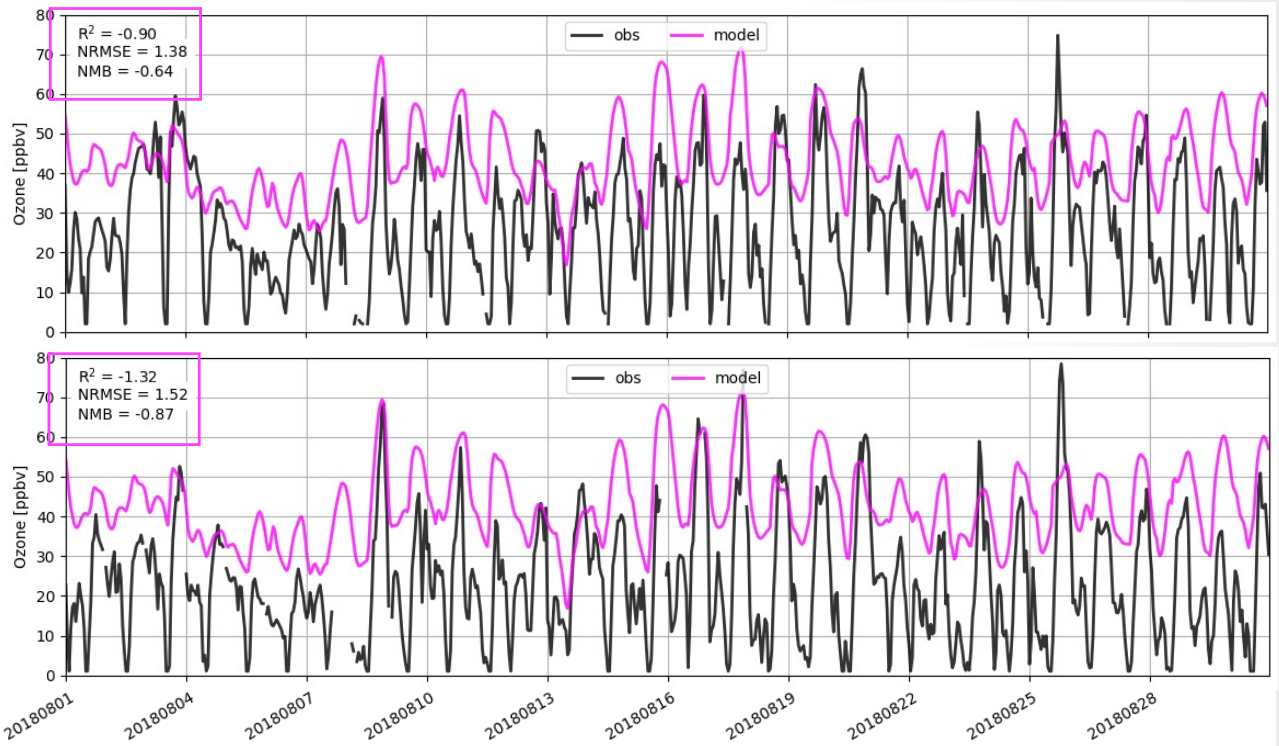
- 1 in one grid box
- 2 share a grid box
- Difficult terrain within each grid box

Improve local forecasts using statistical bias correction



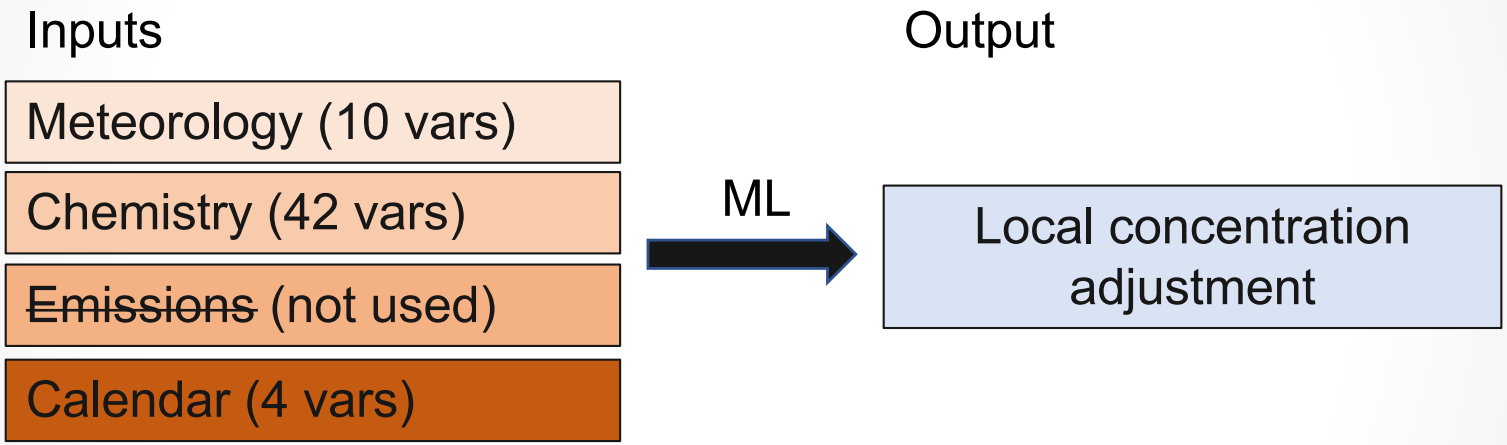
Two observation sites in the same grid box

- GEOS-CF generally over-estimates



Observations Model

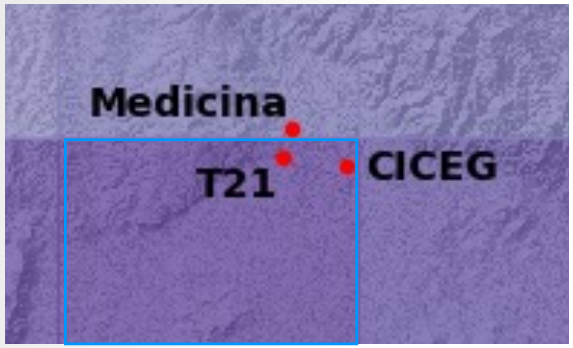
Use machine learning to correct for small scale variability and/or model biases



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

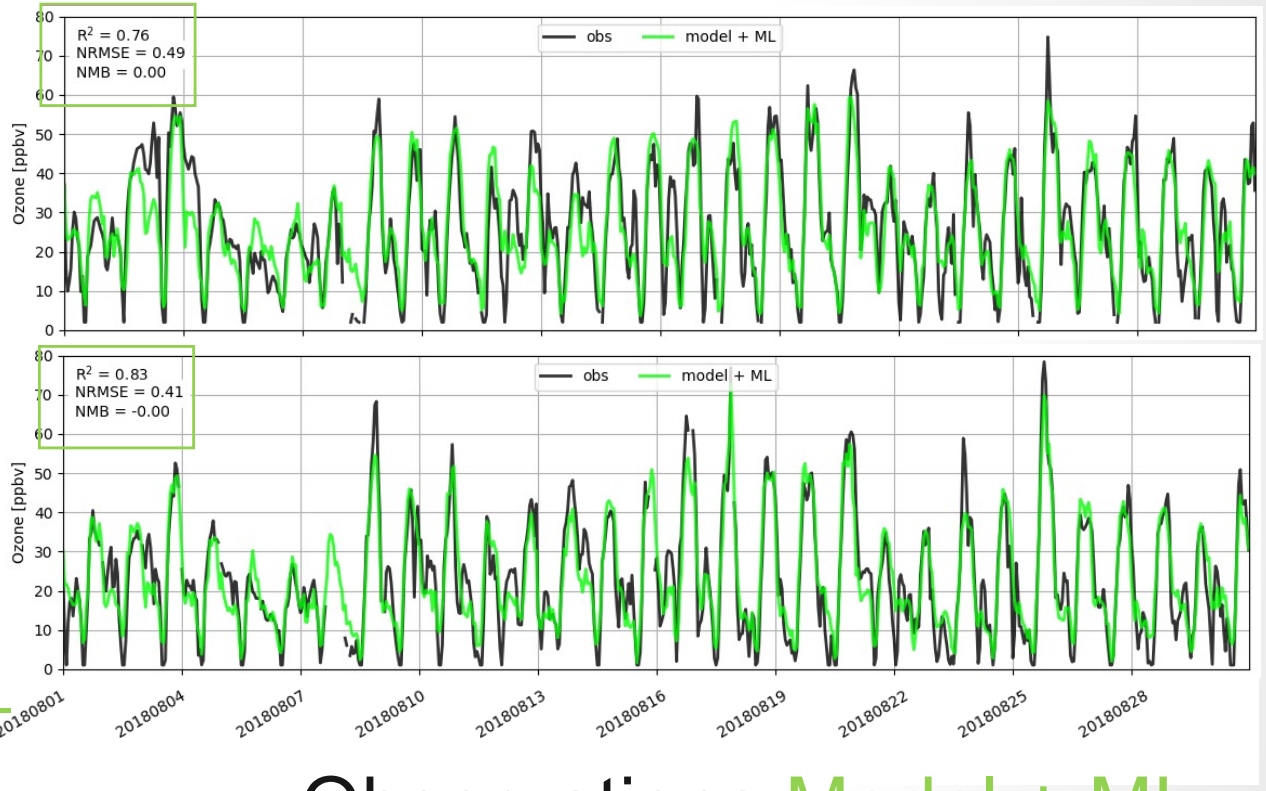
Keller et al., 2021 ACP

Improve local forecasts using statistical bias correction



Two observation sites in the same grid box

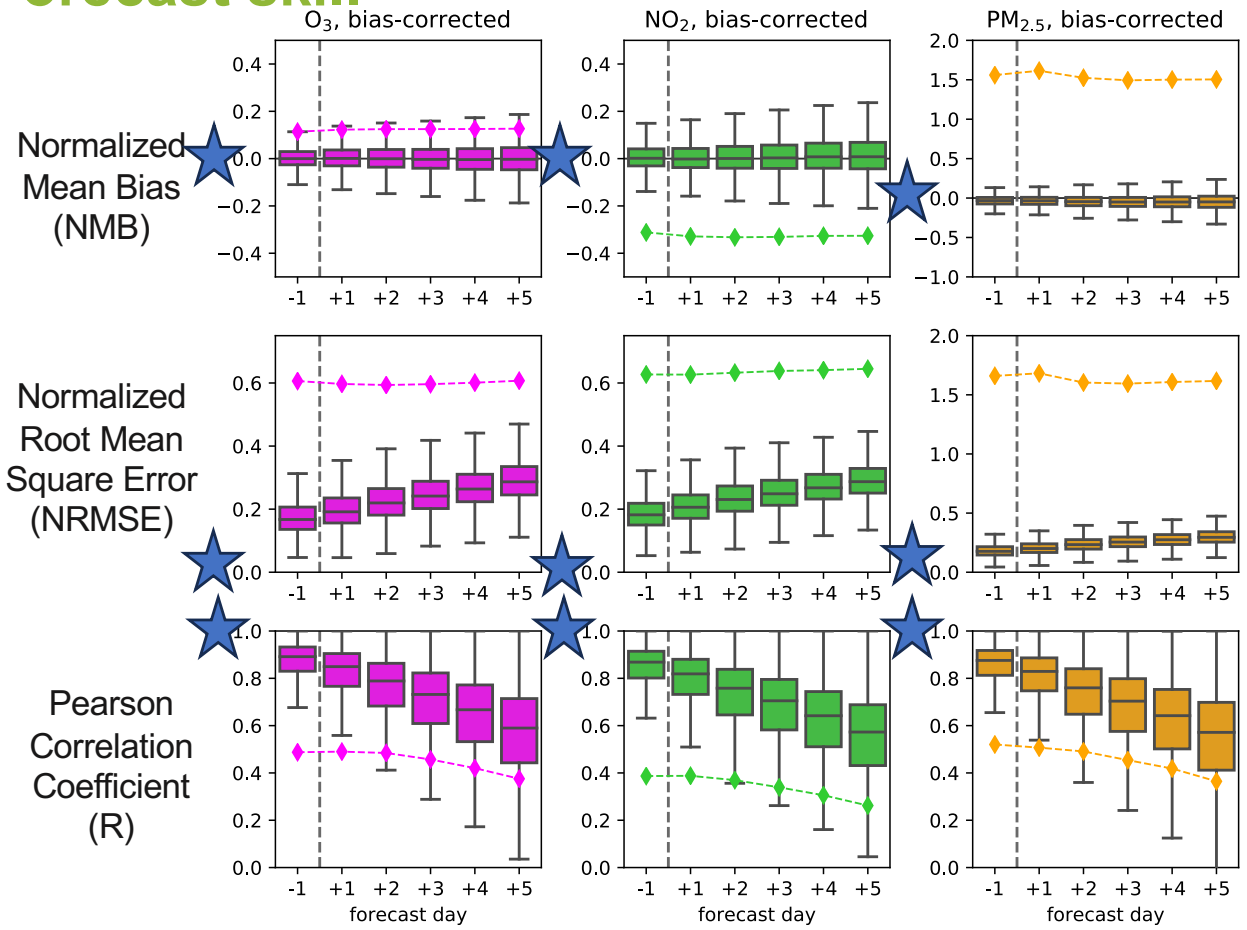
- GEOS-CF+ML captures diurnal variability at sub-grid scale



Observations Model + ML

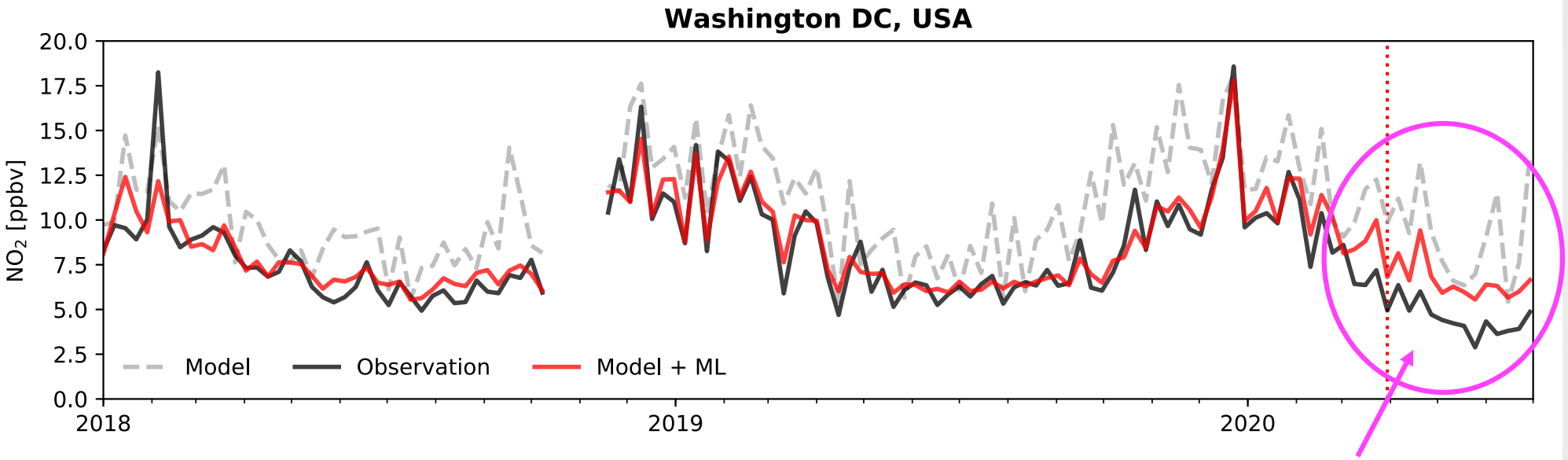
GEOS-CF "Air Quality" Forecast skill

- ✓ 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

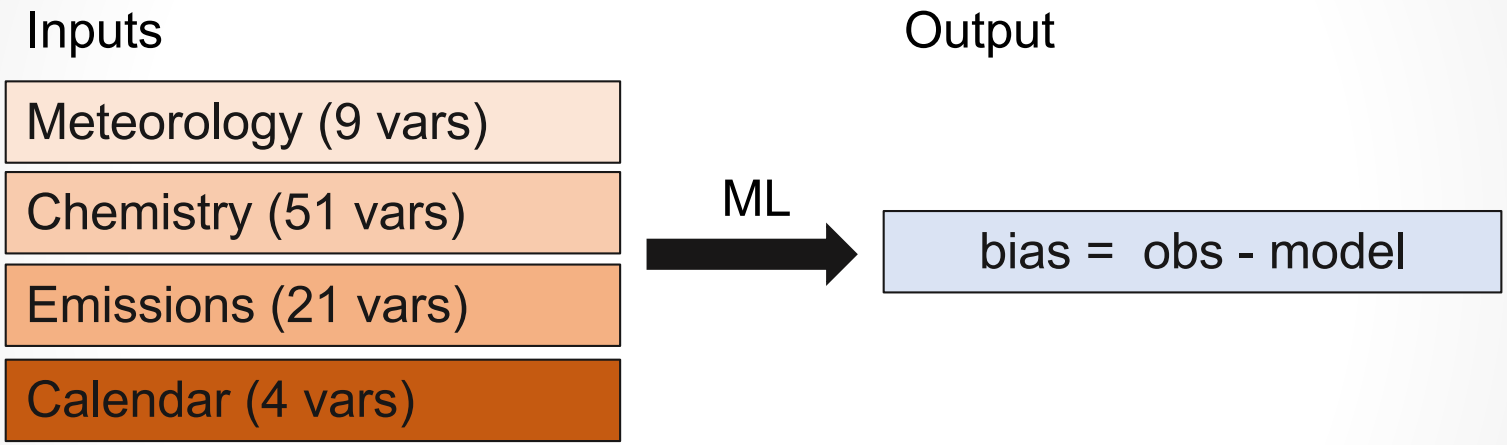
Application of the GEOS-CF ML algorithm



Impact of COVID-19 restrictions

Keller et al., 2021 ACP

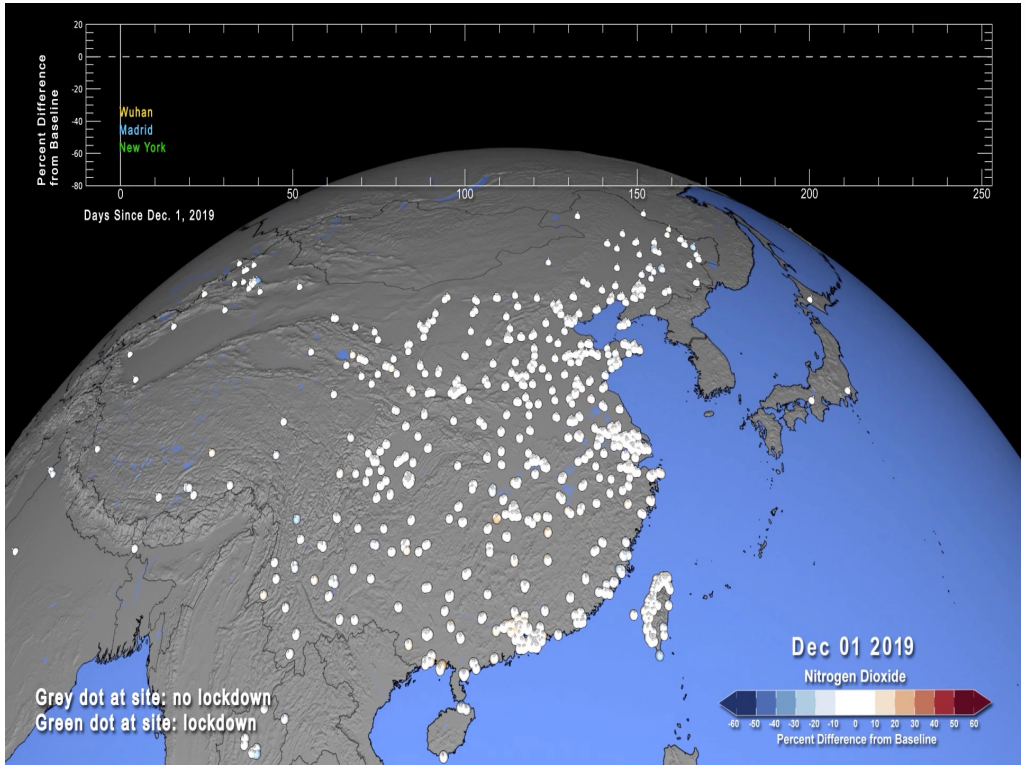
Apply bias-correction to model output using machine learning (using historical observation-model comparisons)



- Algorithm: gradient boosted decision trees (XGBoost)
- Training: 2018-2019 (8-fold cross validation)

Keller et al., 2021 ACP

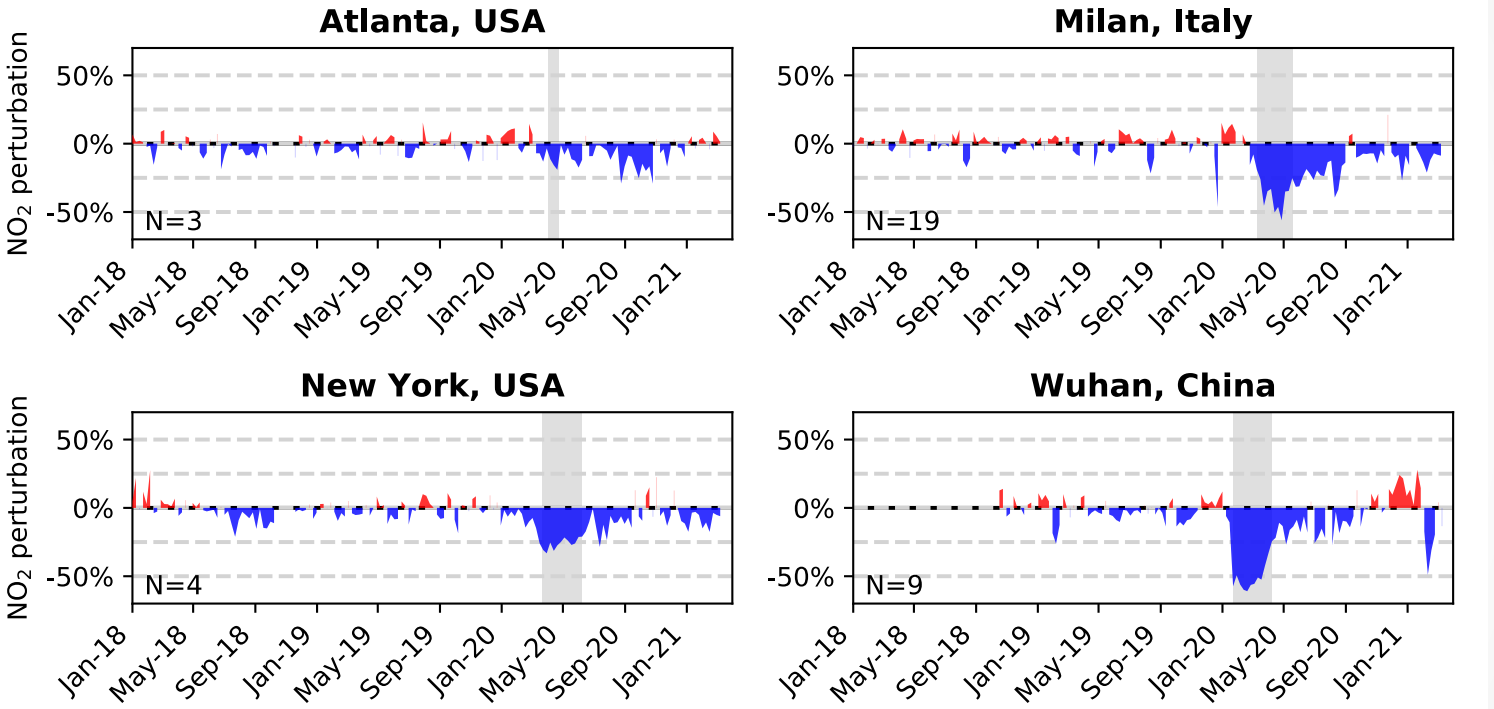
Apply analysis to 5756 sites worldwide



https://svs.gsfc.nasa.gov/13753 https://svs.gsfc.nasa.gov/4872

https://www.nasa.gov/feature/goddard/2020/nasa-model-reveals-how-much-covid-related-pollution-levels-deviated-from-the-norm

Observation-model differences indicate city-wide NO_2 declines of up to 50% in 2020



Updated through March 16, 2021

Keller et al., 2021 ACP

https://www.nasa.gov/feature/goddard/2020/nasa-model-reveals-how-much-covid-related-pollution-levels-deviated-from-the-norm

National Aeronautics and Space Administration

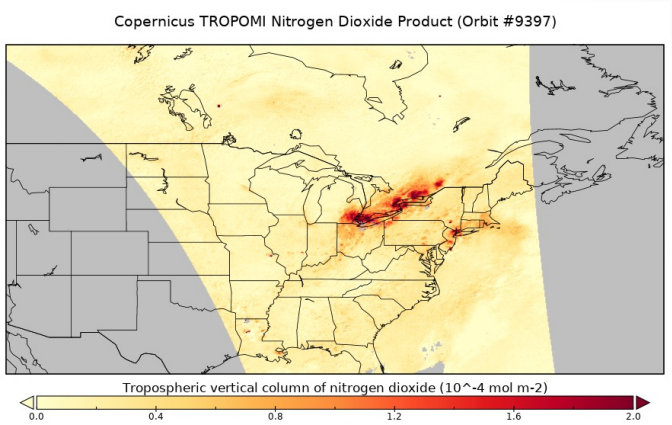
Multiple Sources of Air Quality Data



regulatory monitoring

+ accurate
- expensive
? representativity

form the "backbone" of the monitoring system, but insufficient alone



satellite retrievals

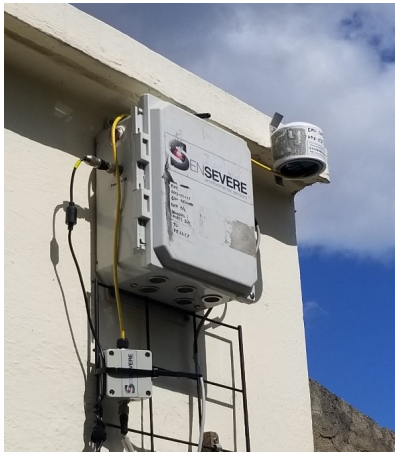
+ global coverage
- low time resolution
- column-integrated

good coverage and frequency, but need to be related to the ground-level situation

low-cost monitoring

+ relatively inexpensive
+ dense/remote deployment
- greater noise and bias

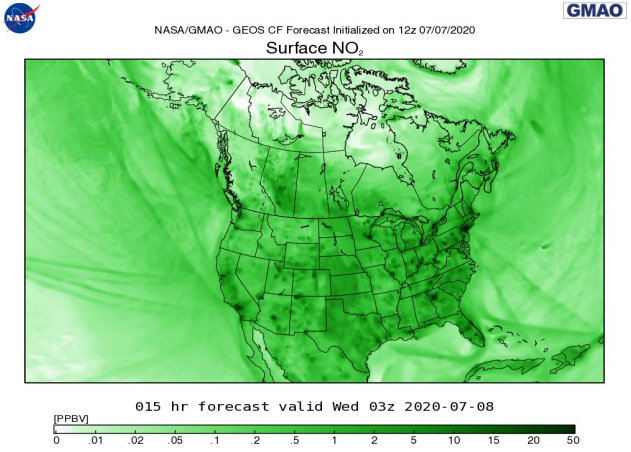
calibration is an open issue, but leveraging network density can offset some of these shortcomings



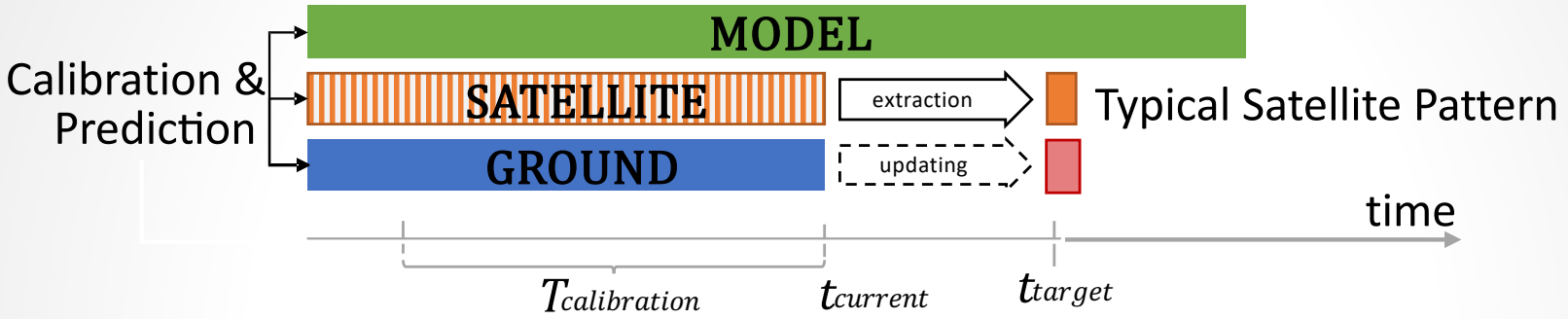
simulation models

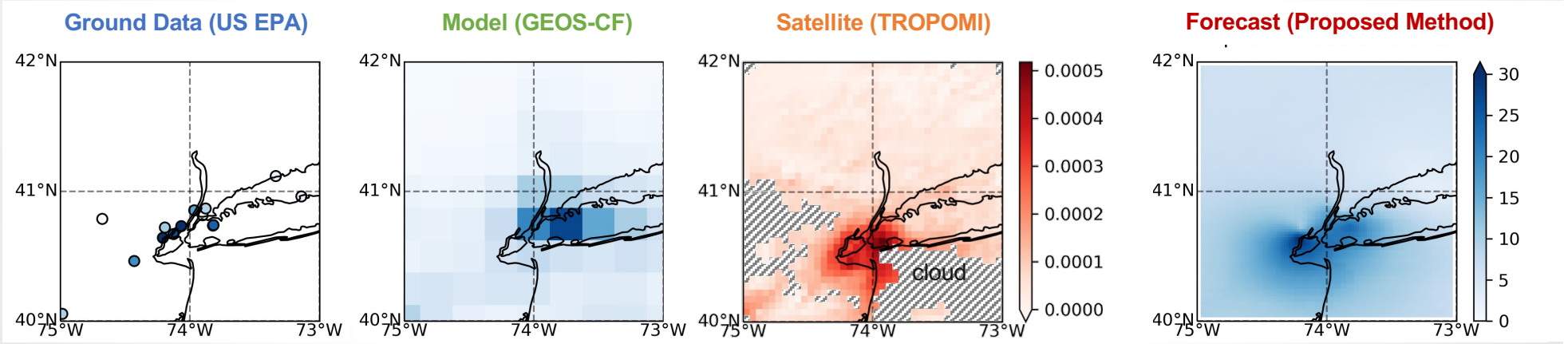
+ global coverage
+ forecasting
- limited resolution

The best tool for prediction, but need the support of other data sources for accuracy



Data Fusion method for city-scale air quality forecasts





Malings et al., 2021 ESS

National Aeronautics and Space Administration

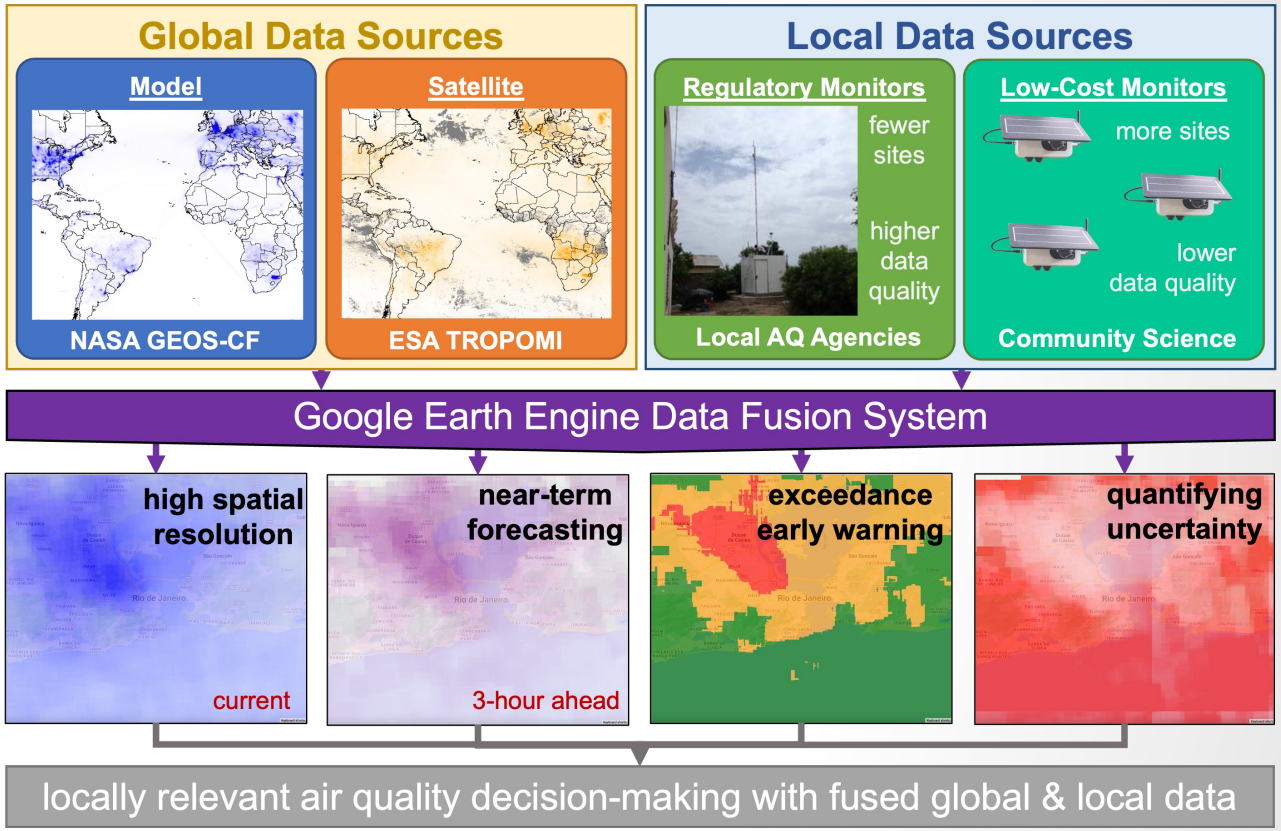
Project's objective to estimate air quality across a city

…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.



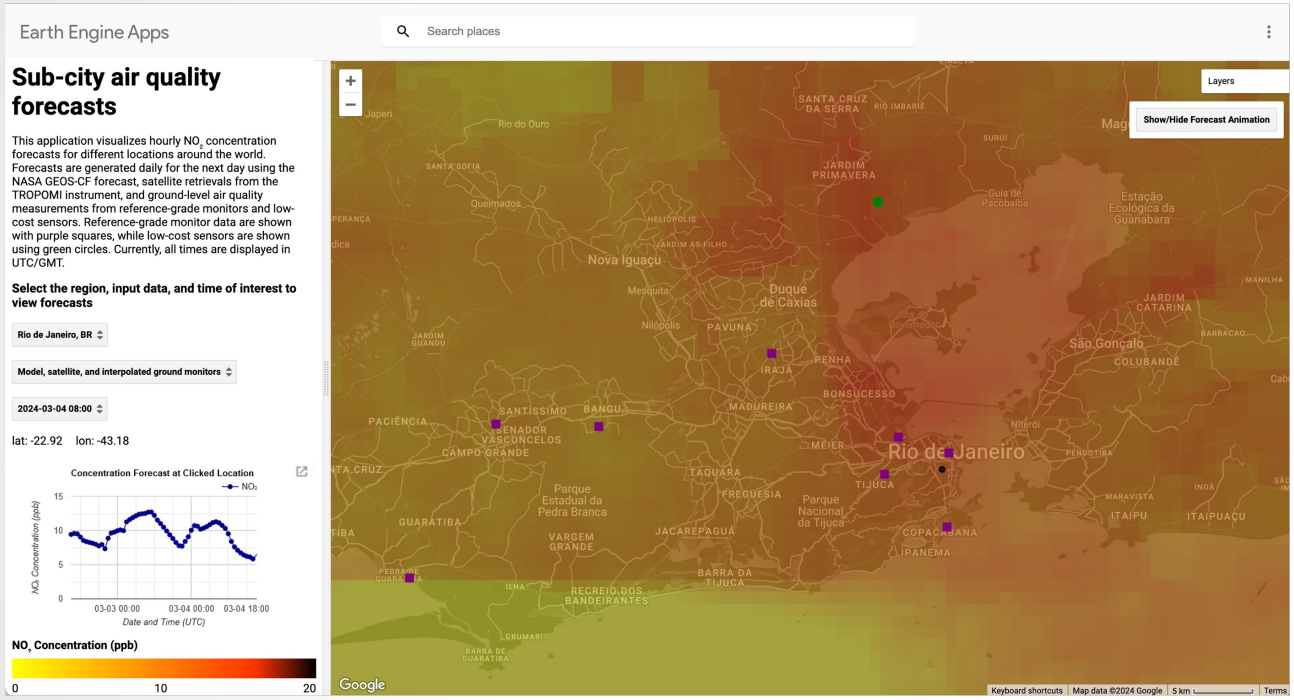
https://gmao.gsfc.nasa.gov/research/science_snapshots/2023/air_quality_data_fusion.php

PI K. Emma Knowland: k.e.knowland@nasa.gov
Co-I Nathan Pavlovic: npavlovic@sonomatech.com
Co-I Carl Malings carl.a.malings@nasa.gov

National Aeronautics and Space Administration

EARTH SCIENCE APPLIED SCIENCES

Pilot deployment of GEE tool in end-user domain of interest



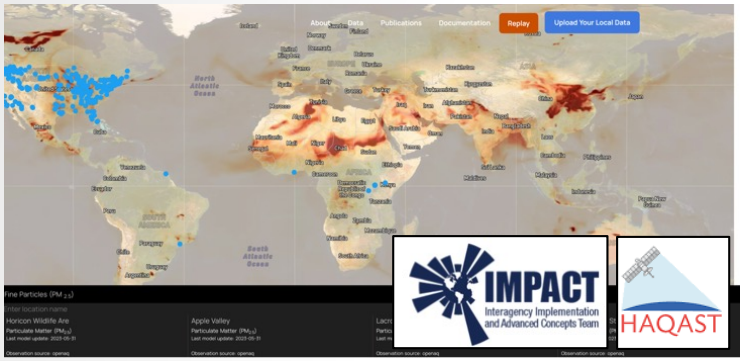
https://gmao.gsfc.nasa.gov/research/science_snapshots/2023/air_quality_data_fusion.php

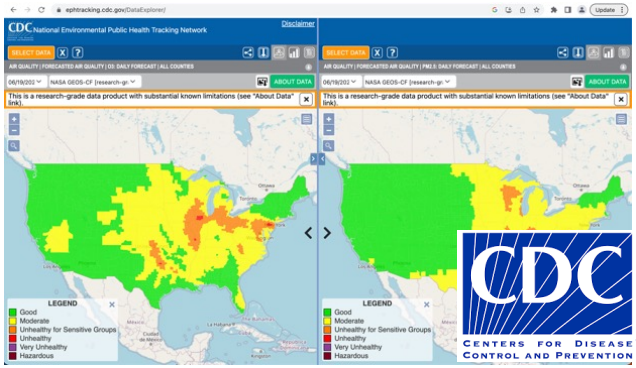
Developing an air quality forecasting model for Rio de Janeiro in collaboration with NASA has been identified as a key target for the Instituto Pereira Passos (IPP) for 2024 by the Rio de Janeiro Mayor's office.

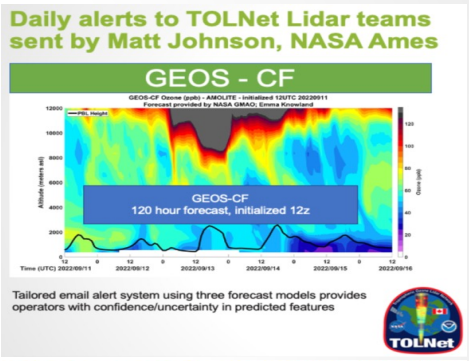
This indicates the value placed on the potential impact of such a tool by the local government and policy-makers.

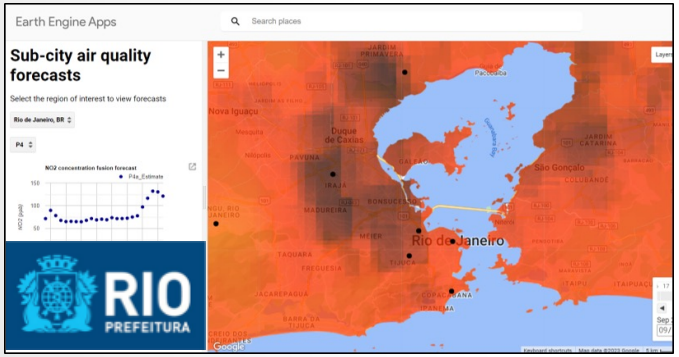
PI K. Emma Knowland: k.e.knowland@nasa.gov
Co-I Nathan Pavlovic: npavlovic@sonomatech.com
Co-I Carl Malings carl.a.malings@nasa.gov

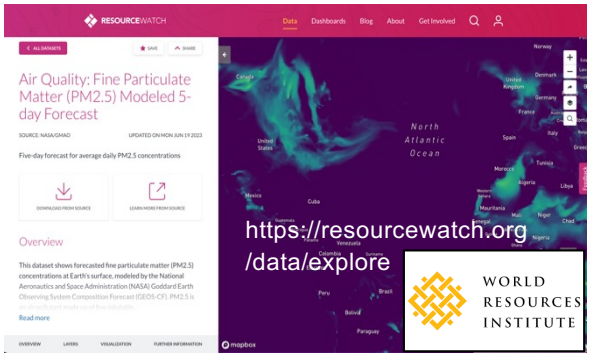
Actively Working With Stakeholders to Meet Their Needs

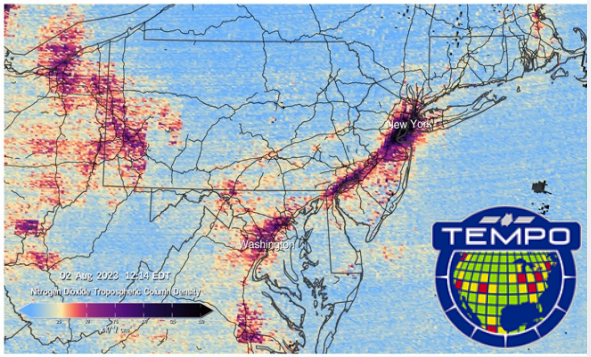










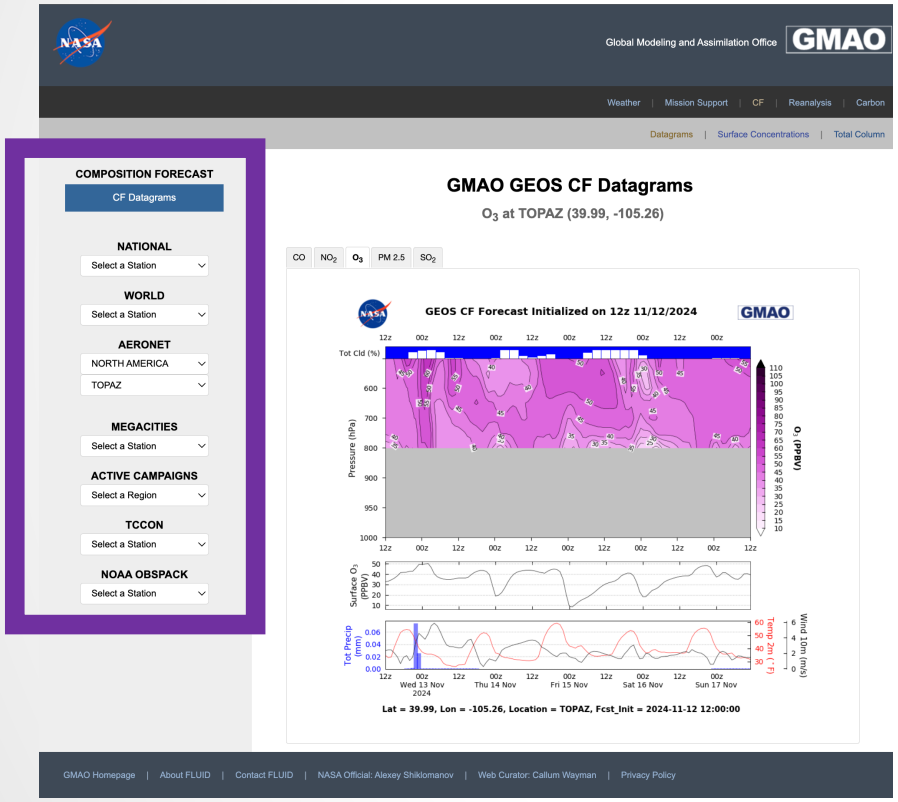


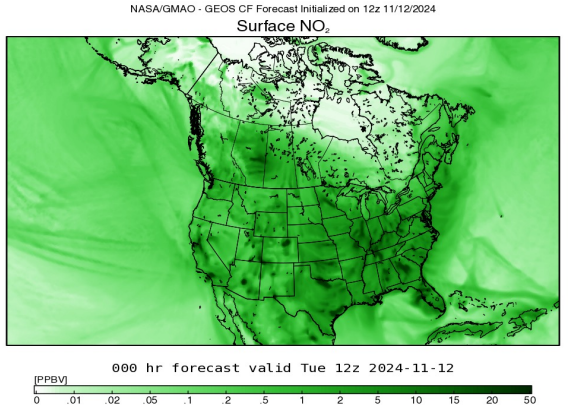
https://gmao.gsfc.nasa.gov/research/science_snapshots/2023/air_quality_data_fusion.php

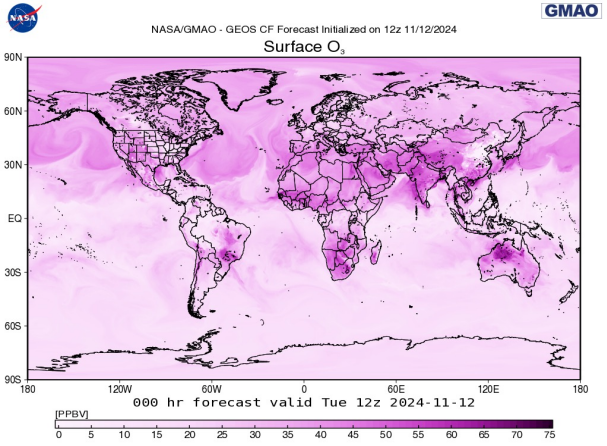
GEOS-CF output is available online in near real-time

Fluid is a mobile-friendly website

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





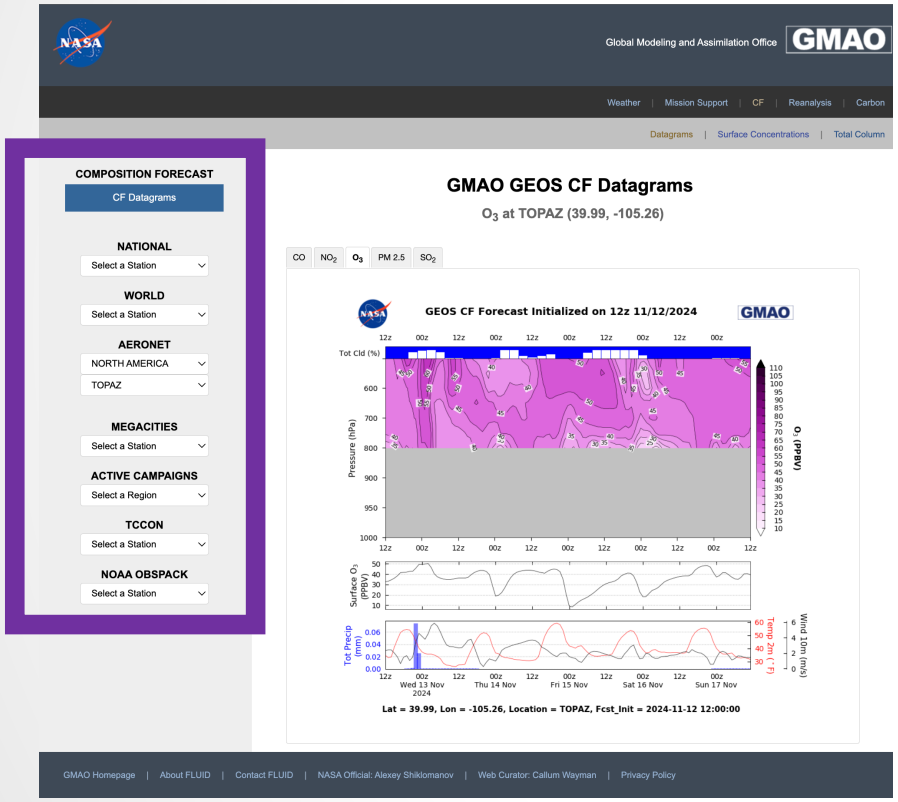


National Aeronautics and Space Administration

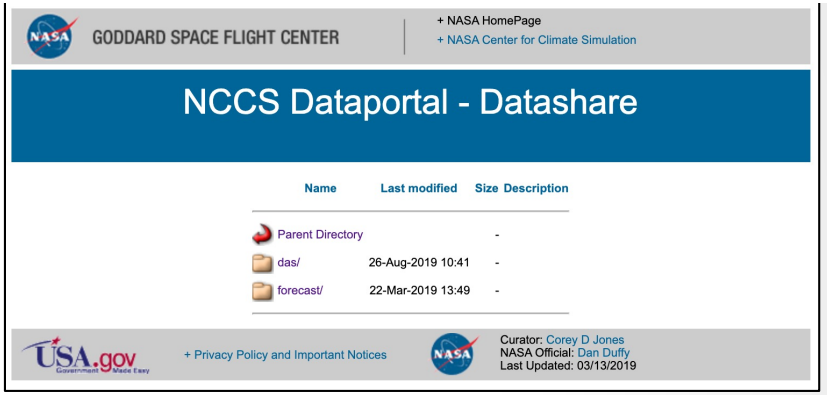
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Fluid is a mobile-friendly website

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/

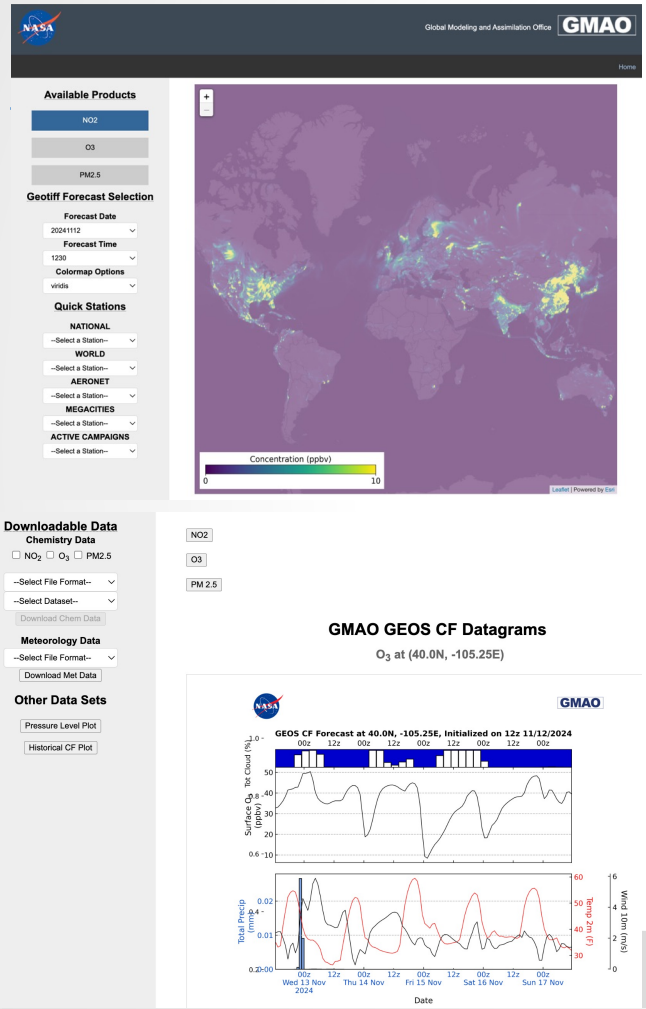
GrADS Data Server - info for /gmao/geos-cf/assim/chm_tavg_1hr_g1440x721_v1 : dds das

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

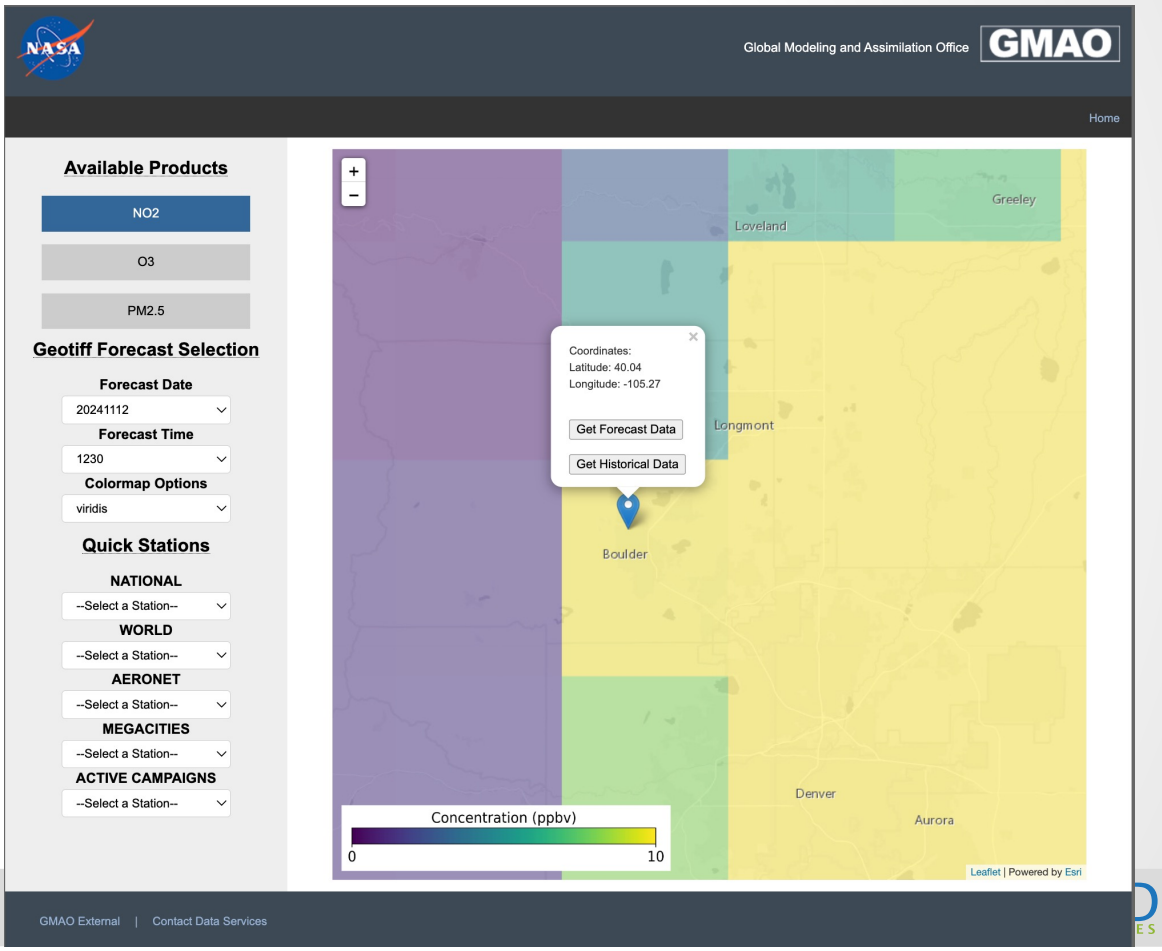
Description:	GEOS CF (Composition Forecast)	
Documentation:	(none provided)	
Longitude:	-180.00000000000°E to 179.75000000000°E	(1440 points, avg. res. 0.25°)
Latitude:	-90.00000000000°N to 90.00000000000°N	(721 points, avg. res. 0.25°)
Altitude:	72.00000000000 to 72.00000000000	(1 points)
Time:	00:30Z01JAN2018 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 forecast imagery is available on-demand

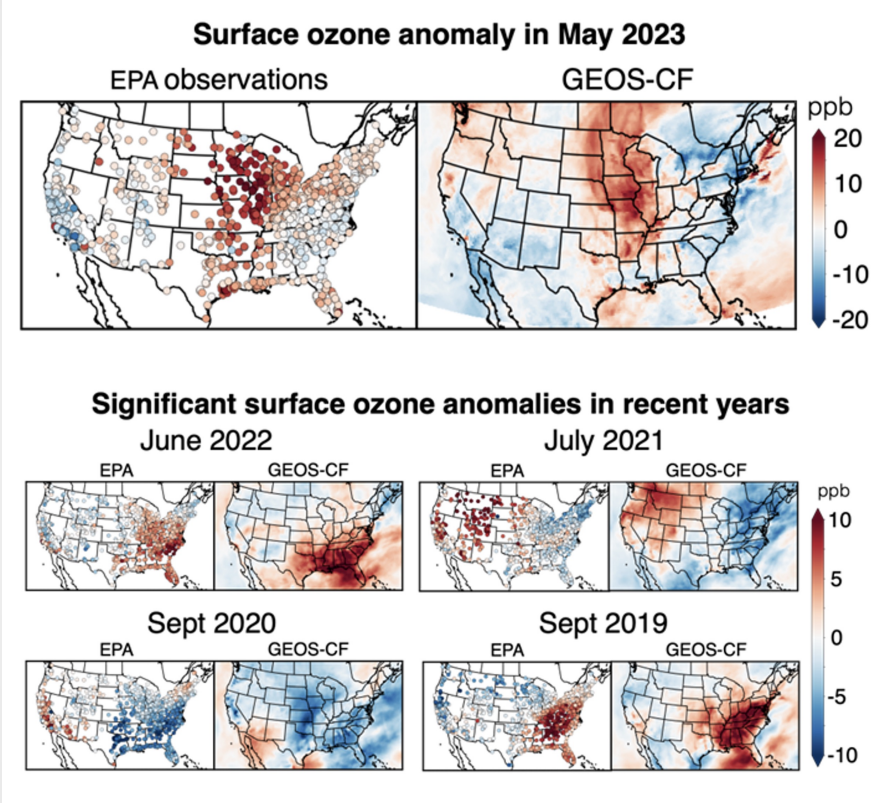
National Aeronautics and Space Administration

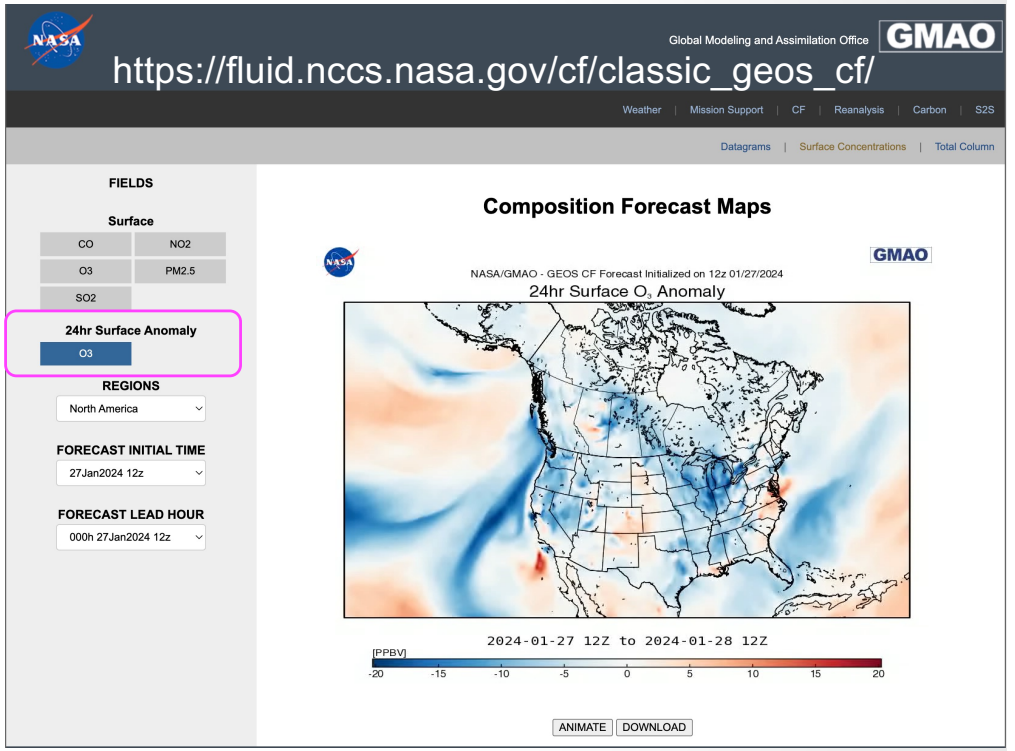


https://fluid.nccs.nasa.gov/cf_map/



Linking Surface Ozone Extremes to Weather Pattern Anomalies





https://gmao.gsfc.nasa.gov/research/science_snapshots/2023/ozone-2023.php

Ongoing Efforts to Expand Data Access – Demand & Opportunity

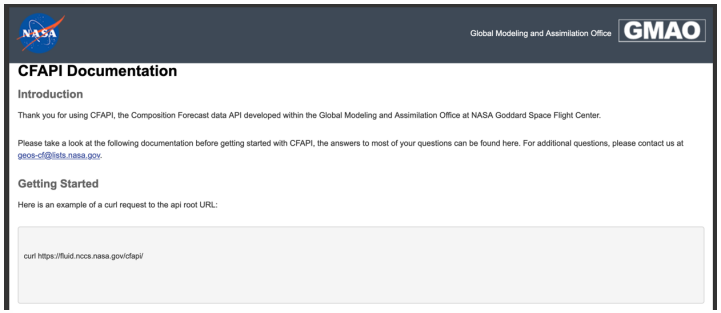
COG

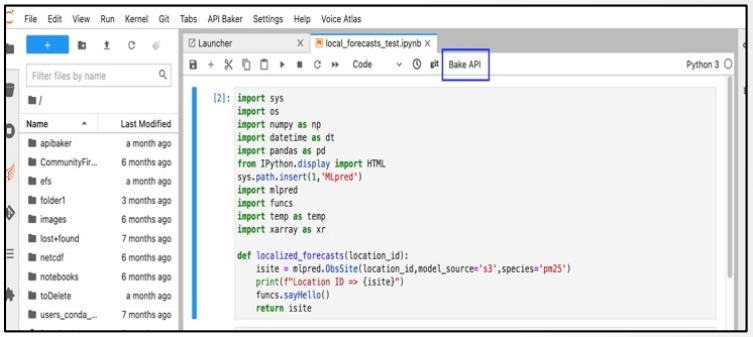
Zarr

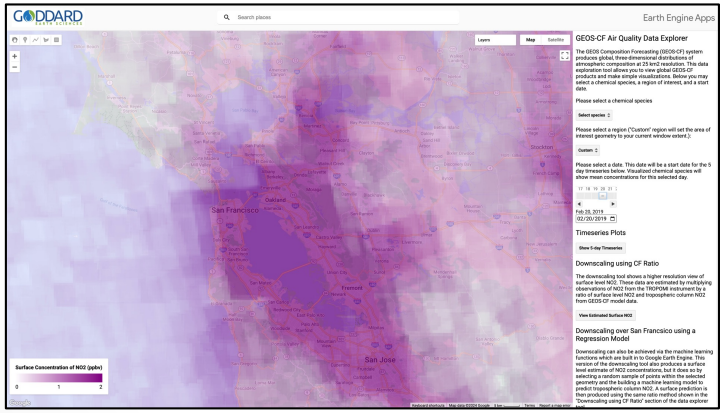
jupyter

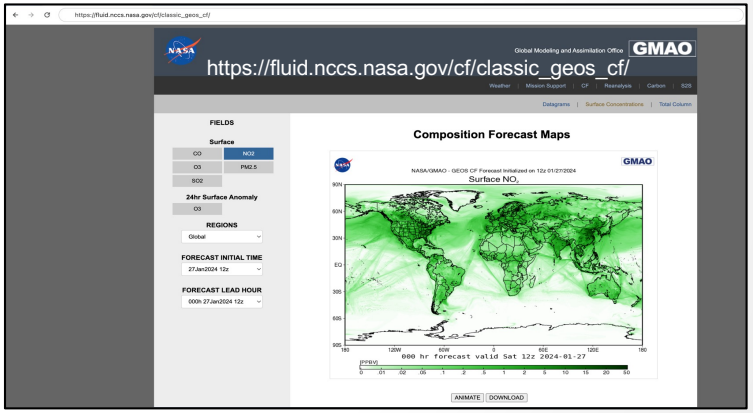
aws

Google Earth Engine



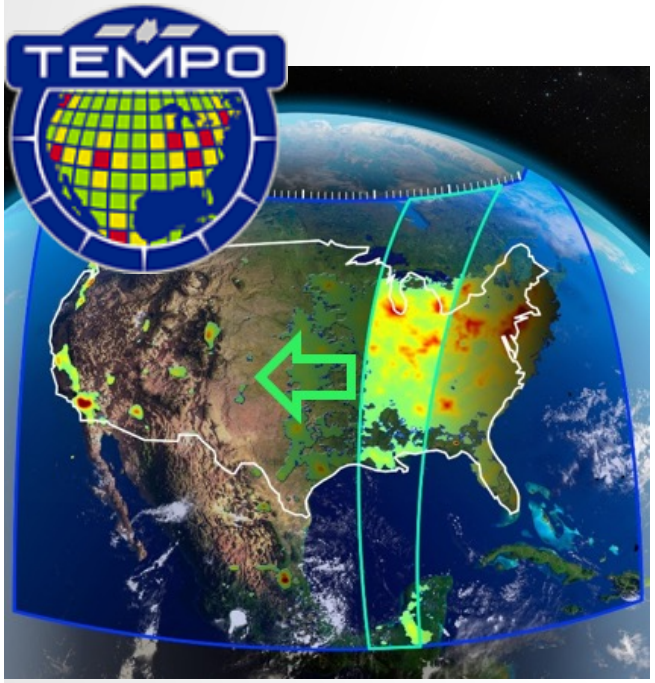






https://gmao.gsfc.nasa.gov/research/science_snapshots/2023/new-generation-gmao-apps.php

Realistic tropospheric and stratospheric composition is critical for many NASA applications





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

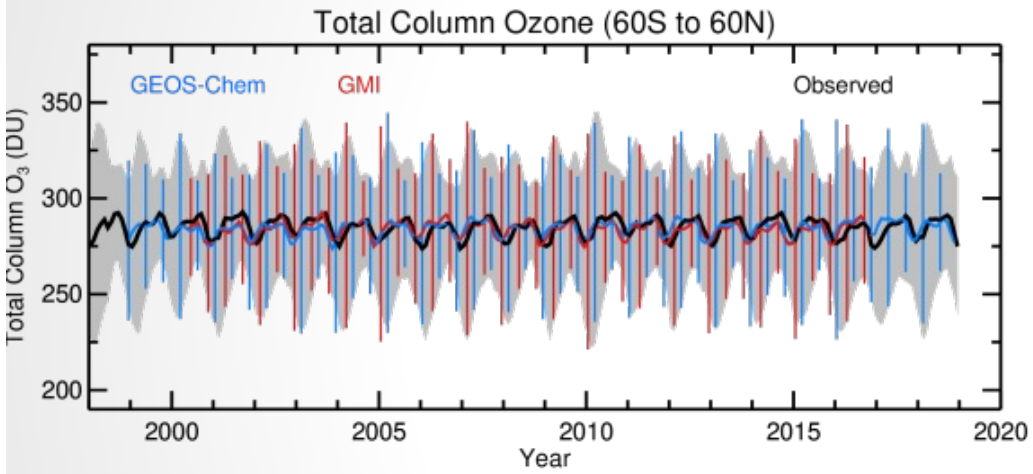
- TEMPO a priori for trace gas retrieval
- NASA field missions (e.g., SCOAPE, FIREX-AQ, TRACER-AQ, ASIA-AQ)
- Daily alerts sent to NASA TOLNet lidar teams (Matt Johnson, NASA Ames)

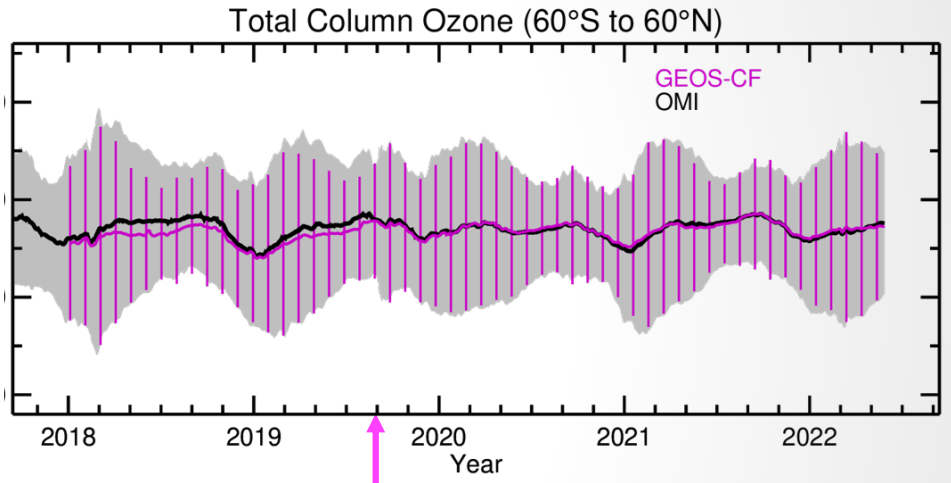


National Aeronautics and Space Administration

GEOS-Chem updates for stratospheric composition

- GEOS-CF Stratospheric O_3 is weakly nudged to the GEOS FP assimilated O_3



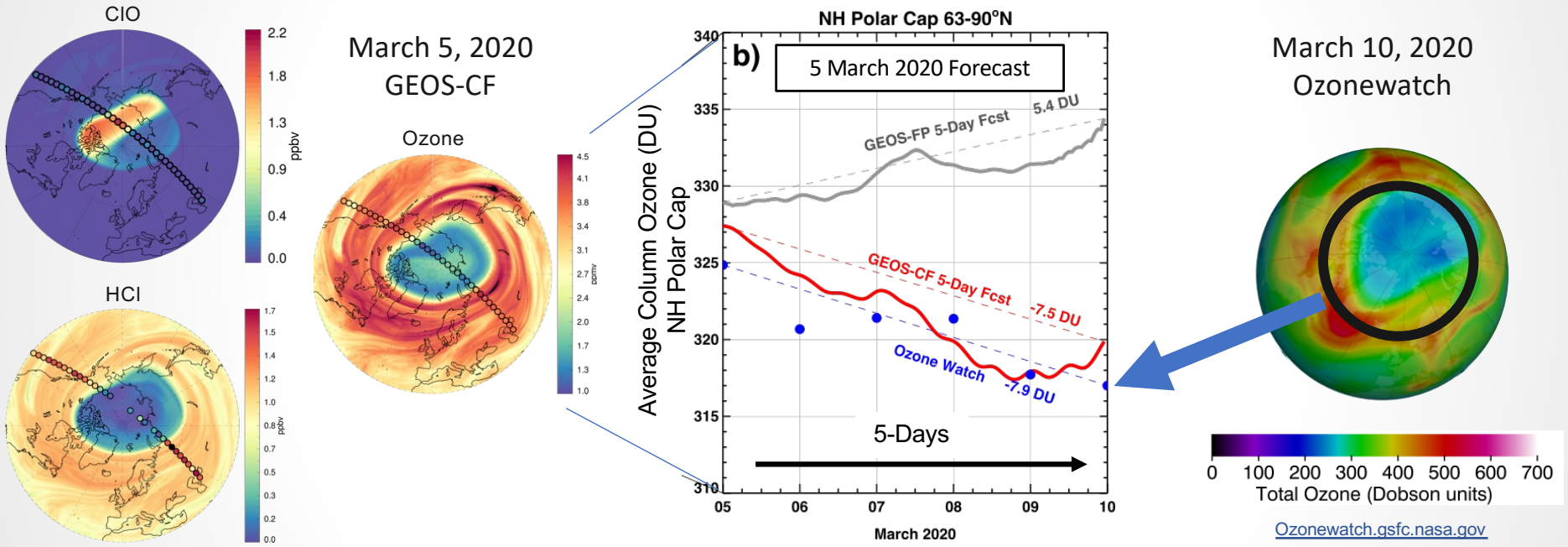


GEOS-Chem non-polar TCO agrees well with GMI simulated TCO and the observable TCO range

Updates were applied to GEOS-CF stratospheric mechanism on July 31, 2019, which improved the treatment of halogen and nitrogen families

Knowland et al., 2022, JAMES

Inclusion of Stratospheric Chemistry in GEOS-CF Provides GMAO Provides GMAO the capability of Realistic Ozone Forecasting



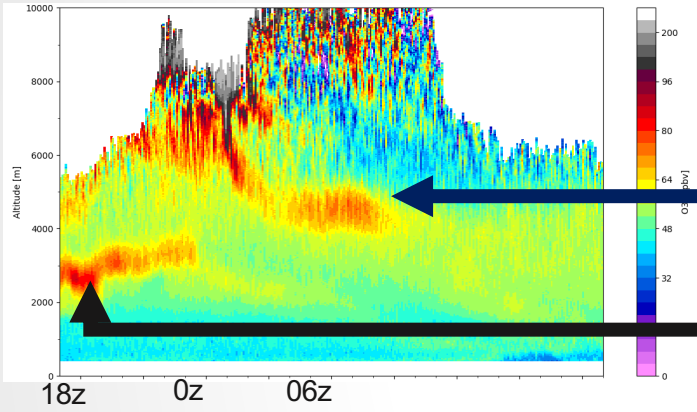
Knowland et al., JAMES, 2022

https://gmao.gsfc.nasa.gov/research/science_snapshots/2023/stratospheric-ozone.php

National Aeronautics and Space Administration

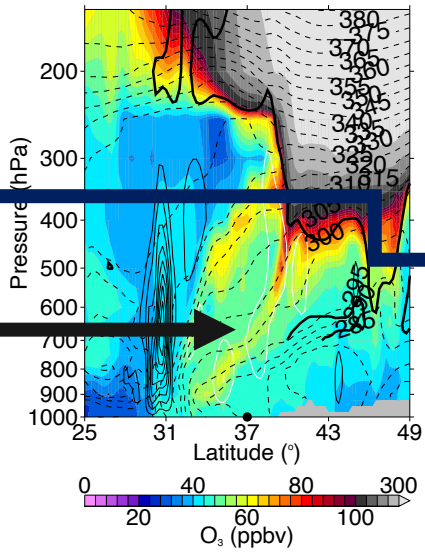
Stratosphere Troposphere Exchange

NASA LaRC Feb 13-14, 2019

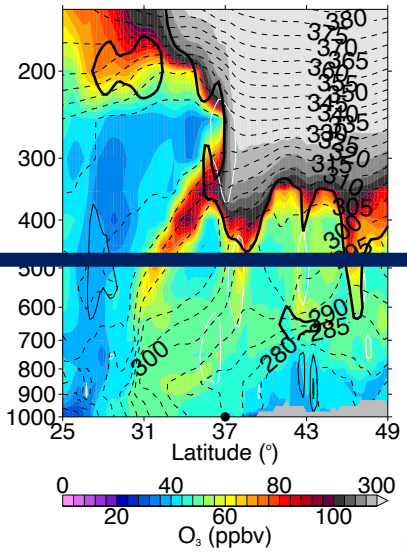


LMOL lidar plot courtesy of G. Gronoff

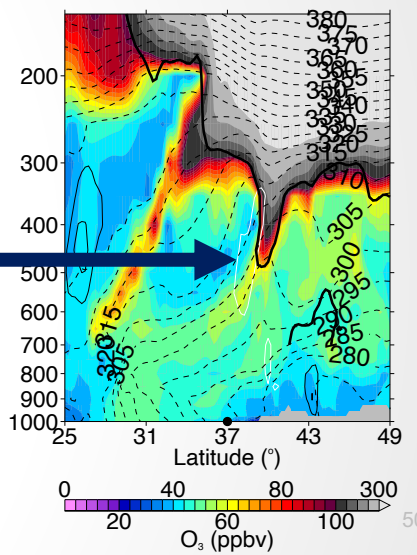
GEOS-CF
Feb 13, 2019 18z



Feb 14, 2019 00z



Feb 14, 2019 06z

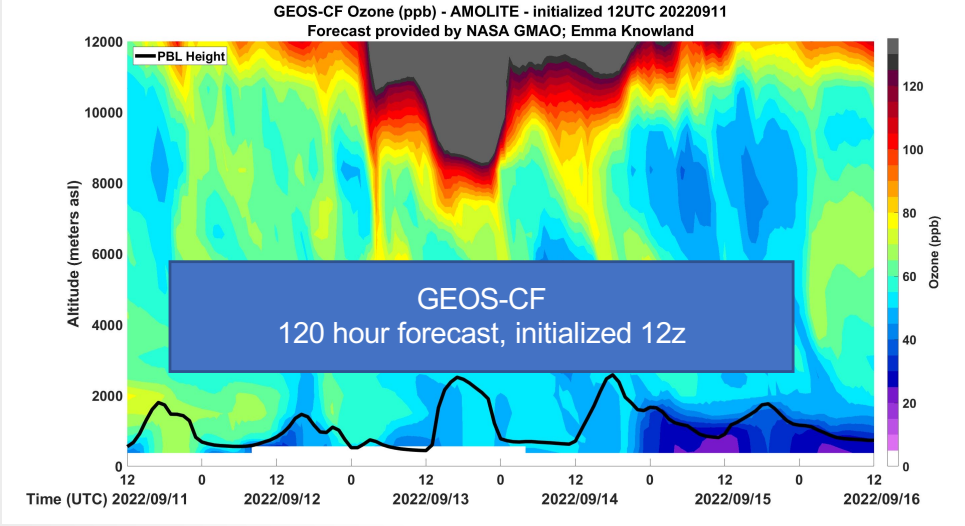


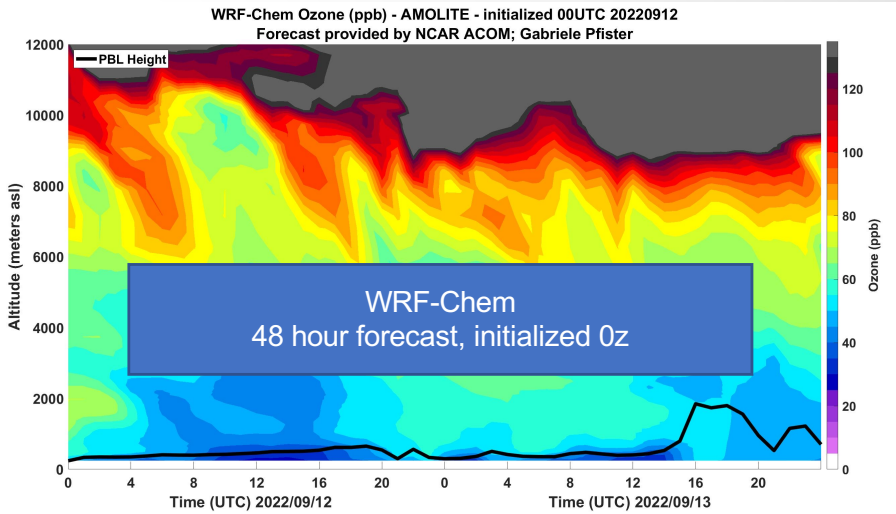
High ozone observed in the troposphere on February 13th and 14th of 2019 at LaRC have stratospheric origin, as indicated by the GEOS-CF curtain plots

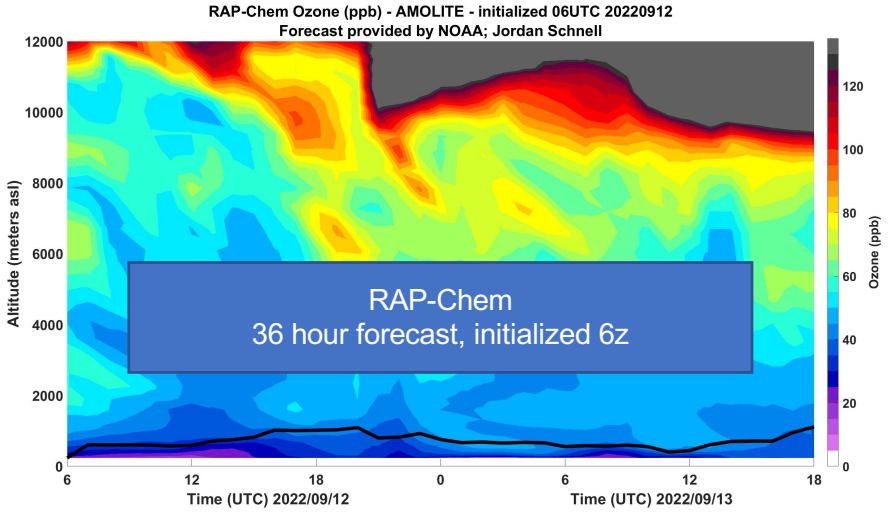
Gronoff, G., Berkoff, T., Knowland, K. E., et al. "Case study of stratospheric Intrusion above Hampton, Virginia: lidar-observation and modeling analysis." Atmos. Environ., 2021, DOI: 10.1016/j.atmosenv.2021.118498

Daily alerts to TOLNet Lidar teams sent by Matt Johnson, NASA AMES

GEOS - CF







Tailored email alert system using three forecast models provides operators with confidence/uncertainty in predicted features

Figures courtesy of Matt Johnson

Upgrade to GEOS-CF Version 2

National Aeronautics and Space Administration

Model components



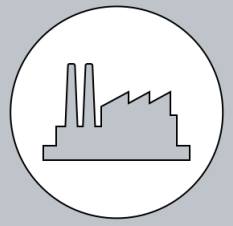
GEOSgcm v10.23 with new model physics

Replay to GEOS-IT

GEOS Chem 14.0

GEOS convective tranport

Emissions



HTAP → CEDS

Updated fire emission factors

Redistributed lightning

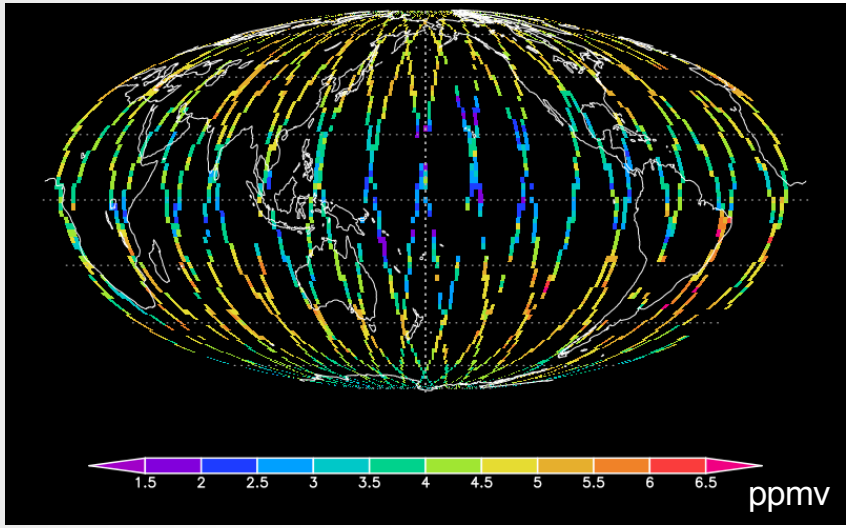
Data assimilation



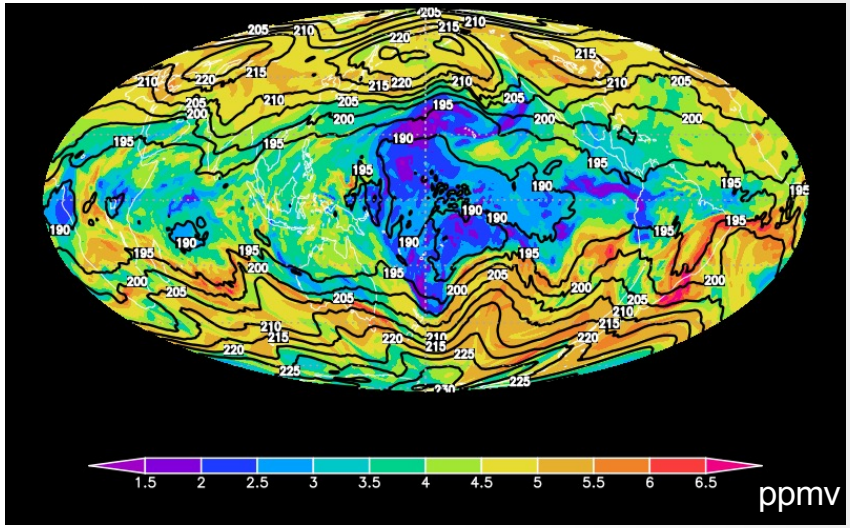
3D-Var assimilation of ozone, NO_2 and SO_2 satellite data

Constituent data assimilation

MLS water vapor at 100 hPa, 2 Jan 2016



Assimilated MLS water vapor and MERRA-2 temperature at 100 hPa, 2 Jan 2016



Data assimilation is a Bayesian method of combining and propagating information from observations in space and time using the governing equations and error estimates.

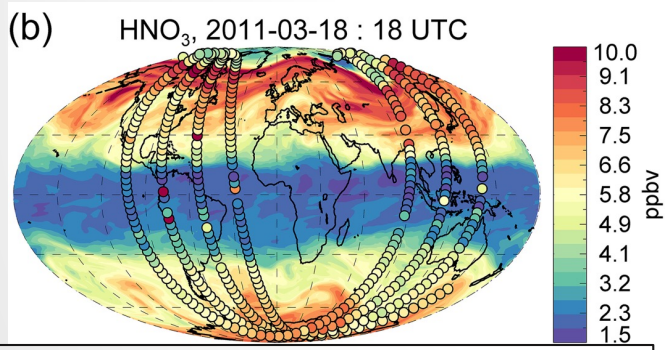
Figures courtesy of Kris Wargan

K. Emma Knowland
k.e.knowland@nasa.gov

Constituent Data Assimilation System (CoDAS)

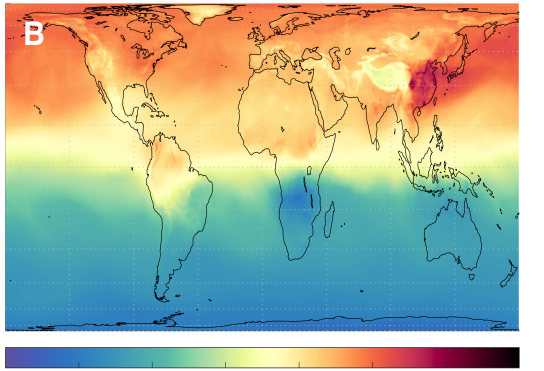
- Designed to be tracer agnostic: can assimilate any type of retrieved constituent observations with an averaging kernel or at a point
  - CoDAS builds on the Gridpoint Statistical Interpolation (GSI) scheme developed at NCEP and GMAO
  - GMAO involved and invested in the constituent DA with JEDI

M2-SCREAM



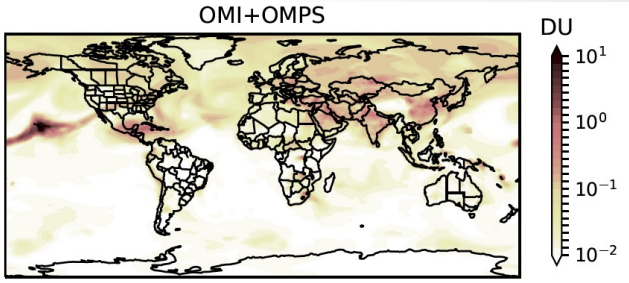
Wargan et al., ESS (2023). DOI: 10.1029/2022EA002632

GEOS-GHG



Weir et al., Sci. Adv. (2021) DOI:10.1126/sciadv.abf9415

GEOS-CF v2

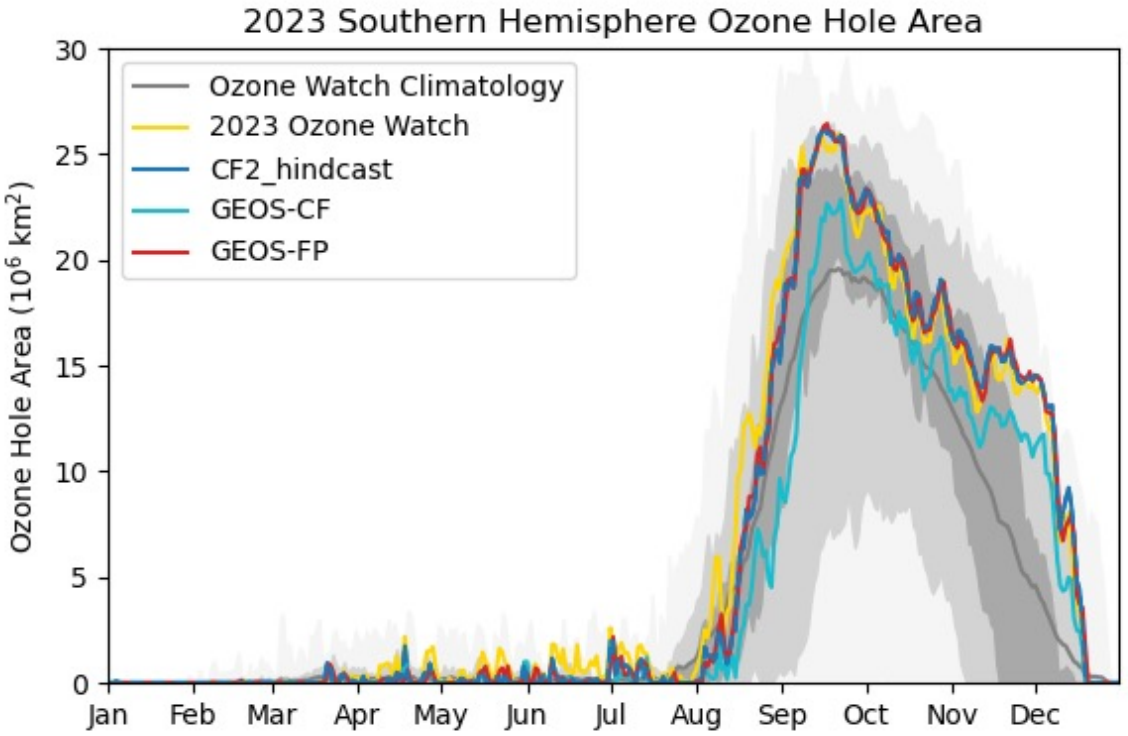


https://gmao.gsfc.nasa.gov/research/science_snapshots/2022/mauna-loa.php

K. Emma Knowland
k.e.knowland@nasa.gov

Improved representation of Stratospheric Ozone Hole

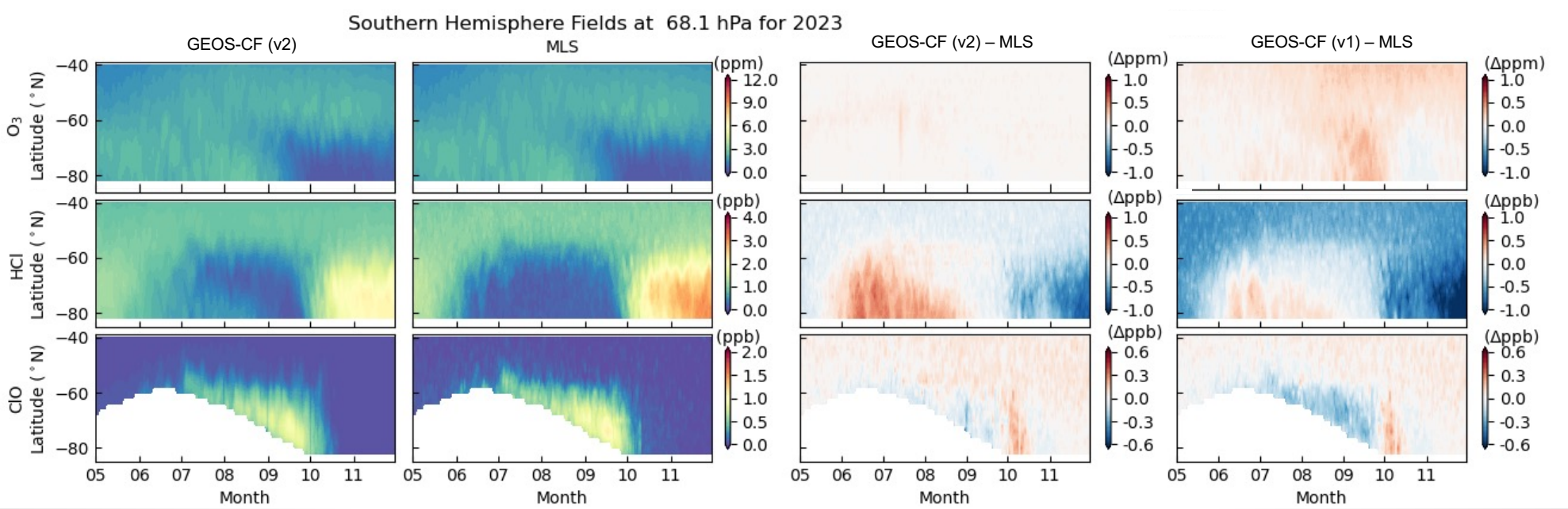
National Aeronautics and Space Administration



Direct assimilation of Aura ozone measurements improves the representation of the Antarctic ozone hole in the updated GEOS-CF system (dark blue) vs the current GEOS-CF system (cyan) and Observations (yellow; ozonewatch based on OMPS for 2023 https://ozonewatch.gsfc.nasa.gov/)

National Aeronautics and Space Administration

GEOS-Chem updates for improved stratospheric chemistry



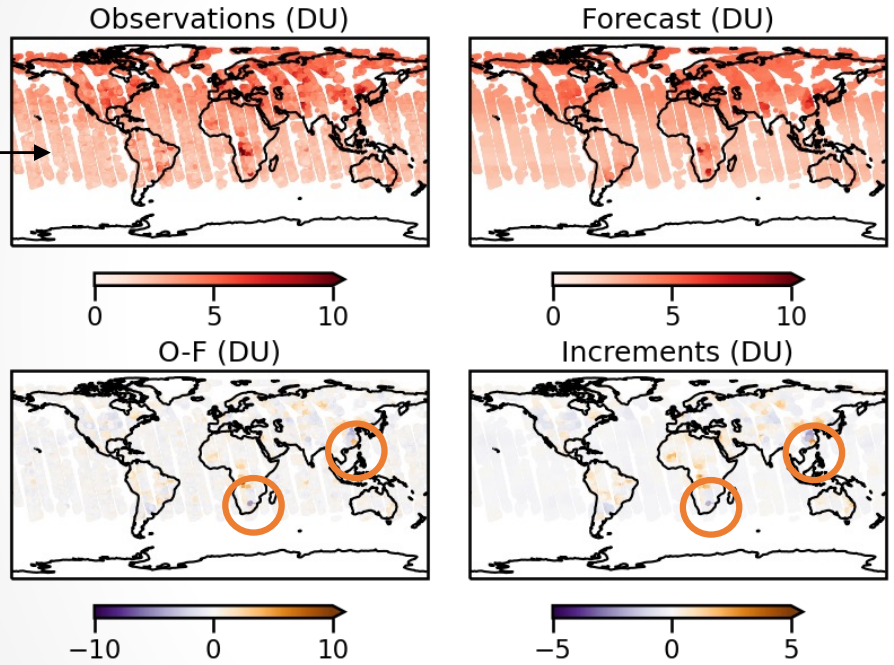
The formation of the ozone hole involves chlorine-driven catalytic loss cycles

- Activation of chlorine chemistry is seen by MLS via the conversion of stable HCl to reactive ClO
- Updates in the GEOS-Chem tropospheric chlorine chemistry improve the representation of the ozone loss cycles in the lower stratosphere

NO_2 assimilation in GEOS-CF v2 improves NO_2 in polluted areas

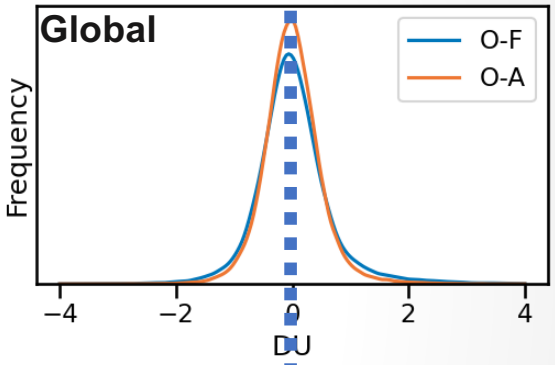
Assimilating OMI NO_2 total slant columns

Mostly Strat NO_2 in remote atmosphere



Increments smaller than O-F's reflects the ratio of observation to background errors

Frequency distributions of O-F and O-A

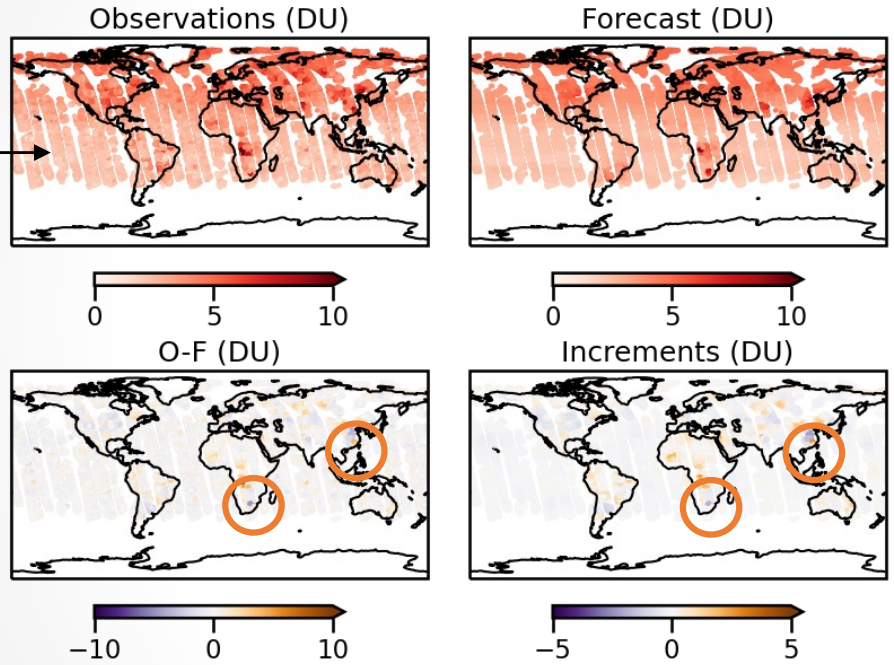


Viral Shah

NO_2 assimilation in GEOS-CF v2 improves NO_2 in polluted areas

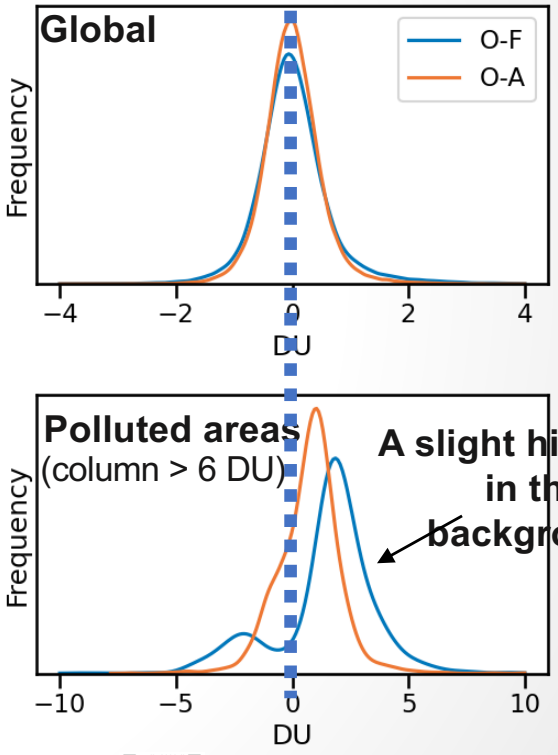
Assimilating OMI NO_2 total slant columns

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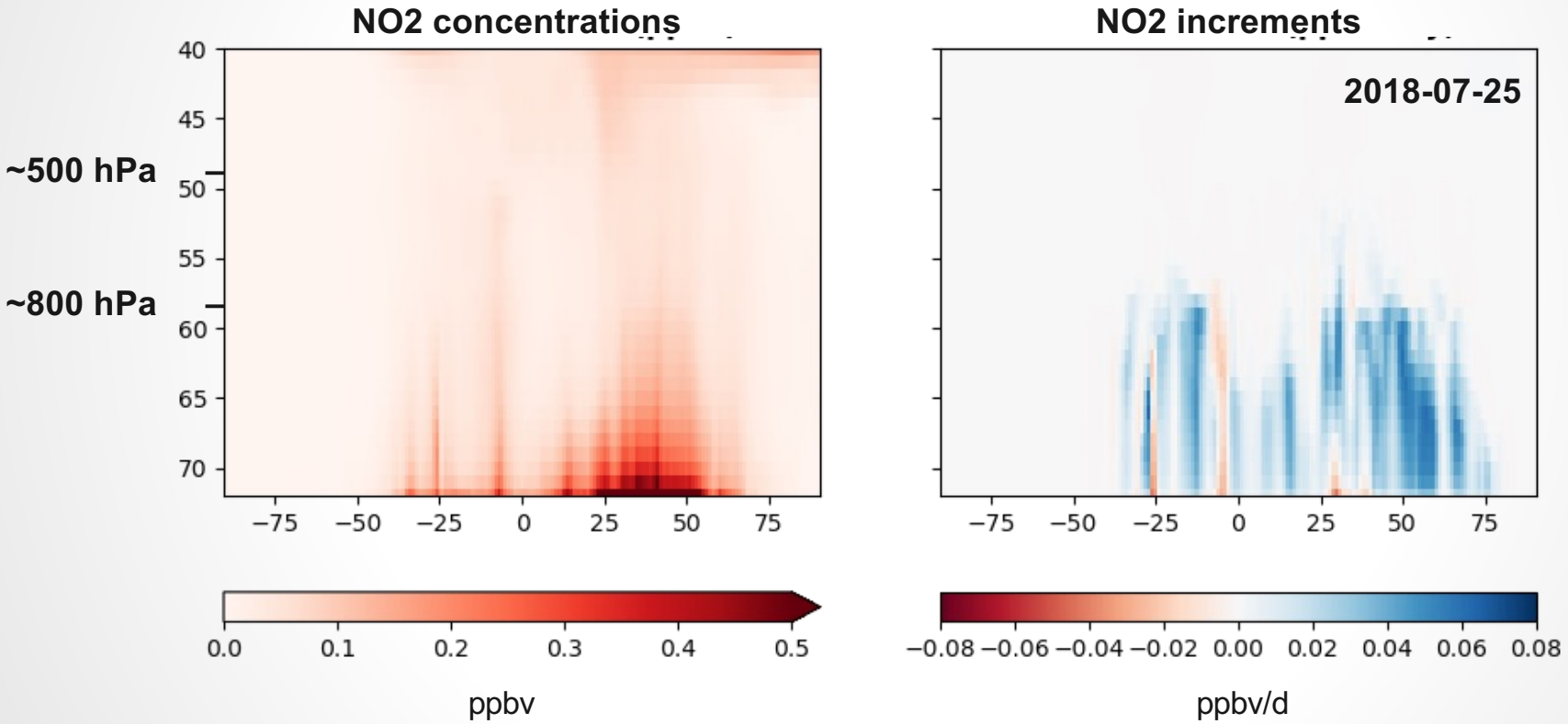
Frequency distributions of O-F and O-A



Viral Shah

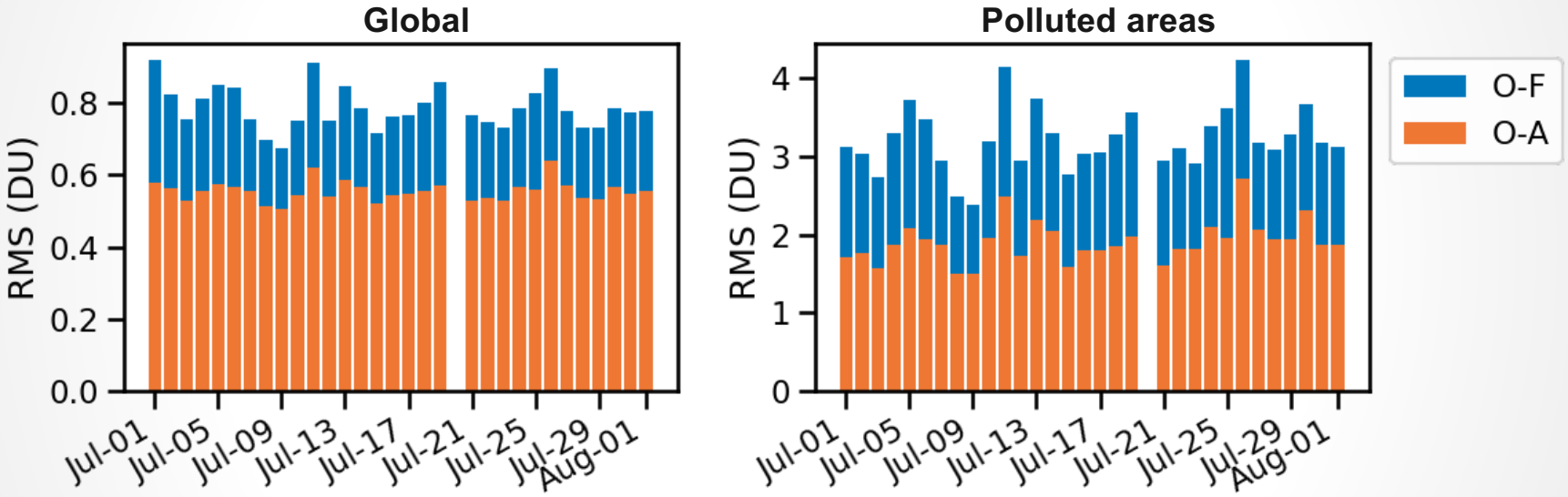
The increments are distributed in the lower troposphere

But are small at the surface where most of the trop NO_2 is present



There is little “memory” of the assimilated data

Because of fast chemistry & prescribed emissions

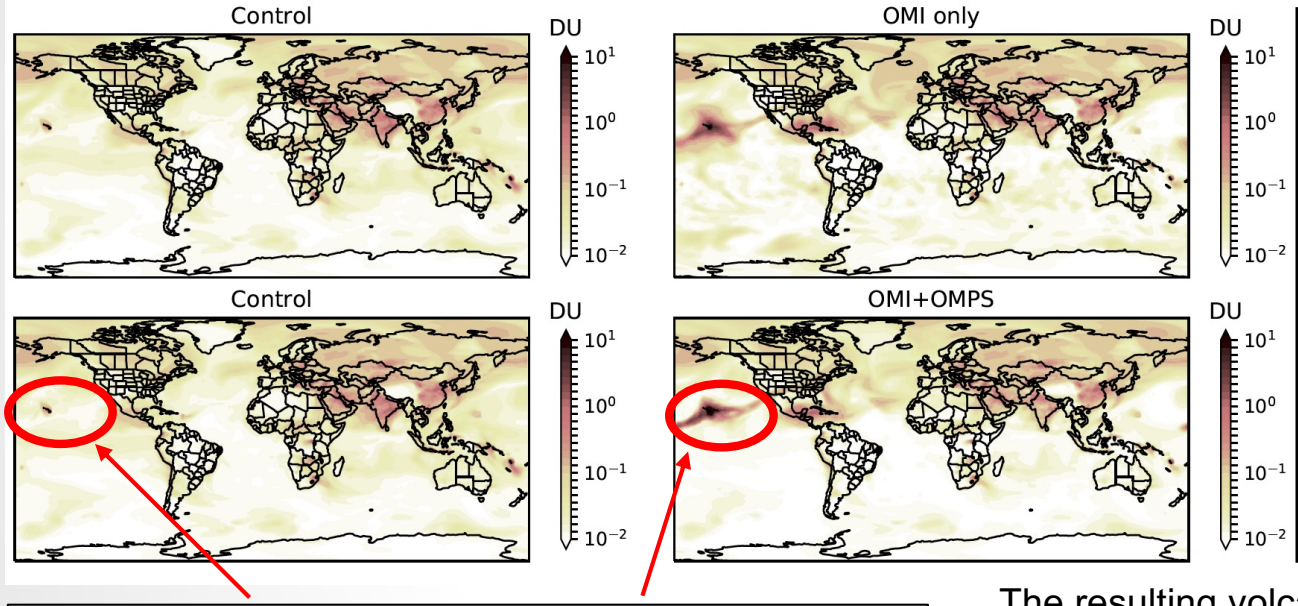


O-F RMS changes little through the month

SO_2 assimilation: Mauna Loa's smoking gun

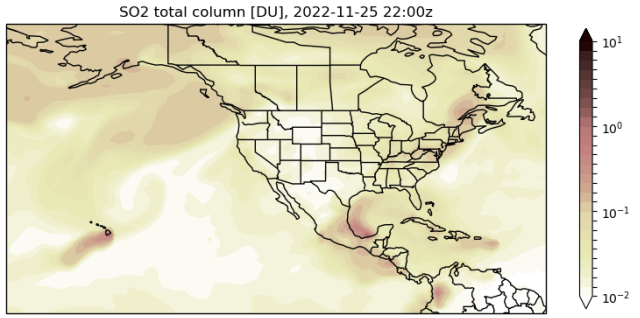
National Aeronautics and Space Administration

Simulated SO_2 total column [DU] for Dec 6, 2022



Mauna Loa eruption only captured in runs with assimilation

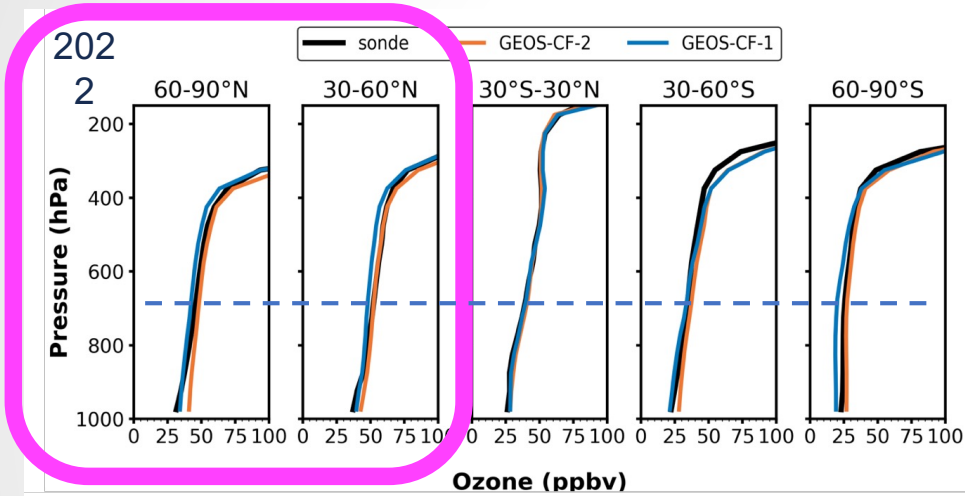
Evolution of assimilated SO_2 from the Mauna Loa eruption in November 2022



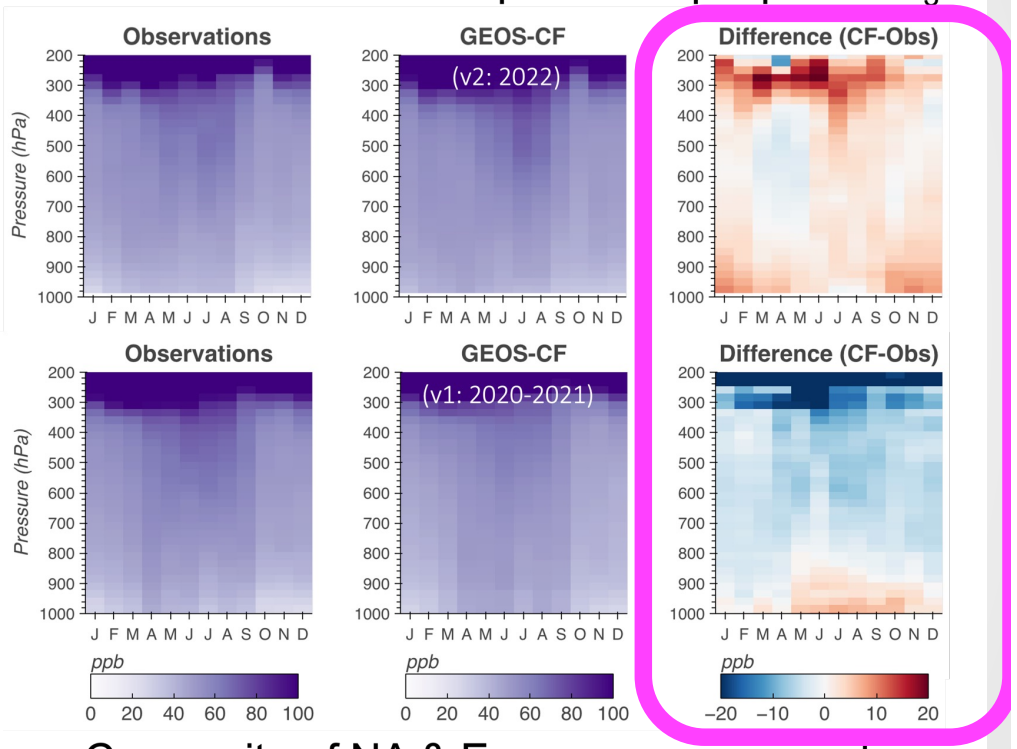
The resulting volcanic plume of sulfur dioxide (SO_2) can be seen from space with satellite instruments such as NASA's Ozone Monitoring Instrument (OMI).

https://gmao.gsfc.nasa.gov/research/science_snapshots/2022/mauna-loa.php

Tropospheric Ozone in V2 is Improved Because of Direct Assimilation



Ozone assimilation ➡ Improved tropospheric O_3

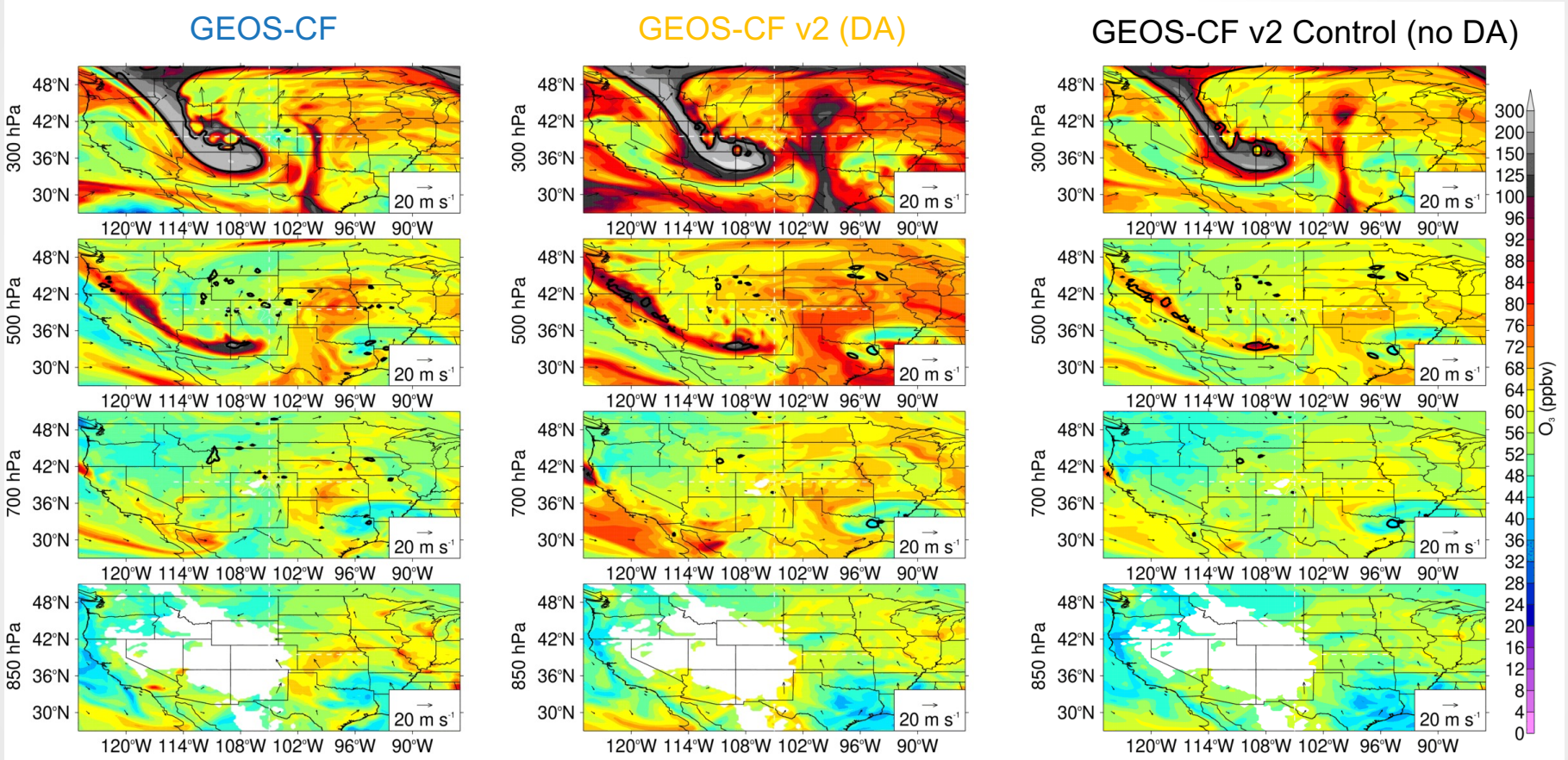


Version 1 Version 2

Composite of NA & European ozonesondes

National Aeronautics and Space Administration

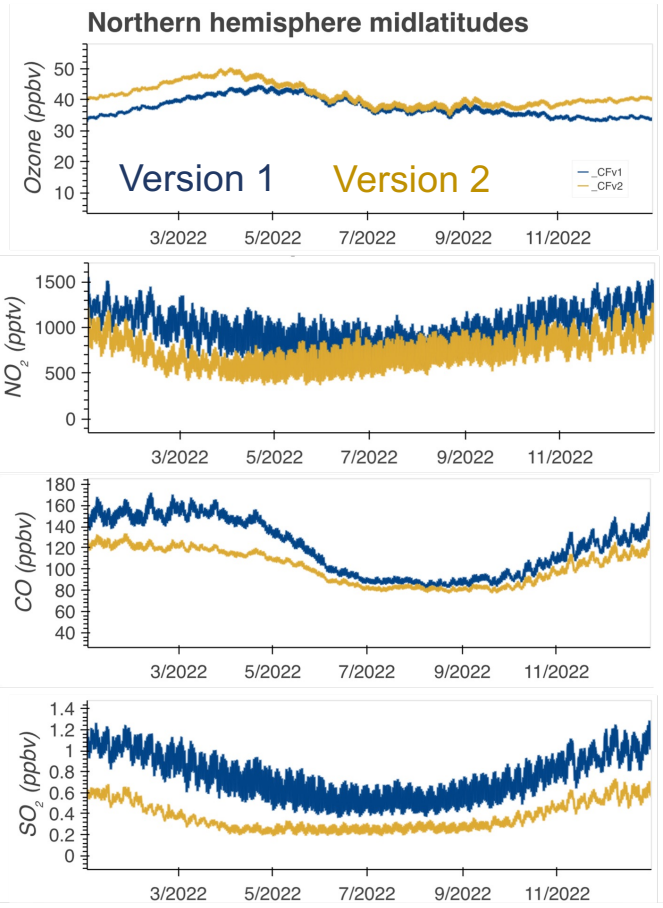
Stratospheric Intrusion case study May 11, 2023



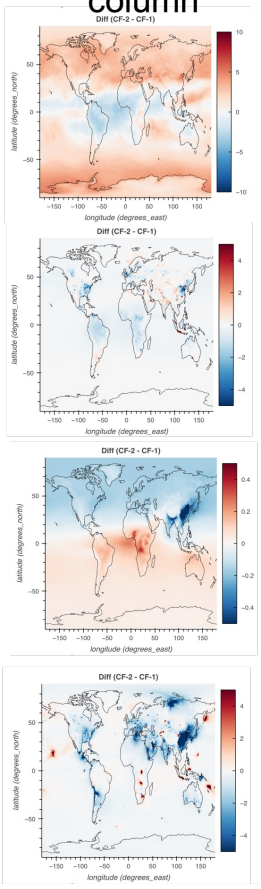
National Aeronautics and Space Administration

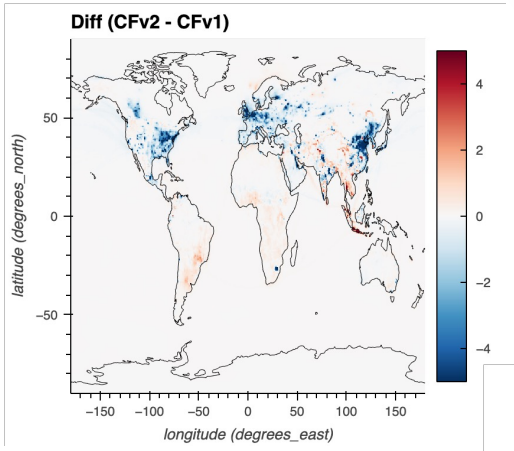
Lower NO_x emissions is leading to higher Ozone in GEOS-CF version 2

2022 Annual surface concentration



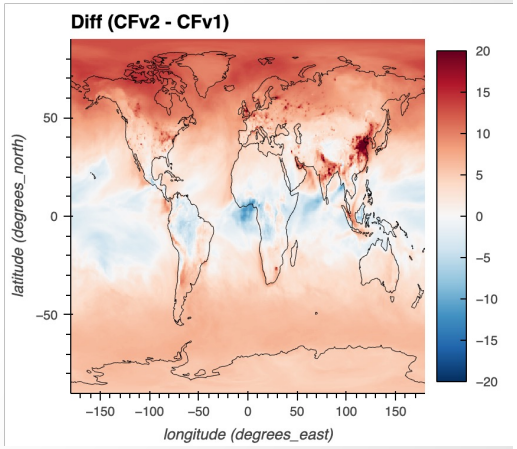
Annual tropospheric column





Surface NO_2 is lower in v2, especially in urban areas

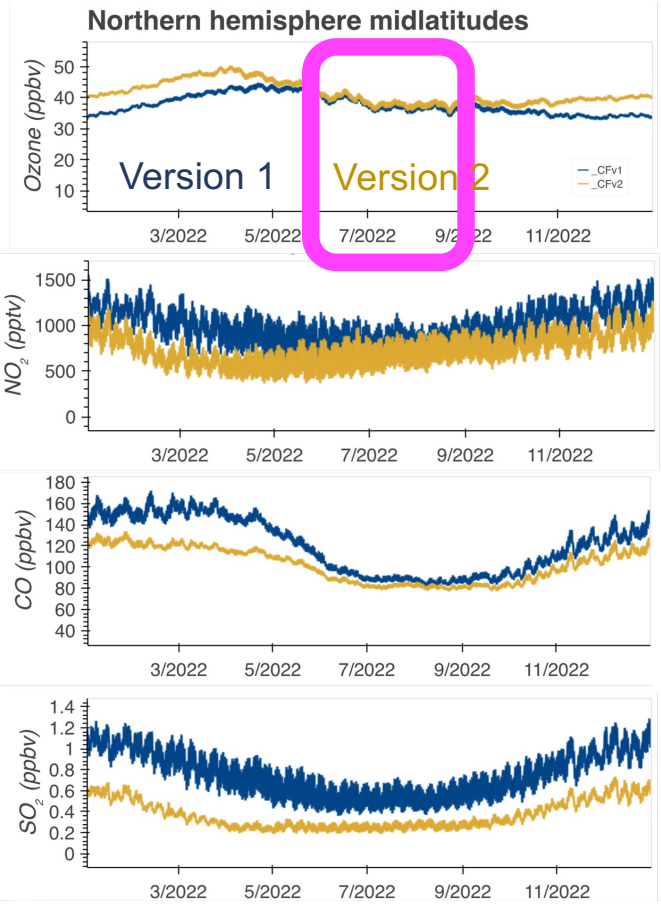
this leads to higher surface O_3



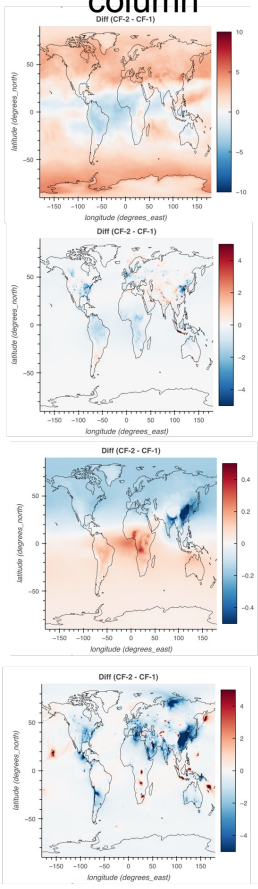
National Aeronautics and Space Administration

With updated GEOS met the summer O_3 bias in Southeast US is reduced

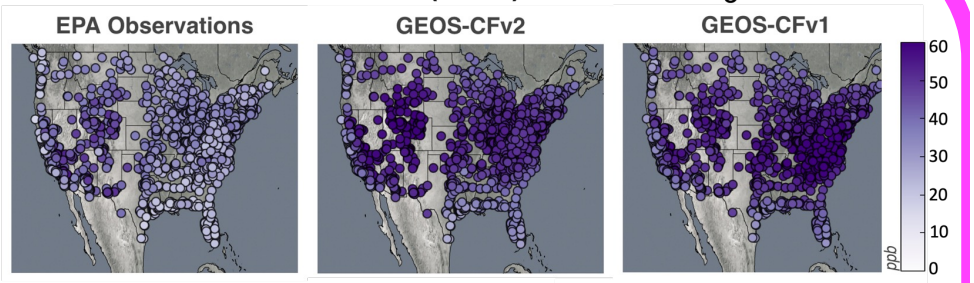
2022 Annual surface concentration



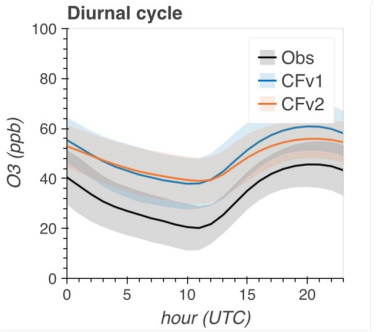
Annual tropospheric column



Summertime (JJA) surface O_3



Surface O_3 in Western US ⬆ and Eastern US ⬇ in version 2 compared to version 1. Overall, the daytime bias ⬇, closer to observations

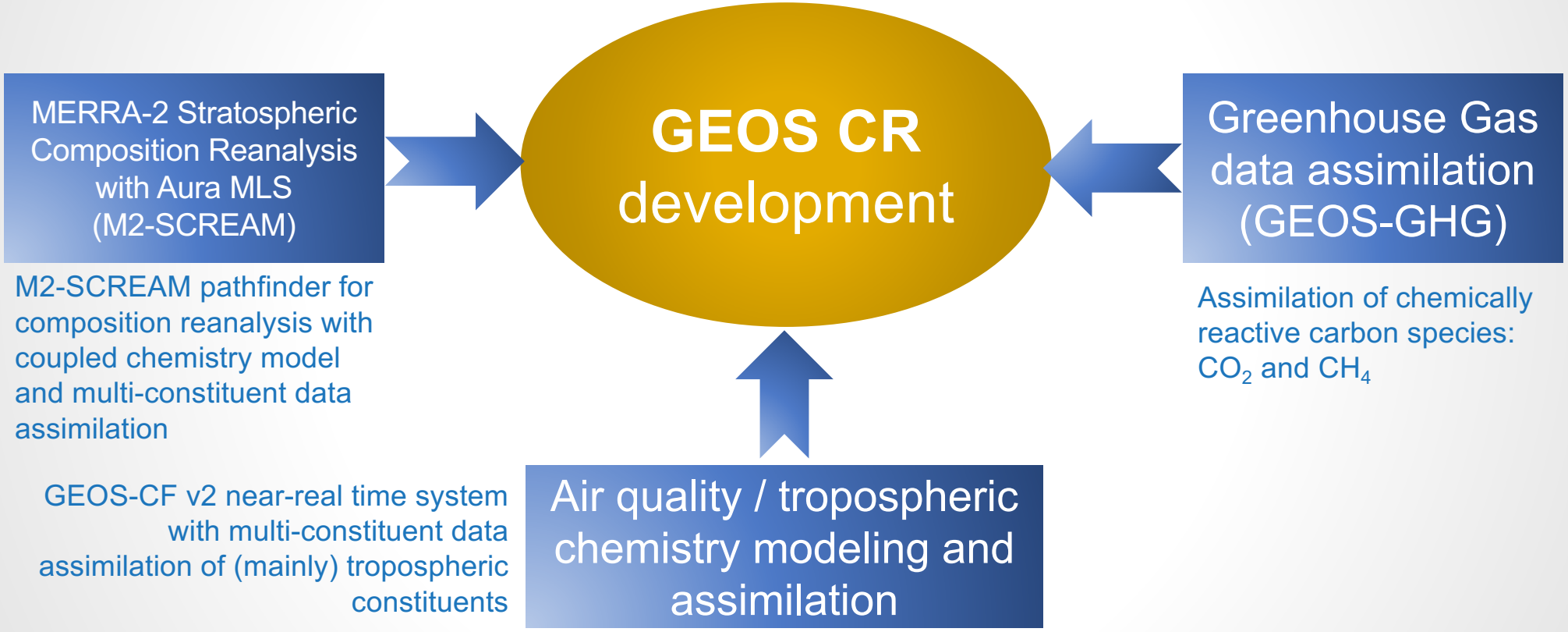


GODDARD EARTH SCIENCES

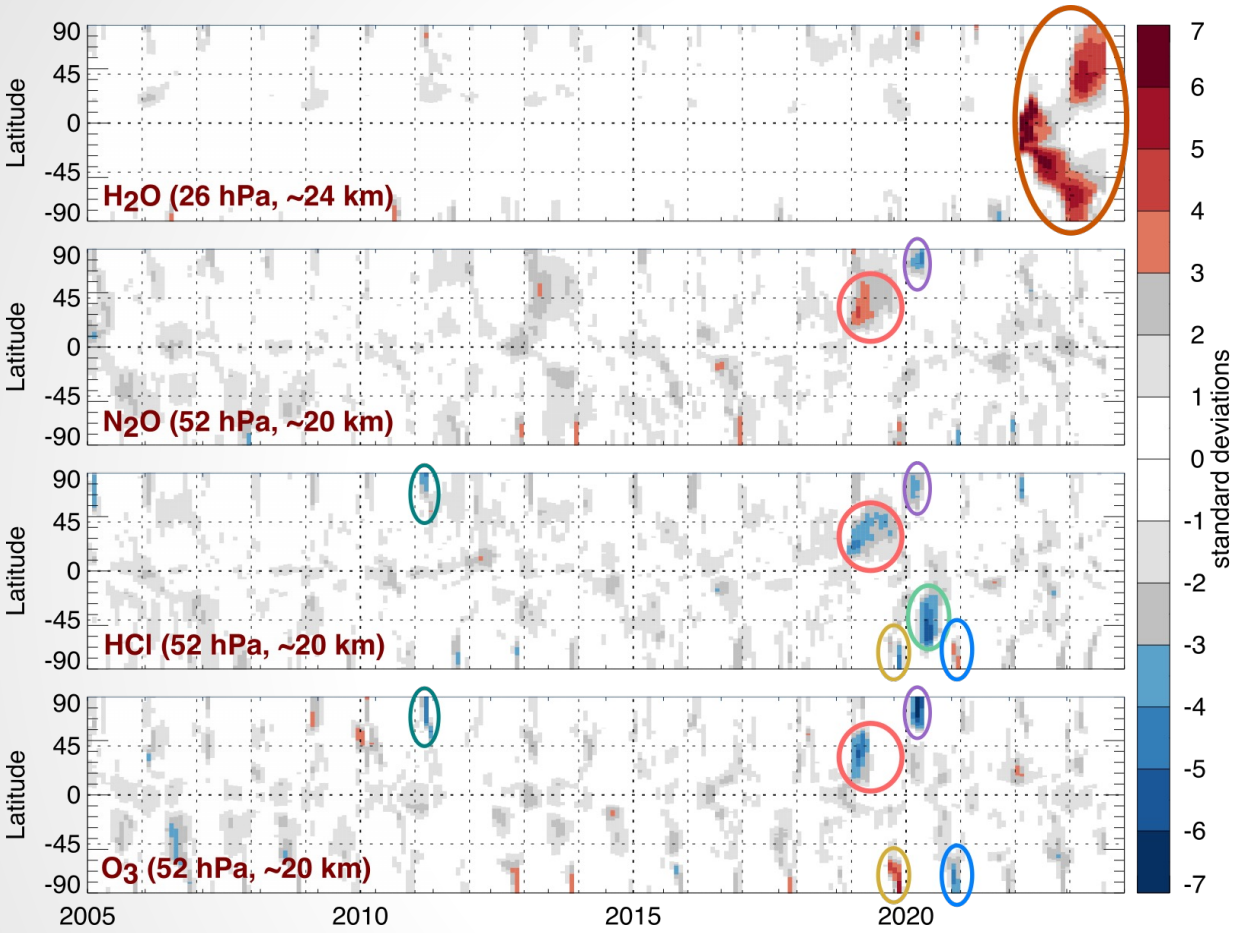
National Aeronautics and Space Administration

GEOS Composition Reanalysis for the 21st Century

Lines of development and legacy systems



K. Emma Knowland
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National Aeronautics and Space Administration

Our surprising stratosphere

2022 Hunga Tonga - Hunga Ha'apai eruption

2020 Long-lasting ozone hole

2020 Australian New Year's wildfires

2020 Exceptionally strong Arctic ozone minimum

2019 Rare sudden stratospheric warming in the Southern Hemisphere

2019 Dynamically driven anomaly

2011 Strong Arctic ozone minimum

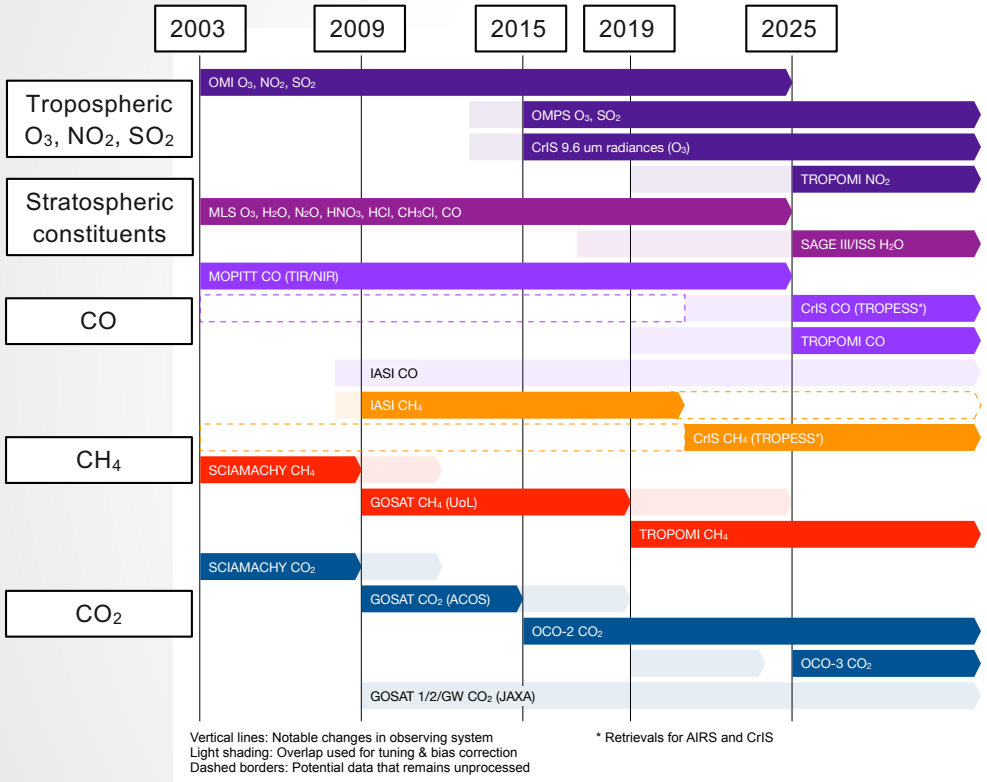
Detrended anomalies in constituent fields from M2-SCREAM

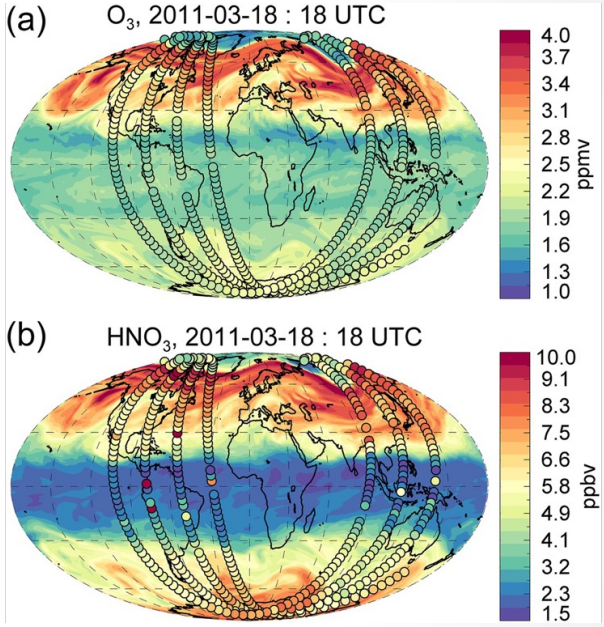
A series of large stratospheric perturbations occurred in the last five years.
Continuing measurements of the stratosphere will be essential for reanalyses.

Salawitch et al., submitted

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k.e.knowland@nasa.gov

A GEOS Composition Reanalysis for ~2000-2025, Based on GEOS-CF V2, M2-SCREAM, and GEOS-GHG



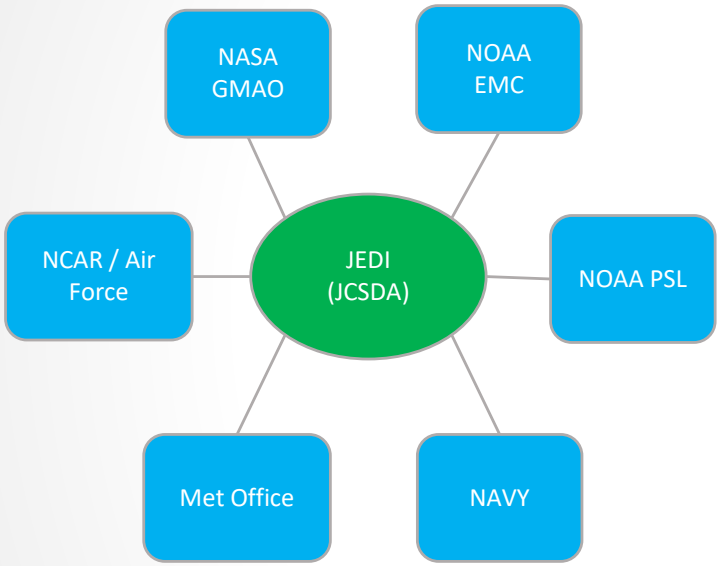


Wargan et al., JAMES, 2023, https://doi.org/10.1029/2022EA002632

GSI-based Constituent Data Assimilation System (CoDAS) forms the backbone to constituent assimilation products

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Community benefit of JEDI data assimilation software



JEDI, managed by the Joint Center for Satellite Data Assimilation (JCSDA), is truly a community effort with no one agency dictating the development.

The only difference between the way GMAO uses JEDI and the way another center uses it is the configuration file.

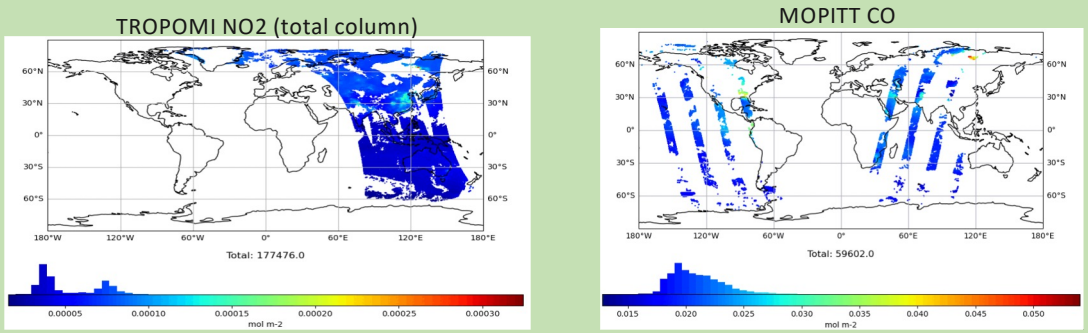
It can be thought of as a repository exhibiting the state-of-the-art in data assimilation knowledge made available to everybody.

As new NASA data come online they can be made available to many users in very short order.

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New developments: JEDI assimilation and faster chemistry

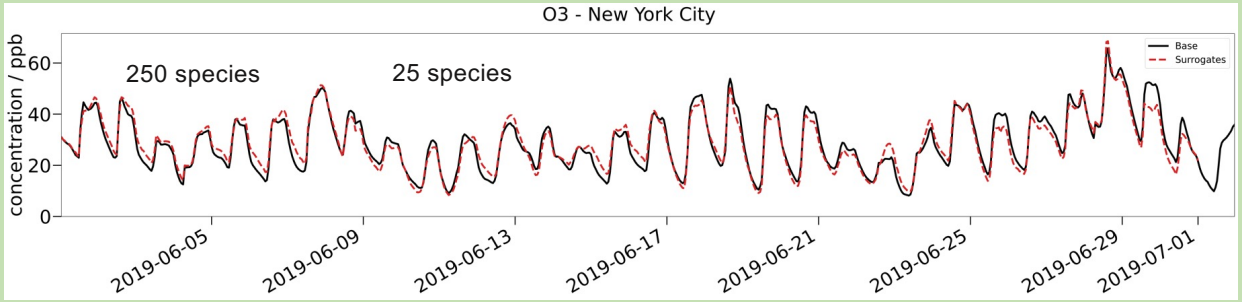
Demonstration: Use of JEDI for GEOS-CF trace-gas monitoring



Figures courtesy of Jérôme Barré

- JEDI assimilation algorithms developed through investment in the JCSDA
- Near-term implementation brings multiple observations in to GEOS-CF, including high-frequency TEMPO data
- Long-term developments include implementation and testing of advanced (non-Gaussian) DA algorithms for constituents and use of modern AI-based techniques

Demonstration: Use of a surrogate model to increase computational efficiency



Ivatt et al., in prep

- Full chemistry model includes more than 250 species – too costly for high resolution forecasts..
- AI surrogate models produce robust short-term simulations with more than 5-fold reductions in memory and compute requirements
- This research result needs to be fully tested at higher resolution and implemented robustly

A 2km-12.5km Global Grid for GEOS

Current configuration for mesoscale meteorology:

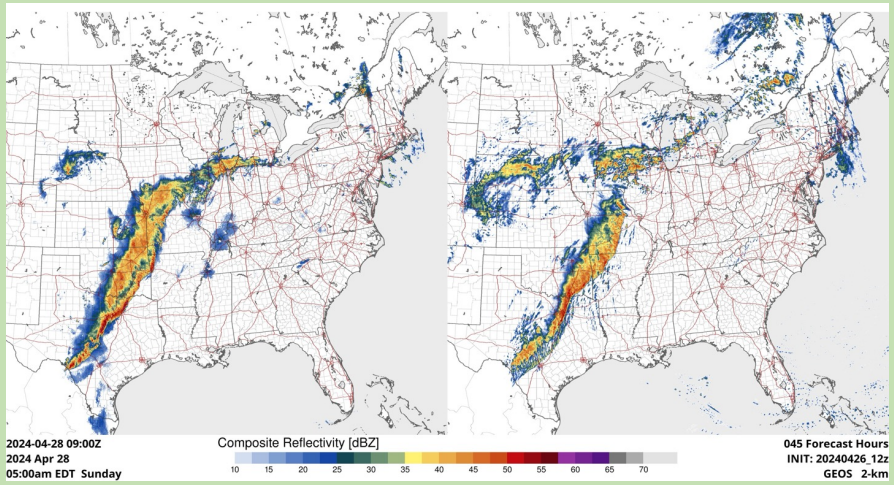
c2160 stretched grid (2km over CONUS)

137 layers: resolves PBL structure, UTLS, etc.

T106 spectral increment filter in replay

13 days/day throughput on 660 AMD Milan Nodes

5.5 hours per 3-day forecast for meteorology

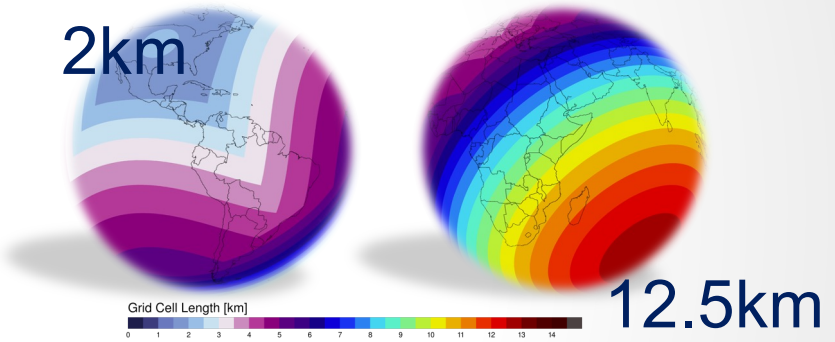


Observed Composite reflectivity at 05UT on on April 28, 2024 (left) and a 45-hour GEOS forecast for the same time (right)

c2160 stretch_fac=2.5

2 km CONUS Grid

Antipole matches current GEOS-FP 12.5 km Resolution



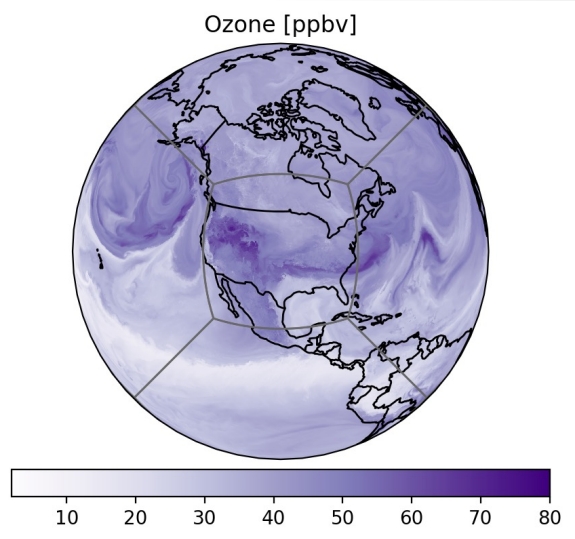
The project will target a radical new incarnation of GEOS-CF that increases resolution to 12.5km globally, with regional scales of 2km over CONUS, to focus on the application of TEMPO observations.

GEOS-CF for Actionable Science

Proposed approach for a GEOS-CF concept that aligns to NASA's current assets and points to the future:

- Focus on TEMPO mission using a global system with refined resolution over North America
- Capitalize on investments in ML-accelerated chemistry mechanism for computational efficiency
- Capitalize on investments in JEDI-based constituent assimilation to prepare for Geo XO era
- Develop a sustainable open data distribution paradigm with comprehensive cloud-based tools for Earth Action

Trial representation of surface ozone on a stretched grid with 8-km resolution over CONUS



The project will target a radical new incarnation of GEOS-CF that increases resolution to 12.5km globally, with regional scales of 2km over CONUS, to focus on the application of TEMPO observations.

Questions about GEOS-CF may be submitted to our email List, geos-cf@lists.nasa.gov.

Sign up for notifications about GEOS-CF production issues and upgrades –

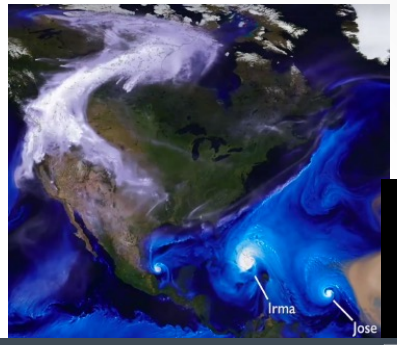
• To subscribe to "geos-cf-users@lists.nasa.gov":
Send an e-mail to geos-cf-users-join@lists.nasa.gov (no subject or text in the body is required).

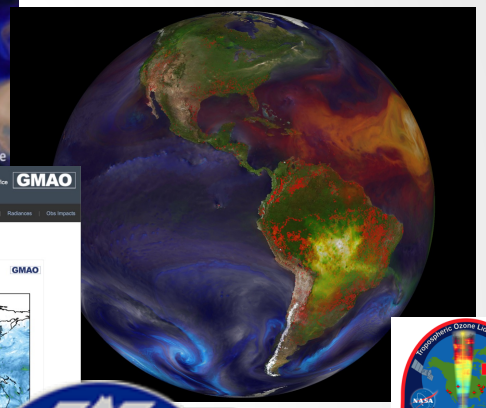
National Aeronautics and Space Administration

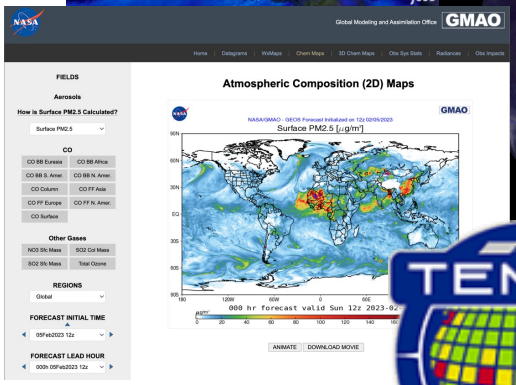
Summary

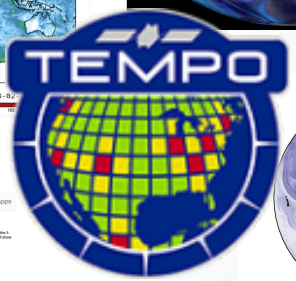
- GMAO has a state-of-the-science Earth System model and data assimilation system
- Involved and invested in new data assimilation infrastructure for multi-constituent data assimilation system
- GEOS-CF Version 1 grew from ROSES funding and has expanded GMAO's role in global composition forecasting
- Support of additional NASA science teams (providing a priori for TEMPO trace gas retrievals, field campaigns, …)
- GEOS-CF Version 2 introduces assimilation and other improvements (model transport, emissions) and is the basis for GMAO's constituent reanalysis

Thank you for listening!

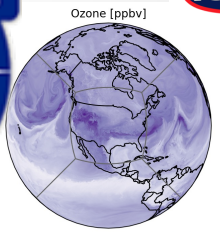


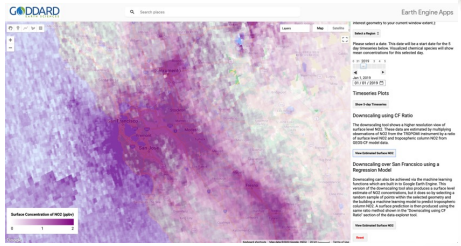


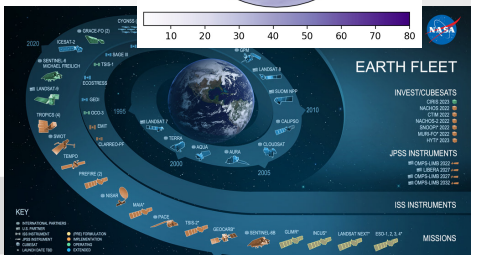












GMAO Global Modeling and Assimilation Office
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