National Aeronautics and Space Administration

Global-to-Local Air Quality Forecasts using the NASA GEOS Composition Forecasting System

Emma Knowland*, Christoph Keller*, Carl Malings*, Viral Shah+, Pam Wales*, Callum Wayman+, Lesley Ott, Steven Pawson

Global Modeling and Assimilation Office (GMAO)

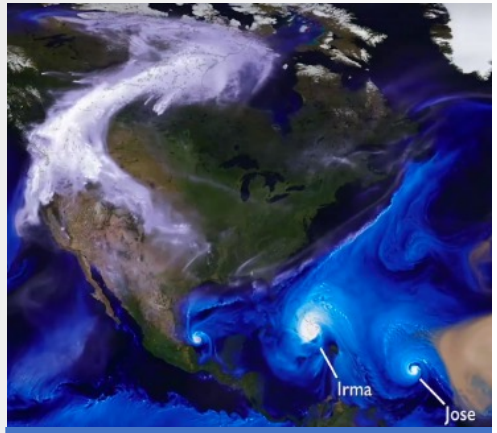
Earth Sciences Division, Sciences and Exploration Directorate,

NASA Goddard Space Flight Center

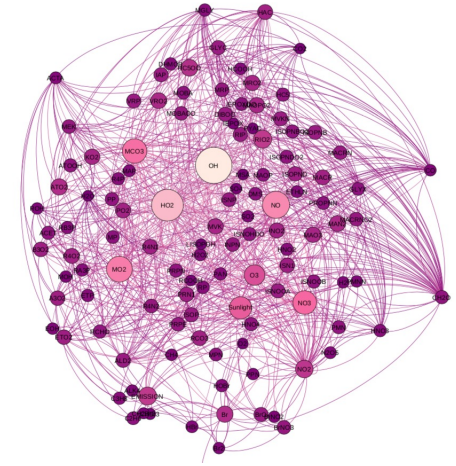
*Also at GESTAR-2, Morgan State University

+Also at Science Systems and Applications, Inc. (SSAI)

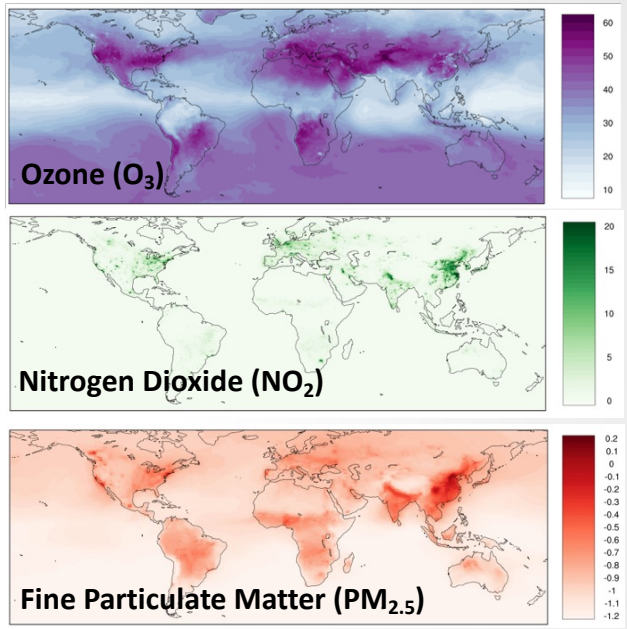
GEOS with Coupled GEOS-Chem chemistry: TEMPO support



GEOS NWP



GEOS-Chem



G5NR - Chem

Hu, L., Keller, C. A., et al (2018). **Global simulation of tropospheric chemistry at 12.5 km resolution: performance and evaluation of the GEOS-Chem chemical module (v10-1) within the NASA GEOS Earth system model (GEOS-5 ESM)**. *Geosci. Model Dev.*, 11, 4603–4620, https://doi.org/10.5194/gmd-11-4603-2018.

GEOS - CF

Keller, C. A., Knowland, K. E., 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

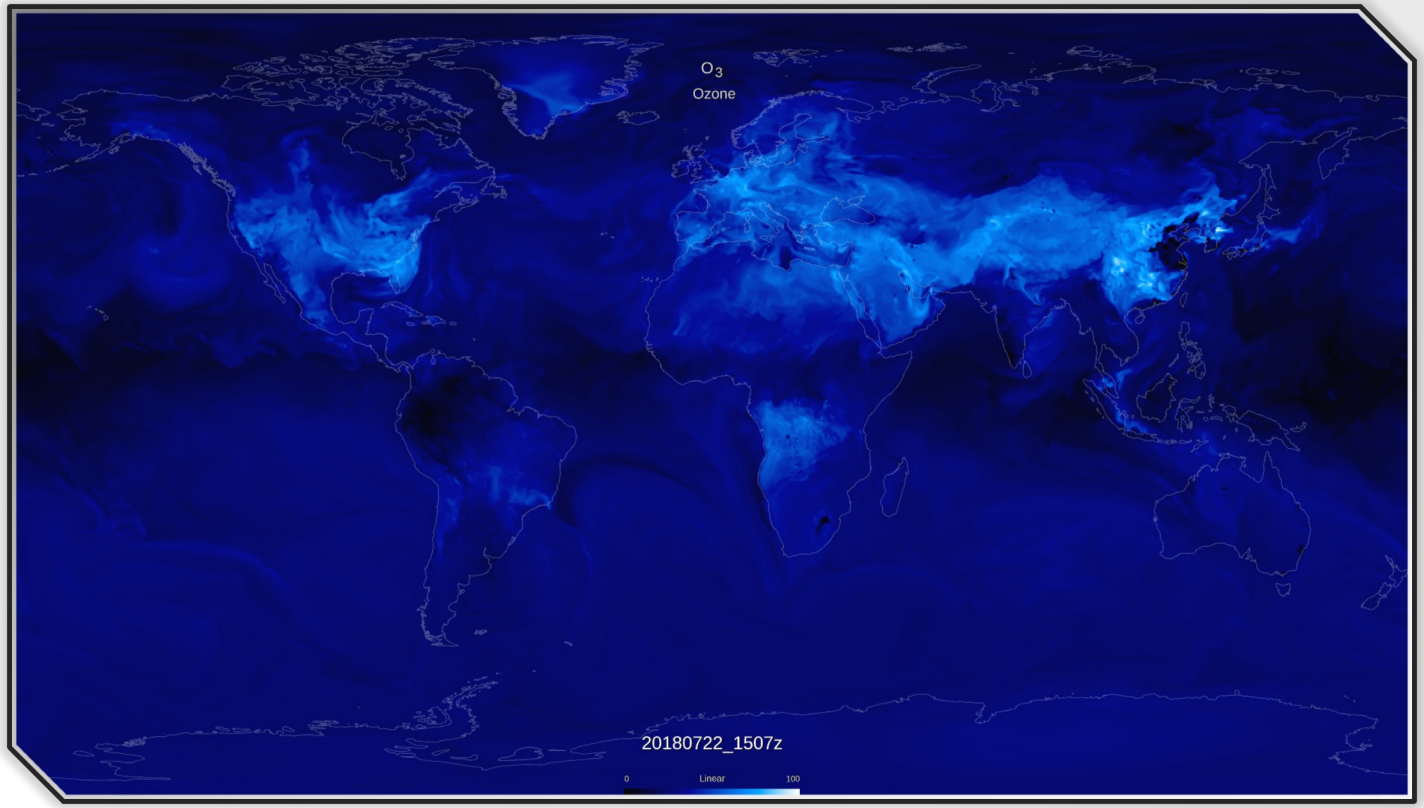
Knowland, K. E., Keller, C. A., et al. (2022). **NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0: Stratospheric Composition.** *JAMES* https://doi.org/10.1029/2021MS002852

Rationale for GEOS-CF

National Aeronautics and Space Administration

Context of NASA's Earth Science Mission:

- EOS mission provides a more-than two-decade record of atmospheric composition
- Assimilated "weather" and complex chemistry module (GEOS-Chem) facilitates generation of this 3D gridded, continuous dataset for research and applications
- Real-time availability is suited for support of suborbital missions and in-situ networks
- Support of TEMPO and other space missions
- Complexity of the chemical mechanism makes GEOS-CF a baseline for more viable "operational" products



https://svs.gsfc.nasa.gov/4754

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

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

GEOS with Coupled GEOS-Chem chemistry: TEMPO support

G5NR-Chem

1 July 2013 – 1 July 2014

- Meteorological "replay"
- c720 (0.125 °,**~12.5 x 12.5 km²**)
- 72 model layers
- GEOS-Chem v10-01 Tropospheric-only mode
- Default GEOS-Chem emissions
- 1-hour, 29 species

GEOS-CF

1 January 2018 - present

- 1-day replay + 5-day forecast
- c360 (0.25°, **~25 x 25 km²**)
- 72 model layers
- GEOS-Chem v12.0.1, with full Tropospheric & Stratospheric chem
- HTAP v2.2 anthropogenic emissions
- 1-hour 2D & 3D output, **including specific TEMPO file for retrievals**

Knowland et al., 2022. "File Specification for GEOS-CF Products." *GMAO Office Note No. 17 (Version 1.3), available from http://gmao.gsfc.nasa.gov/pubs/office_notes*

TEMPO specific collection: "sat_inst_1hr_r721x361_v72"

Regional Chemistry and Meteorology Diagnostics to support TEMPO satellite

Frequency: *hourly instantaneous from 00:00 UTC*

Spatial Grid: *3D, model-level, subset region of full horizontal resolution*

Dimensions: *longitude=721, latitude=361, every 0.25º*

longitude: 0º to -180º

latitude: 0º to 90º

vertical level: *72 layers*

Granule Size: *~258 MB per file*

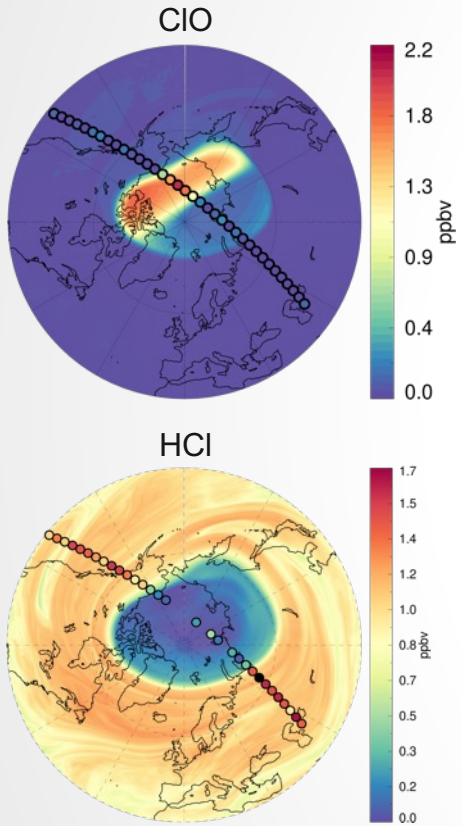
Start date: 00 UTC 1 January 2022

Mode: Replay only; Forecasts available based on mission requirements

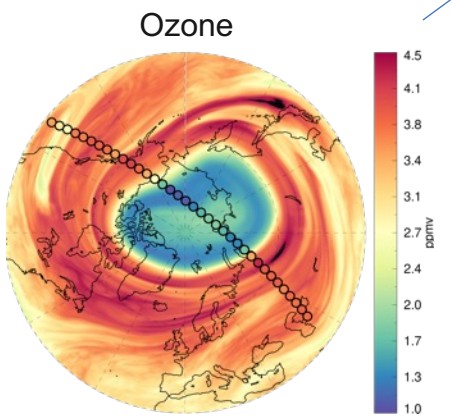
Name	Dim	Description	Units
BrO	tzyx	Bromine monoxide (BrO, MW = 96.00 g mol-1) volume mixing ratio dry air	mol mol-1
FRSEAICE	tyx	ice covered fraction of tile	1
FRSNO	tyx	fractional area of land snowcover	1
GLYX	tzyx	Glyoxal (CHOCHO, MW = 58.00 g mol-1) volume mixing ratio dry air	mol mol-1
HCHO	tzyx	Formaldehyde (CH2O, MW = 30.00 g mol-1) volume mixing ratio dry air	mol mol-1
HNO2	tzyx	Nitrous acid (HNO2, MW = 47.00 g mol-1) volume mixing ratio dry air	mol mol-1
IO	tzyx	Iodine monoxide (IO, MW = 143.00 g mol-1) volume mixing ratio dry air	mol mol-1
NO2	tzyx	Nitrogen dioxide (NO2, MW = 46.00 g mol-1) volume mixing ratio dry air	mol mol-1
O3	tzyx	Ozone (O3, MW = 48.00 g mol-1) volume mixing ratio dry air	mol mol-1
OClO	tzyx	Chlorine dioxide (OClO, MW = 67.00 g mol-1) volume mixing ratio dry air	mol mol-1
PHIS	tyx	surface geopotential height	m+2 s-2
PS	tyx	surface pressure	Pa
Q	tzyx	specific humidity	kg kg-1
SNODP	tyx	snow depth	m
SNOMAS	tyx	Total snow storage land	kg m-2
SO2	tzyx	Sulfur dioxide (SO2, MW = 64.00 g mol-1) volume mixing ratio dry air	mol mol-1
T	tzyx	air temperature	K
TROPPB	tyx	tropopause pressure based on blended estimate	Pa
U2M	tyx	2-meter eastward wind	m s-1
V2M	tyx	2-meter northward wind	m s-1
ZPBL	tyx	planetary boundary layer height	m

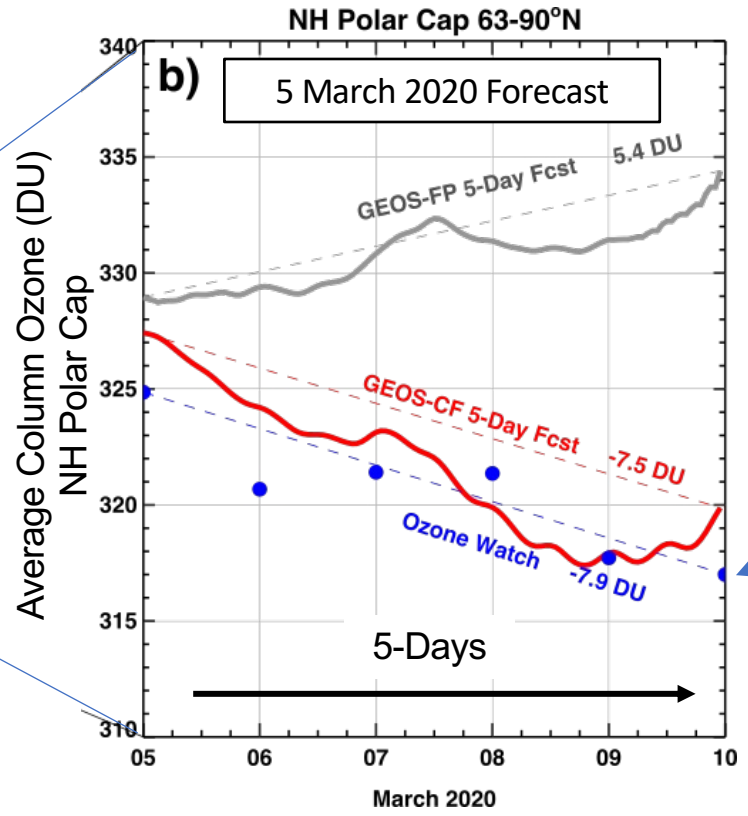
Knowland et al., 2022. "File Specification for GEOS-CF Products." *GMAO Office Note No. 17 (Version 1.3), available from http://gmao.gsfc.nasa.gov/pubs/office_notes*

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

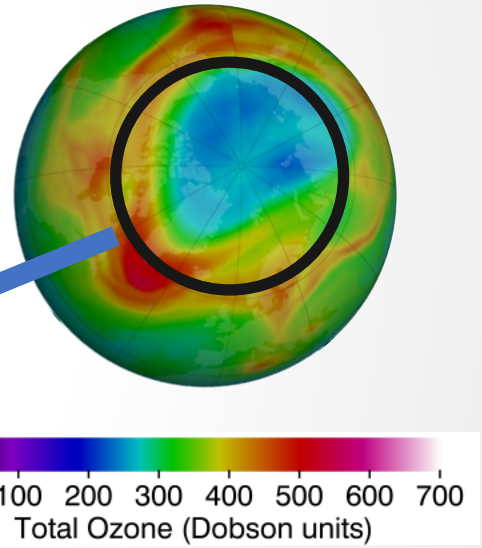


March 5, 2020
GEOS-CF





March 10, 2020
Ozonewatch



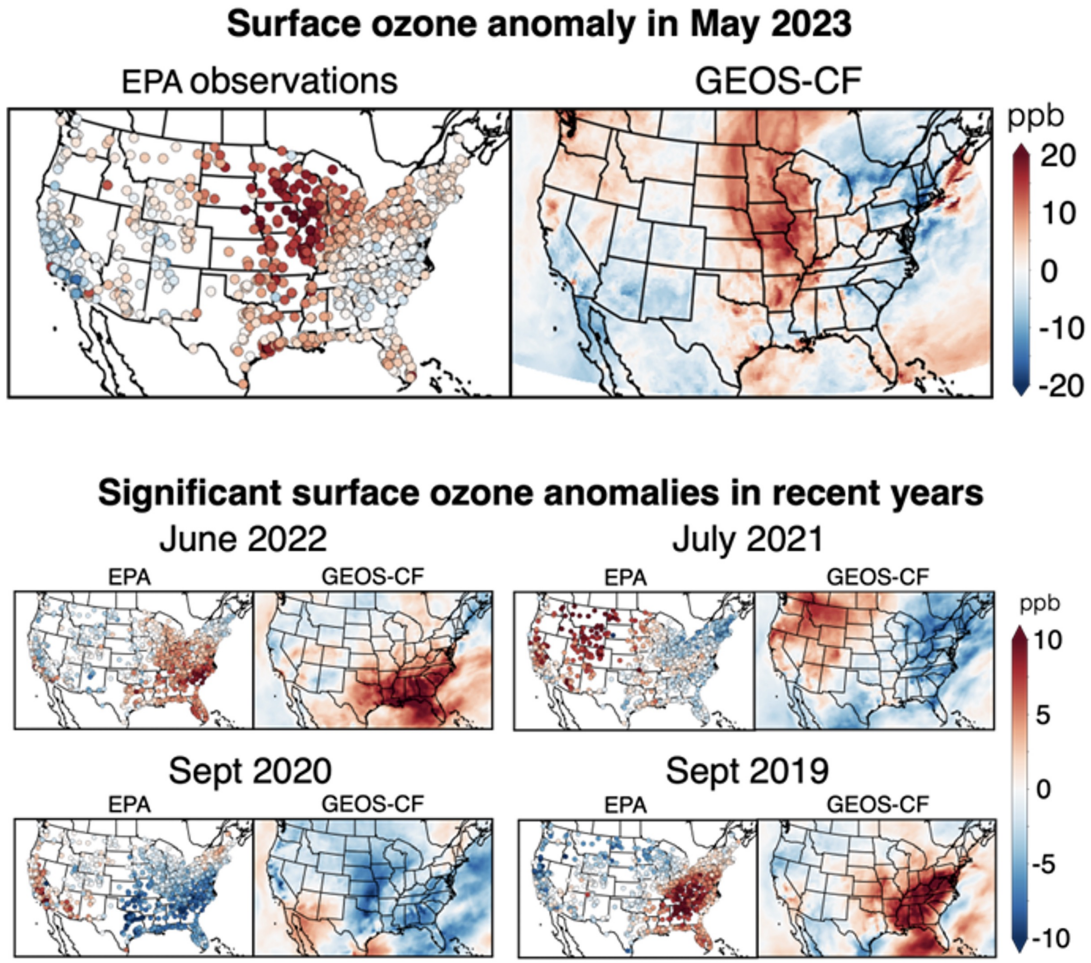
Ozonewatch.gsfc.nasa.gov

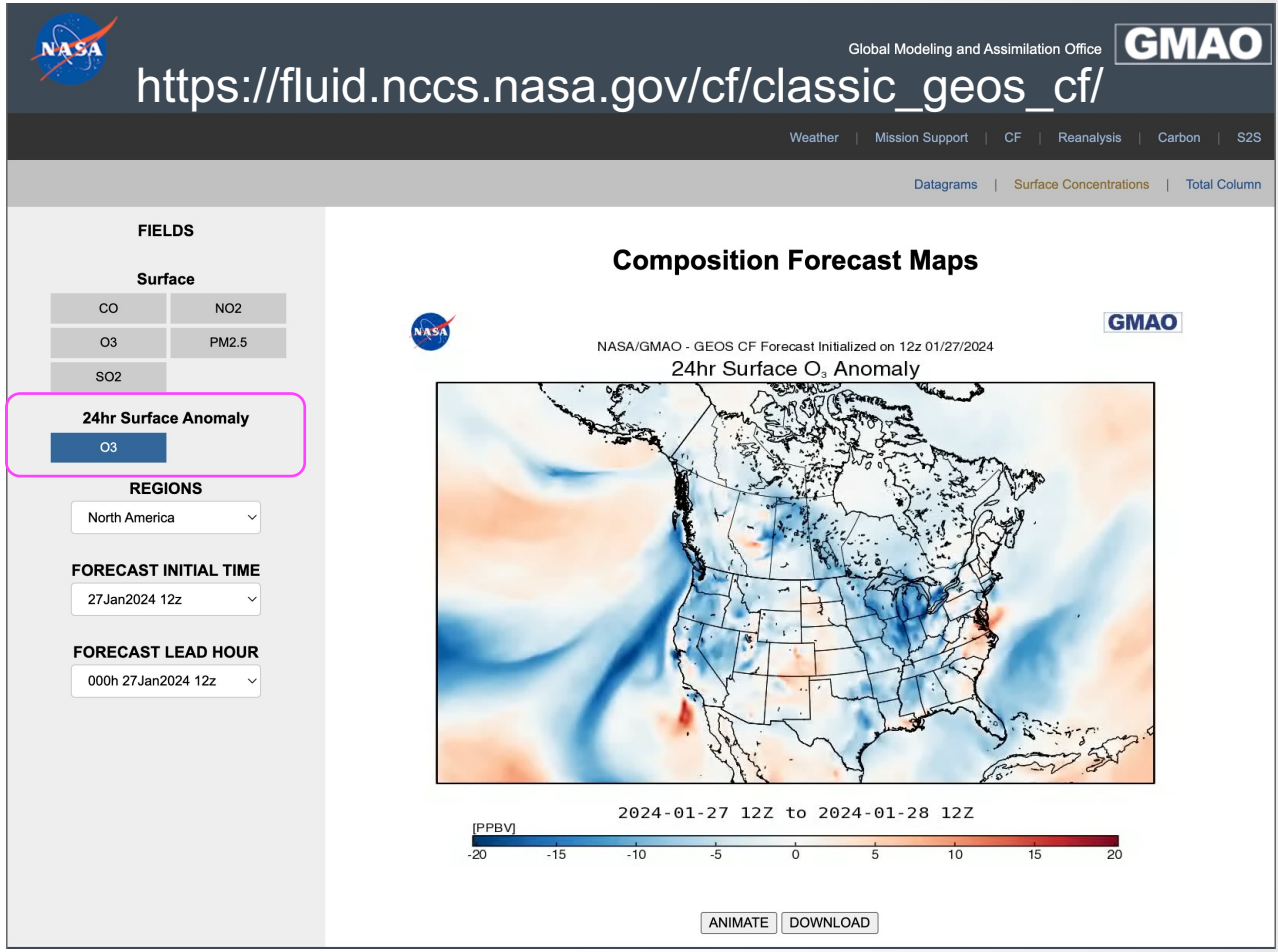
Knowland et al., JAMES, 2022, https://doi.org/10.1029/2021MS002852

Emma Knowland

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

Linking Surface Ozone Extremes to Weather Pattern Anomalies

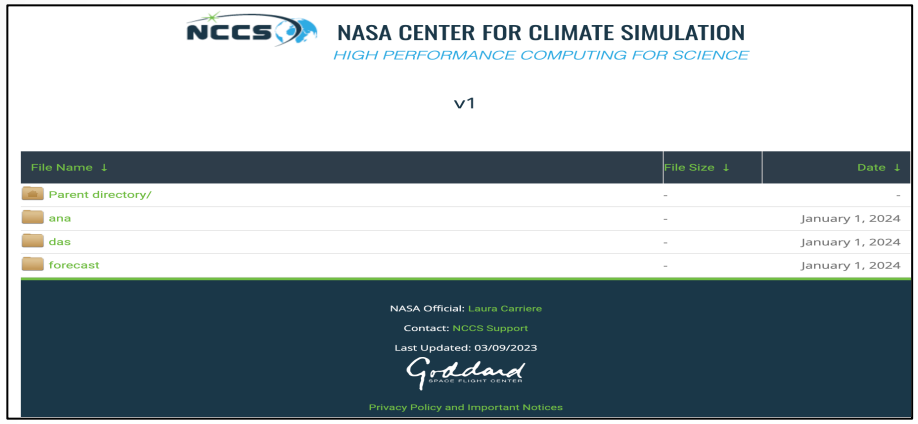


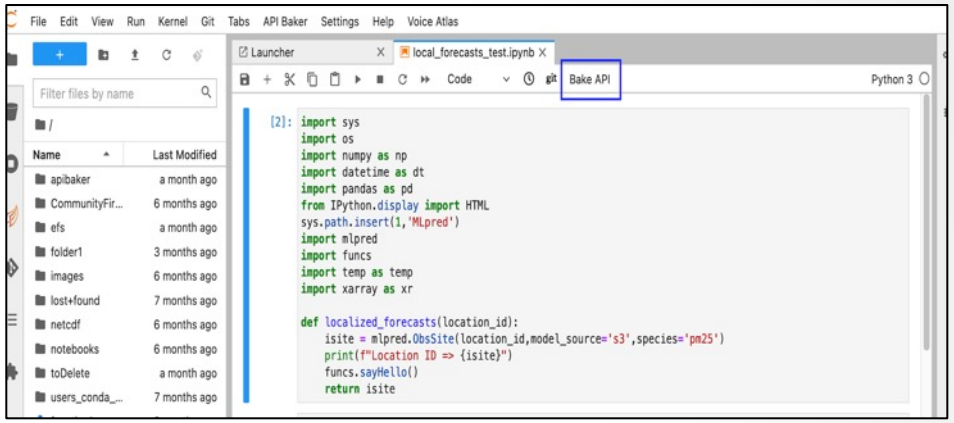


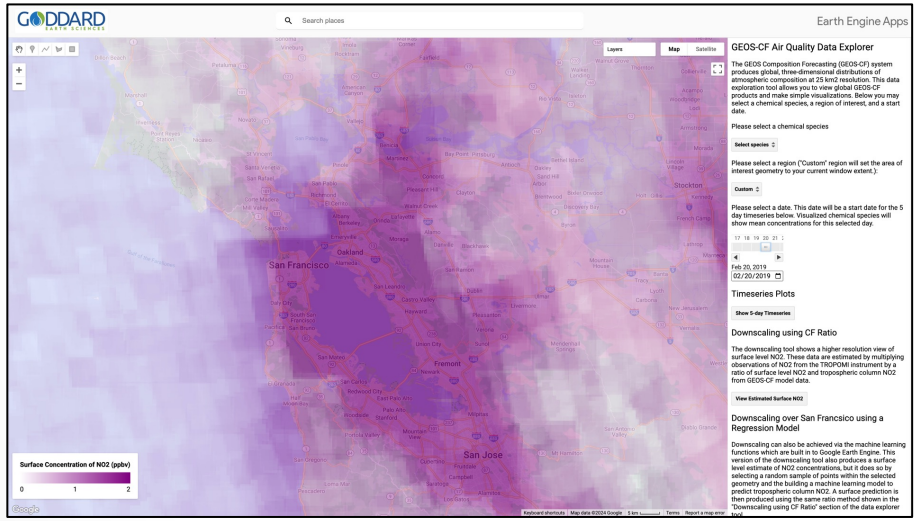
Viral Shah

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

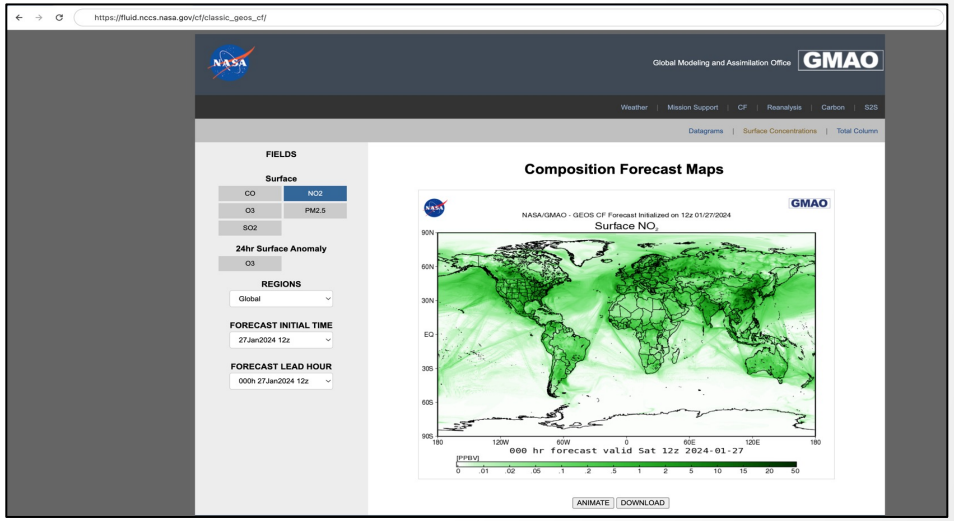
Ongoing Efforts to Expand Data Access – Demand & Opportunity







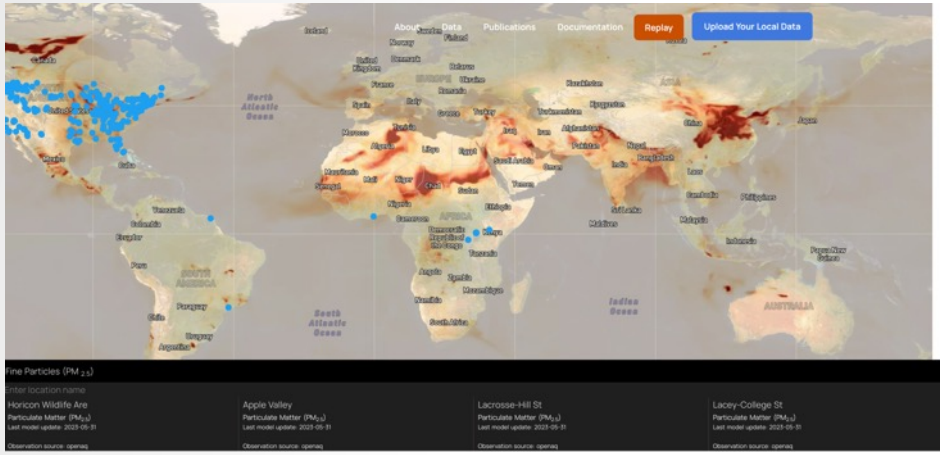
https://gmao.gsfc.nasa.gov/research/science_snapshots/2023/new-generation-gmao-apps.php

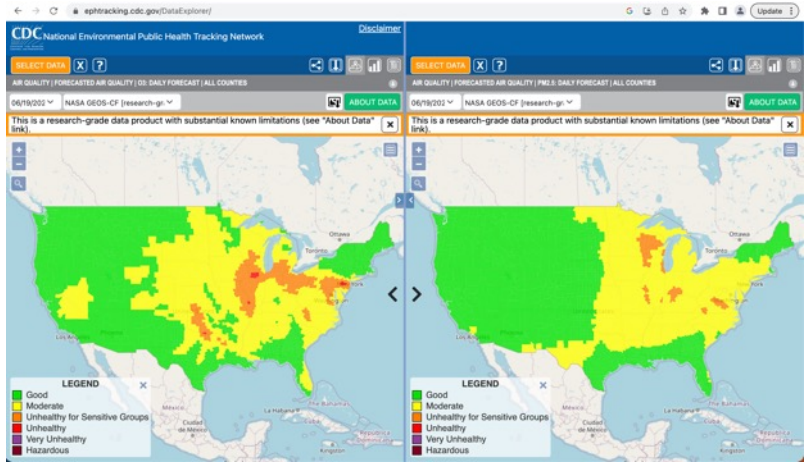


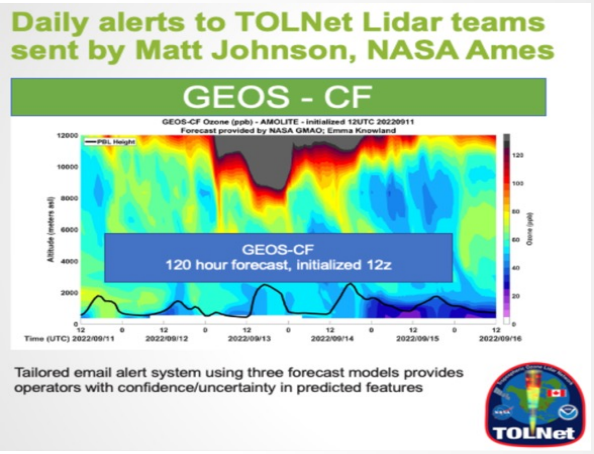
Forecast visualizations and links to data available at fluid.nccs.nasa.gov/cf and /cf_map

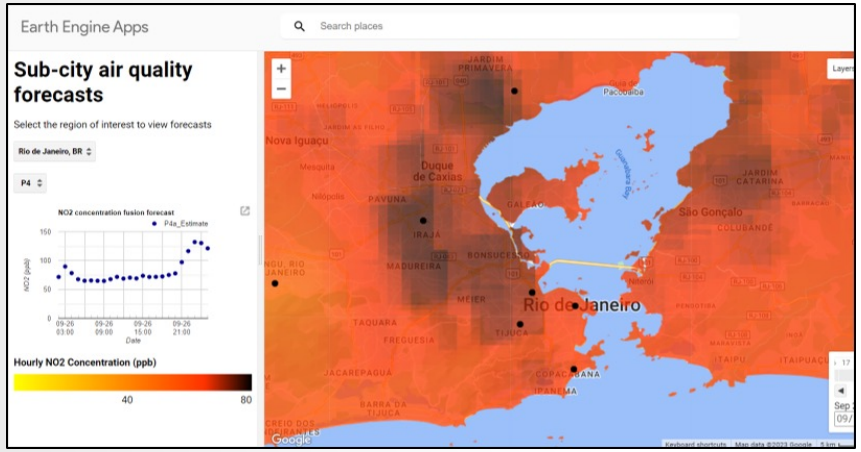
Callum Wayman

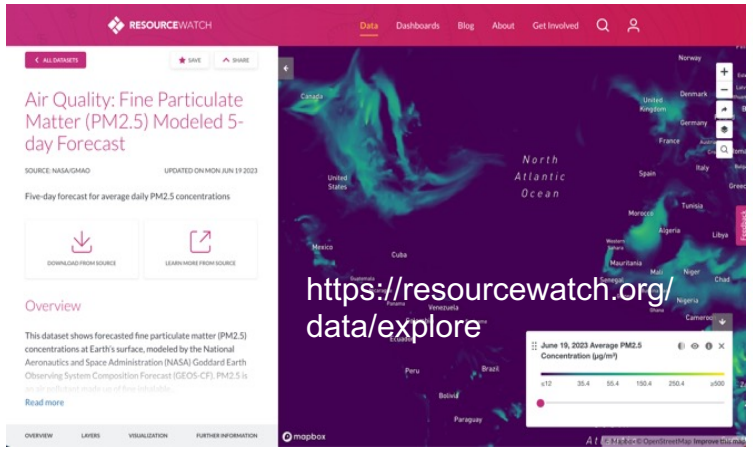
Actively Working With End Users to Meet Their Needs

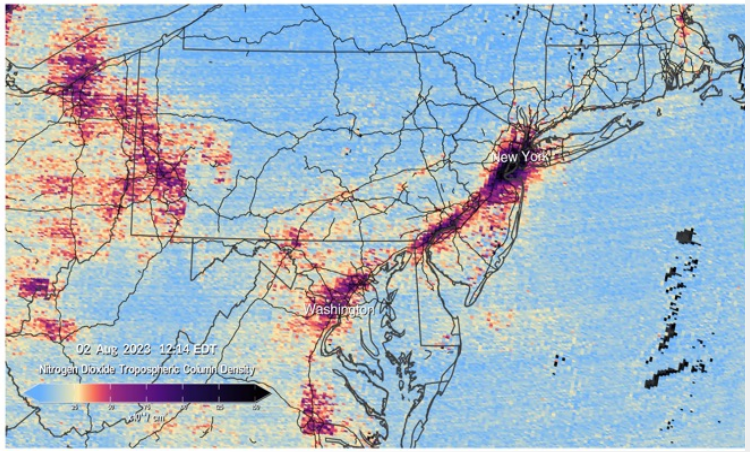








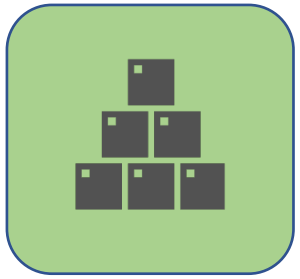
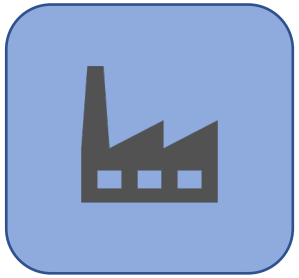
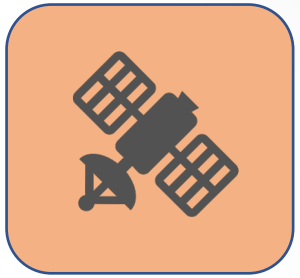




Carl Malings

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

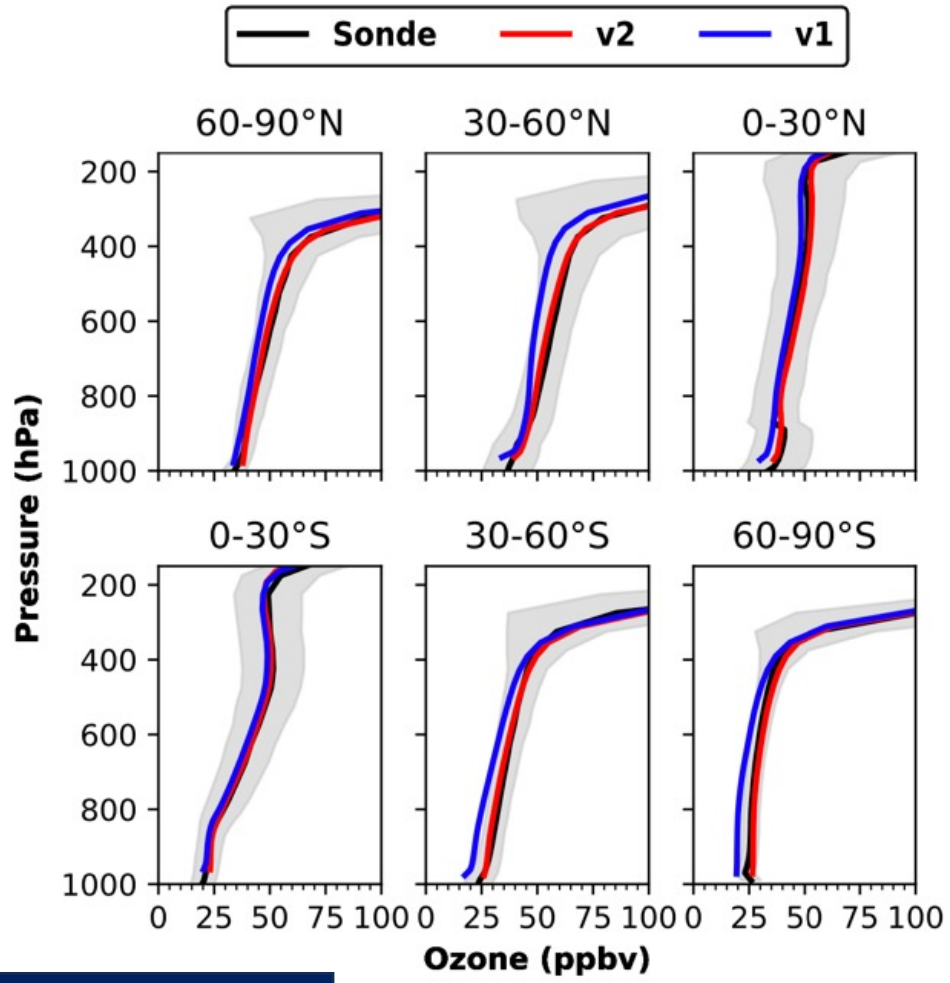
Upgrade to GEOS-CF Version 2

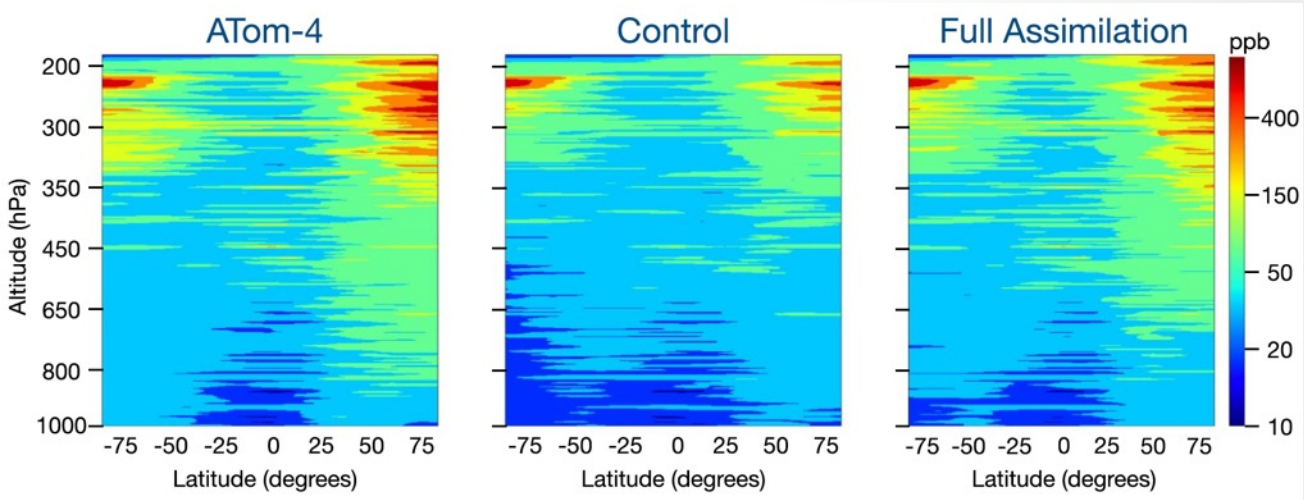
	Model Components	Emissions	Observations
			
Version 2 (spinning up)	**GEOS as of 2023:** - GEOSgcm v10.23.0 - Online tracer convection - GEOS-Chem v14	- CEDS inventory (up to 2019) - Updated fire emission factors - Redistributed lightning	Direct assimilation of O_3, NO_2, SO_2 (3D-Var) using CoDAS
Version 1 (current system)	**GEOS as of 2017:** - Icarus-1_0 - GEOS-Chem v12.0.1	HTAP v2.2 (base year 2010)	Nudge stratospheric ozone to GEOS-FP

Transition from v1 to v2 is costly and compute-resource limited, partly because of the need to run for at least a couple of years at high spatial resolution at the same time GEOS-CF v1 is still running

Christoph Keller

Tropospheric Ozone in V2 is Improved Because of Direct Assimilation





Kelp et al., *Environ. Res. Lett.*, 2023,
https://doi.org/10.1088/1748-9326/acf0b7

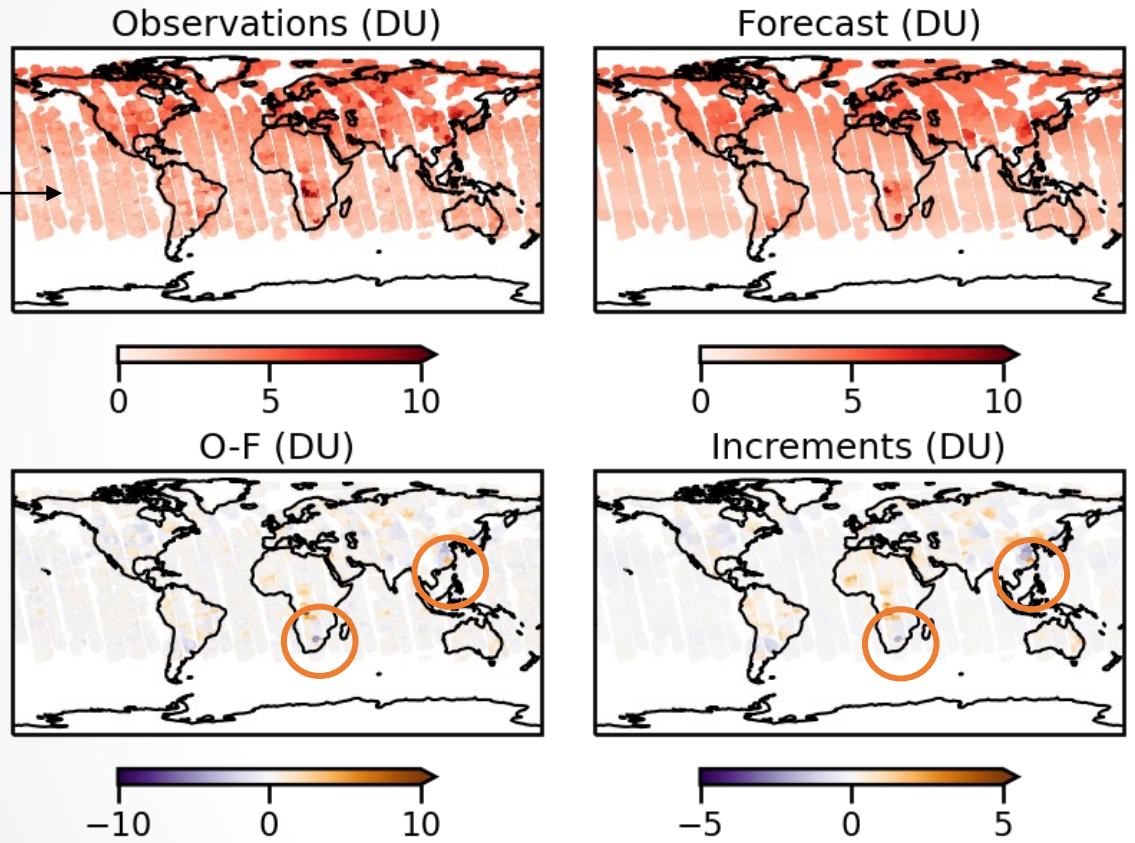
Ozone assimilation drastically **improves the representation of ozone in the remote atmosphere** according to this comparison to ATom-4 measurements and a version of the GEOS-CF v2 system used in testing.

Viral Shah

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

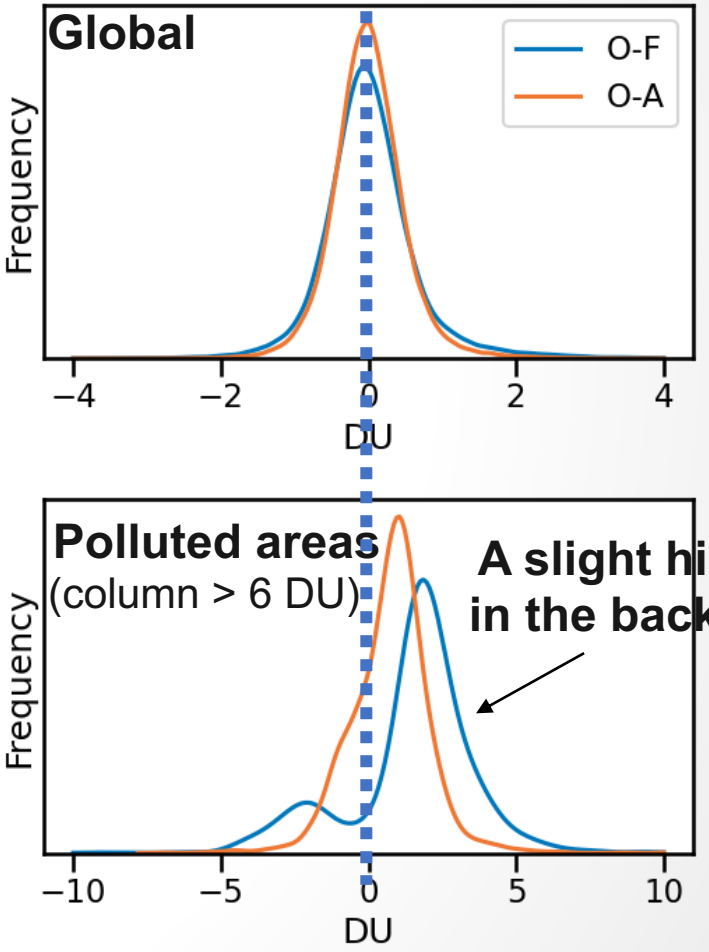
Assimilating OMI NO_2 total slant columns

Mostly Strat NO_2 in remote atmosphere



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

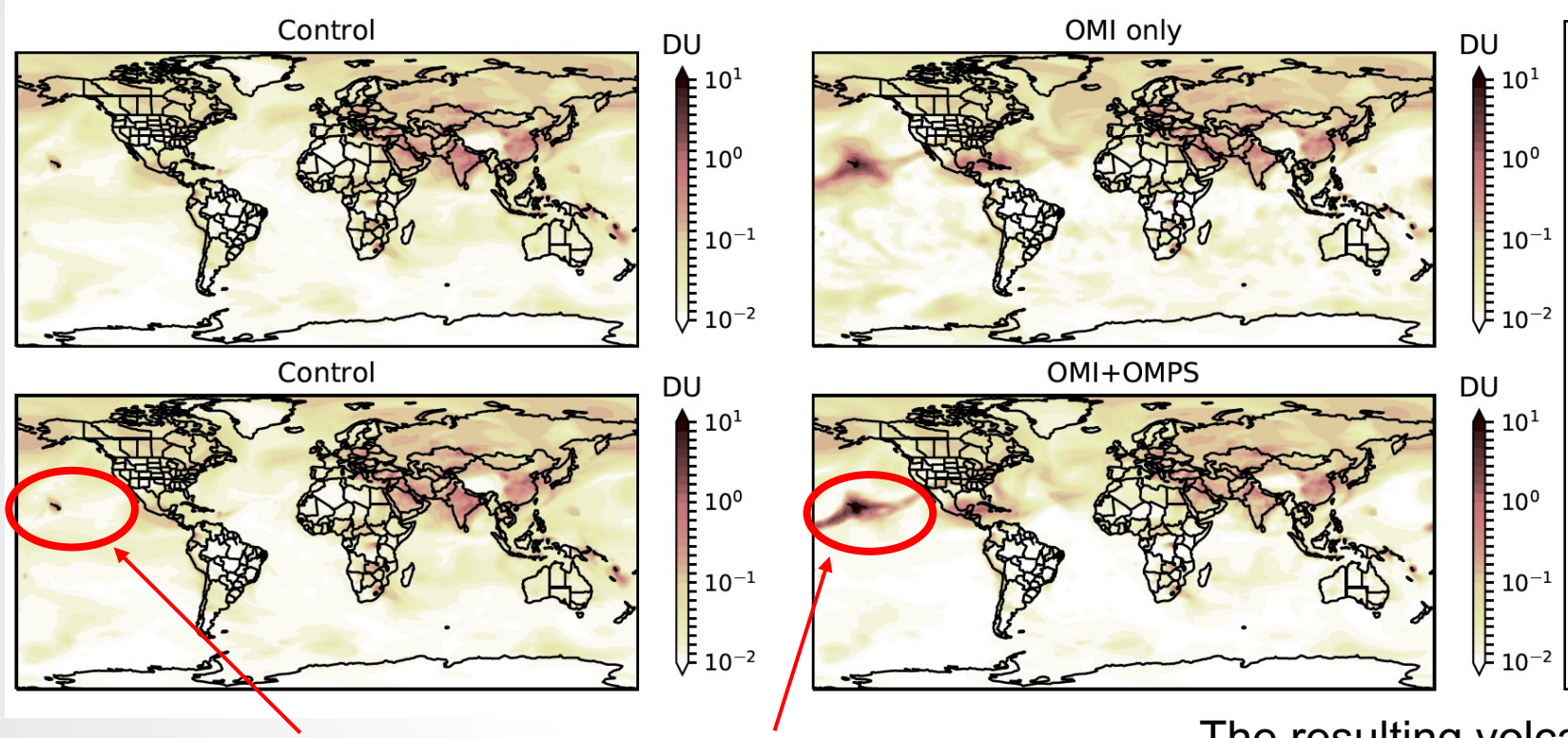
Frequency distributions of O-F and O-A



Viral Shah

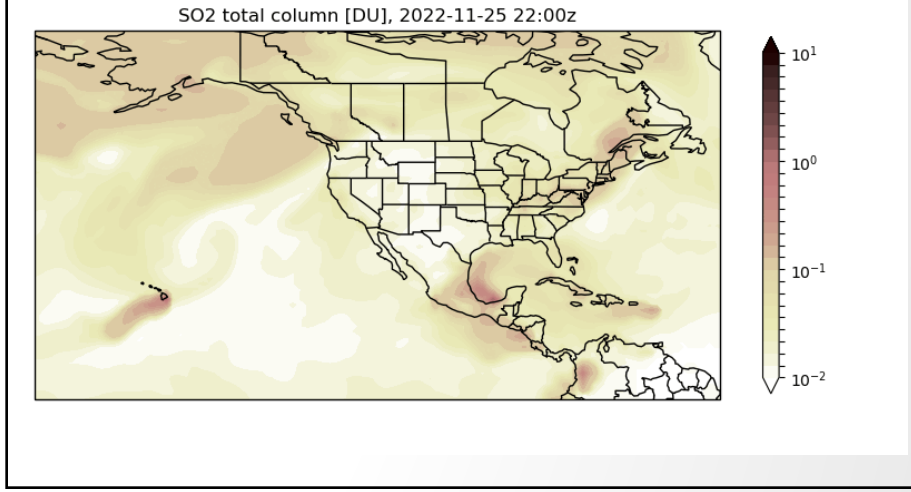
SO_2 assimilation: Mauna Loa's smoking gun

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

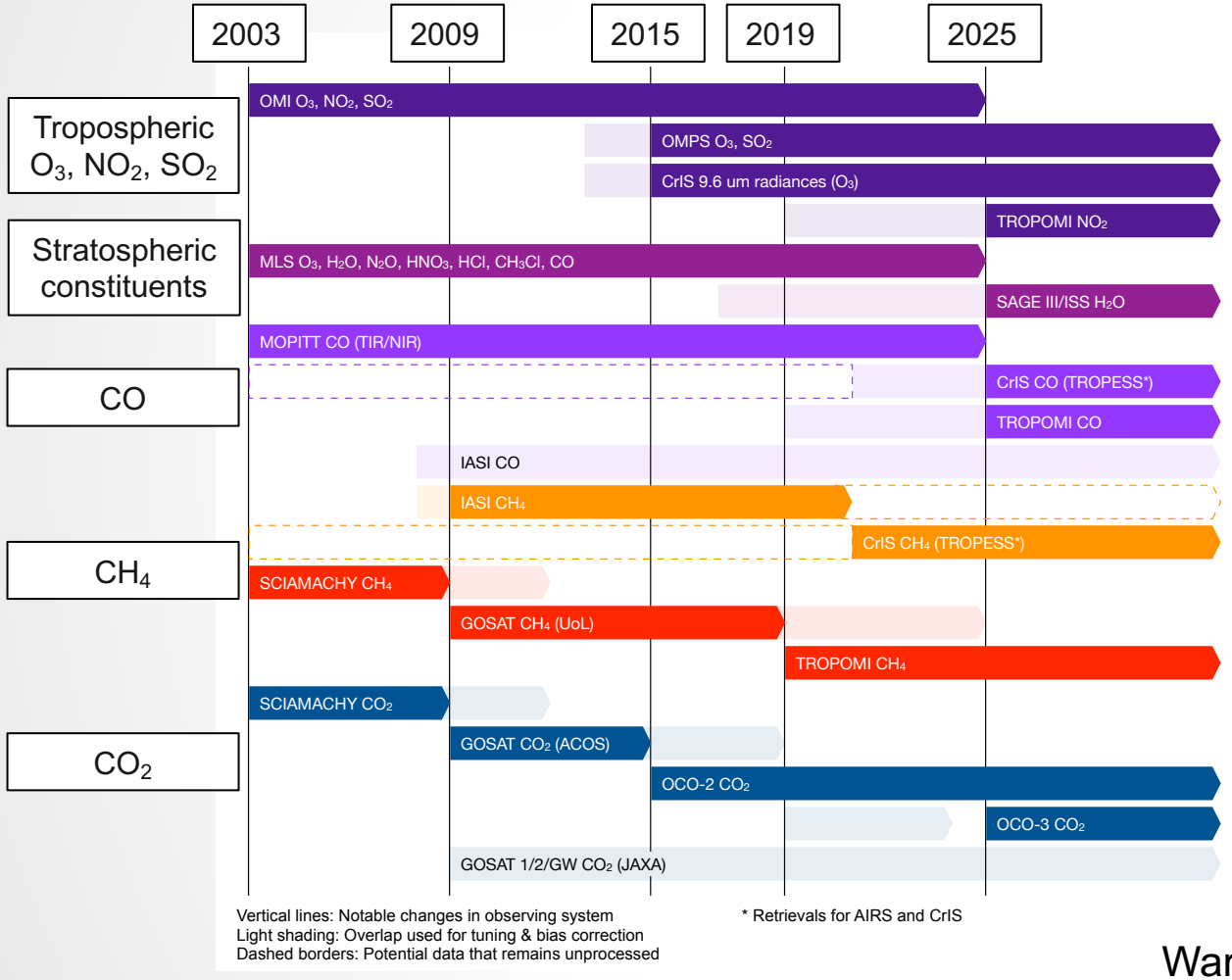


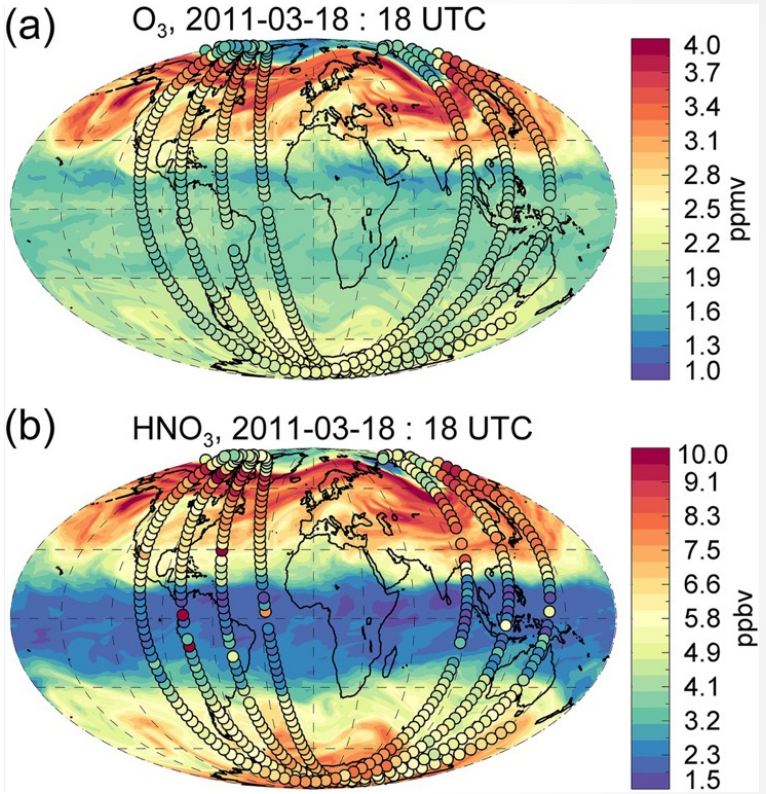
The resulting volcanic plume of sulfur dioxide (SO_2) can be seen from space with satellite instruments such as NASA's Ozone Monitoring Instrument (OMI).

Christoph Keller

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

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





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

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

Summary and Long-Term Perspective

GEOS-CF has been an exciting project!

- Version 1 grew from ROSES funding and has expanded GMAO's role in global composition forecasting
  - New capabilities (stratospheric prediction, surface ozone anomalies, …)
  - Support of additional NASA science teams (providing a priori for TEMPO trace gas retrievals, field campaigns, …)
  - Rapid growth in users from the Applications (especially health) perspective
- Version 2 introduces assimilation and other improvements (model transport, emissions)
  - Basis for GMAO's constituent reanalysis
  - Explore web-based distribution and more open-source analysis tools (GEE, AWS,…)
- Also excited about …
  - Opening opportunities for data assimilation with JEDI (a community effort across agencies)
  - Regional grid refinements

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).

