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# NASA GEOS Composition Forecast: Overview, TEMPO Support, and Version 2 updates

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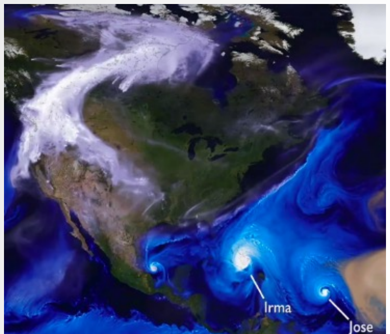
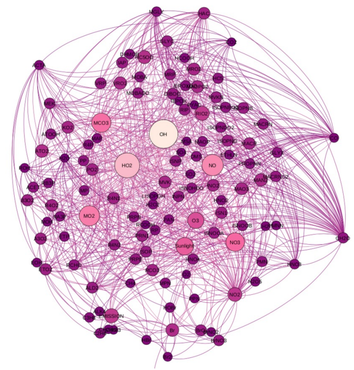
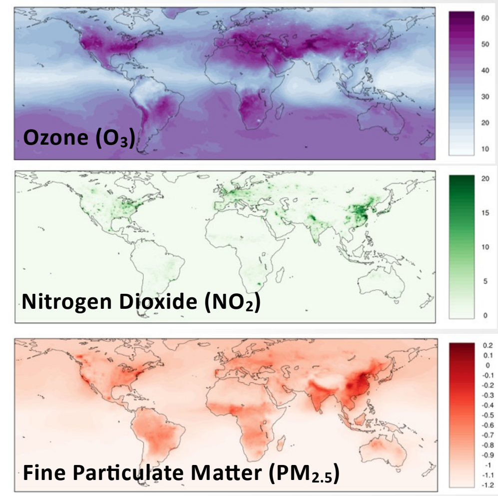
# GEOS with Coupled GEOS-Chem chemistry: TEMPO support




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

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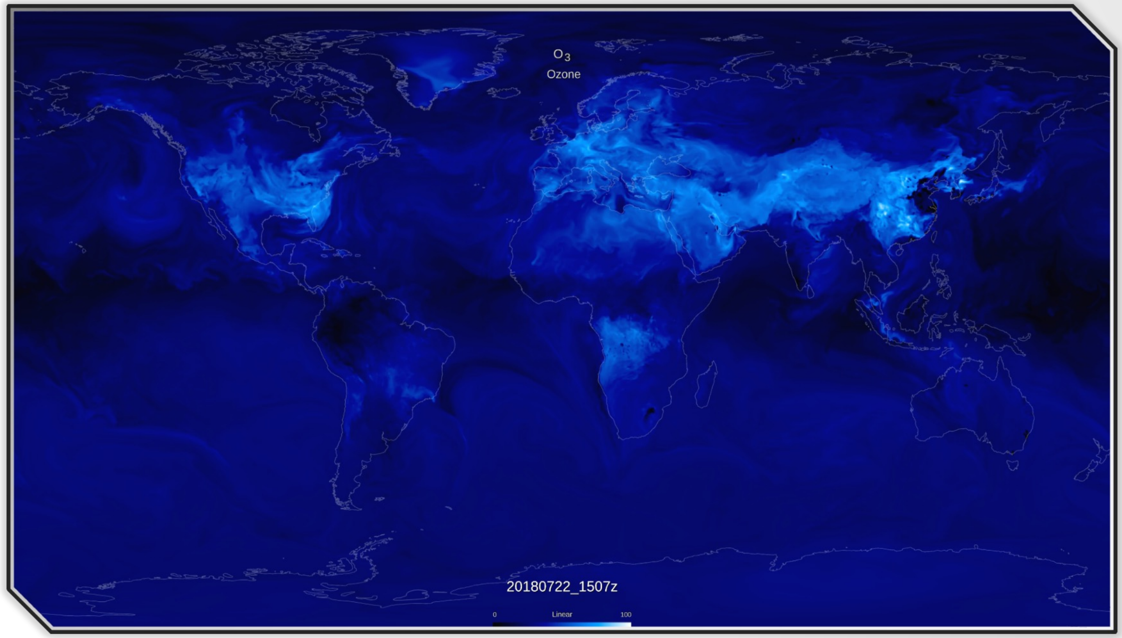
Context of NASA's Earth Science Mission:

- 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

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# GEOS with Coupled GEOS-Chem chemistry: TEMPO support

## G5NR-Chem

1 July 2013 – 1 July 2014

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

## GEOS-CF

1 January 2018 - present

- 1-day replay + 5-day forecast
- GEOS-Chem v12.0.1, with full Tropospheric & Stratospheric chem
- c360 (0.25°, **~25 x 25 km²**)
- 72 model layers
- 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*

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# 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

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*

| 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 |
| OCIO | tzyx | Chlorine dioxide (OCIO, 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 |

# Upgrade to GEOS-CF Version 2

## 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**



https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/
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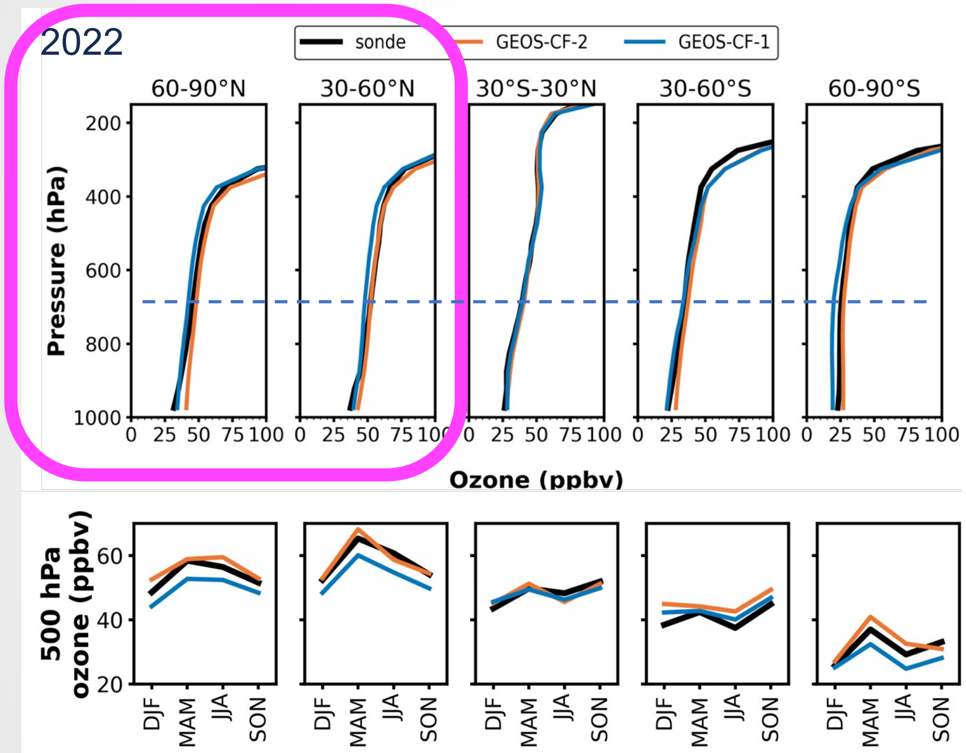
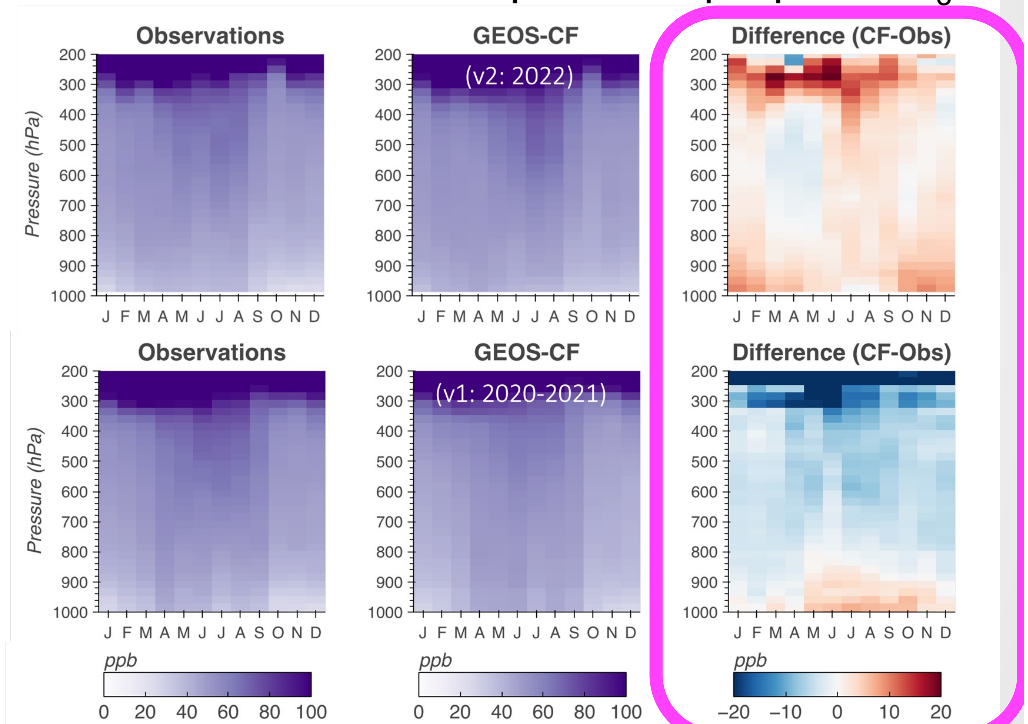
# Tropospheric Ozone in V2 is Improved Because of Direct Assimilation




Version 1 Version 2

Ozone assimilation ➡️ Improved tropospheric $O_3$




Composite of NA & European ozonesondes

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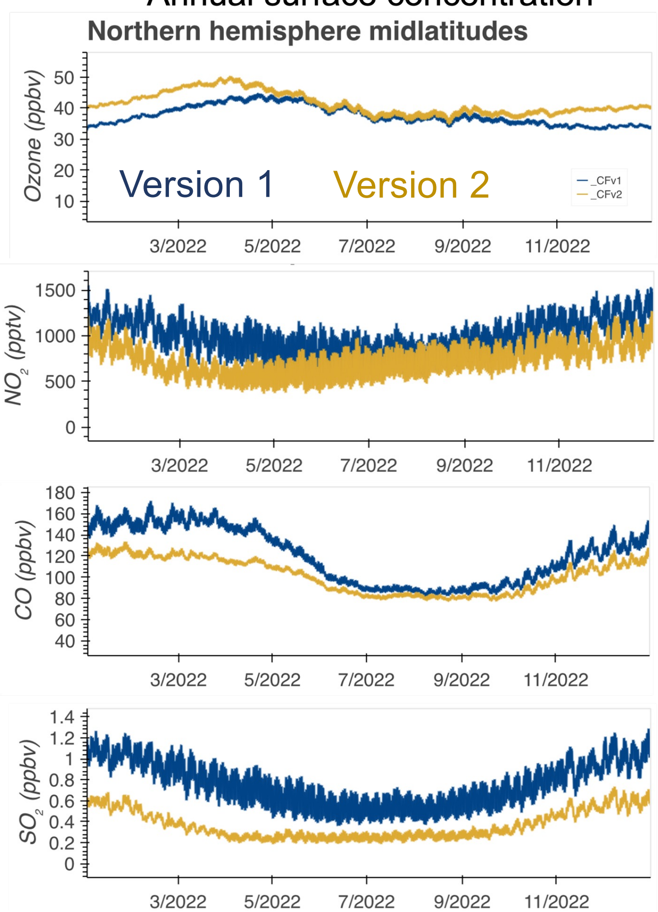
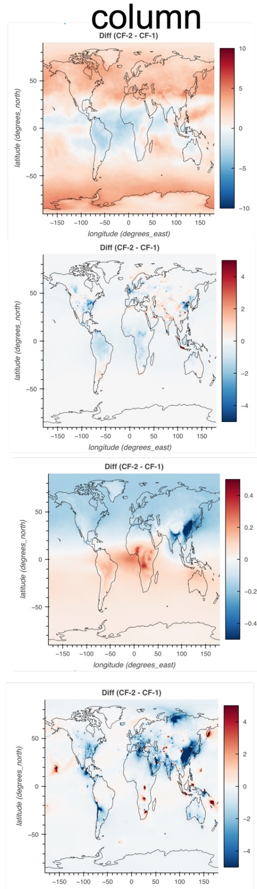
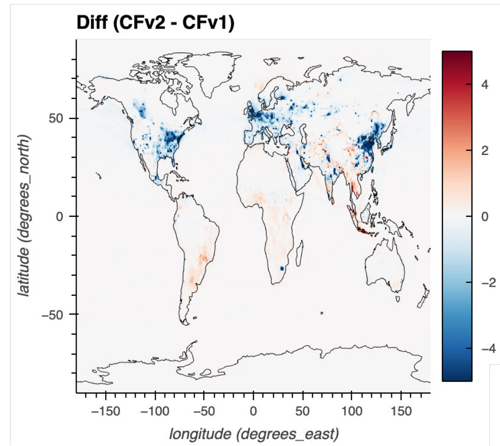
# Lower NOx emissions is leading to higher Ozone in GEOS-CF version 2

2022 Annual surface concentration



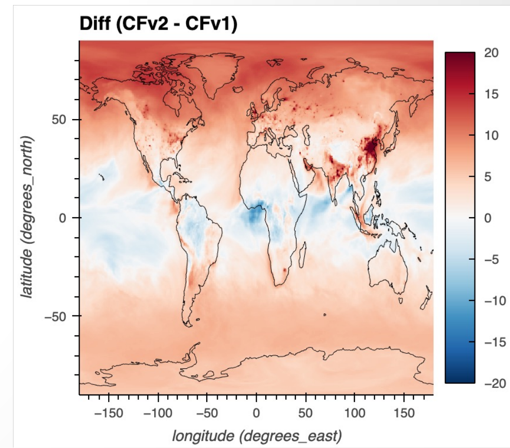

Annual tropospheric column




⬅ Surface $NO_2$ is lower in v2, <u>especially in urban areas</u>

➡ this leads to higher surface $O_3$

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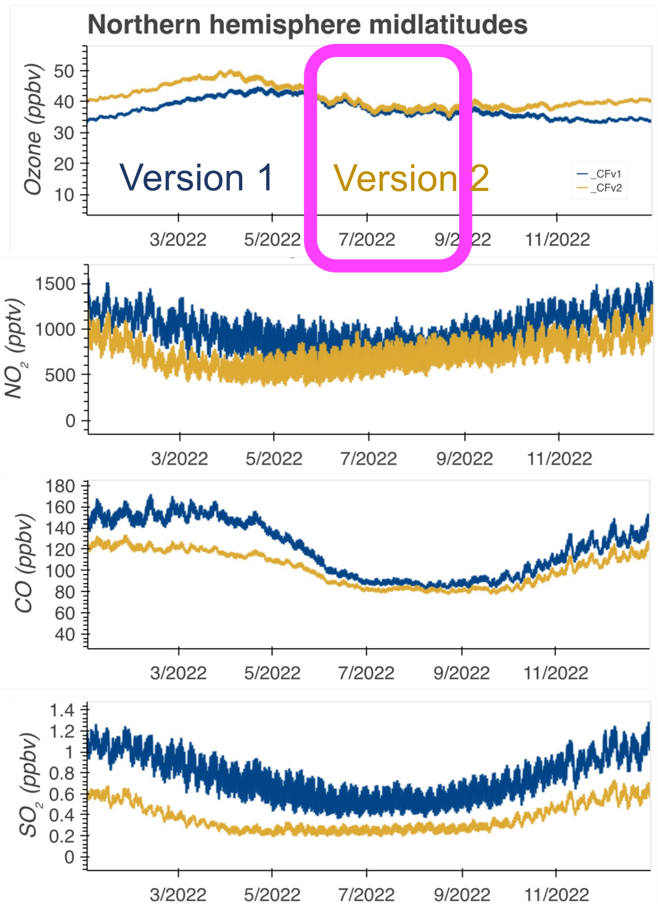
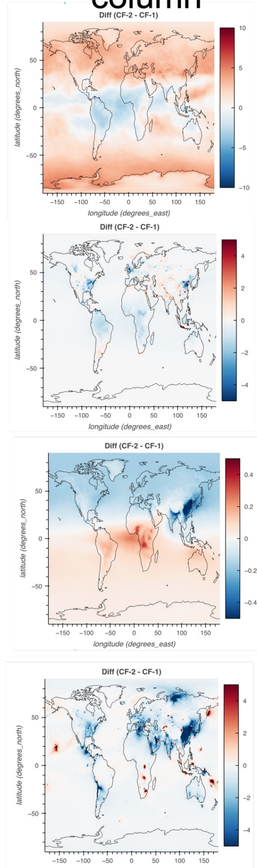
# With updated GEOS met the summer $O_3$ bias in Southeast US is reduced

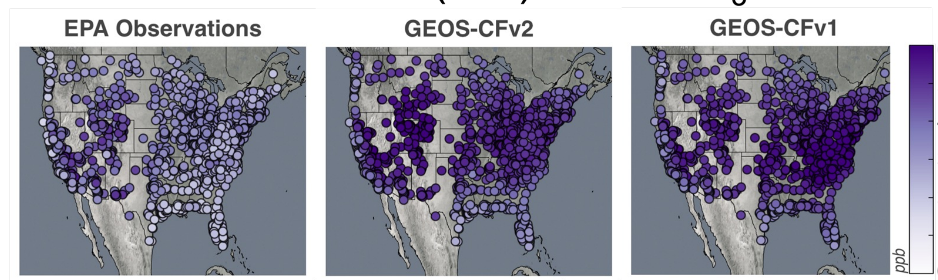
2022 Annual surface concentration



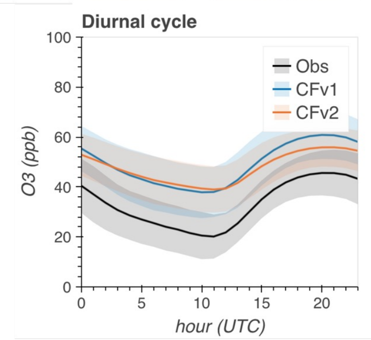

Annual tropospheric column




## 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

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# Summary and Long-Term Perspective

- 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 and higher vertical resolution in GEOS
  - Chemistry speed-ups

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

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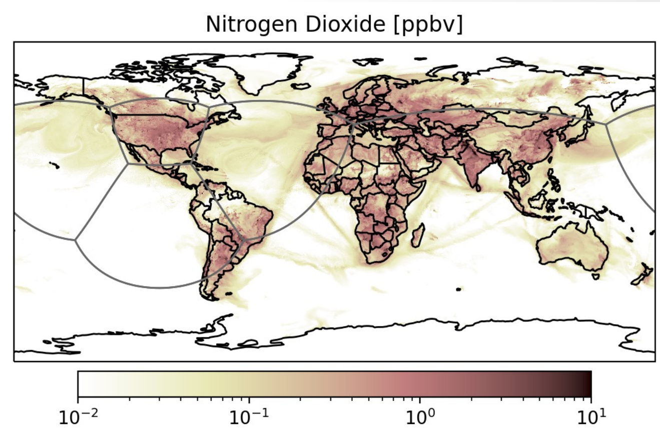
Send an e-mail to geos-cf-users-join@lists.nasa.gov (no subject or text in the body is required).






https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/
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