National Aeronautics and Space Administration

NASA GEOS Composition Forecast system: GEOS-CF

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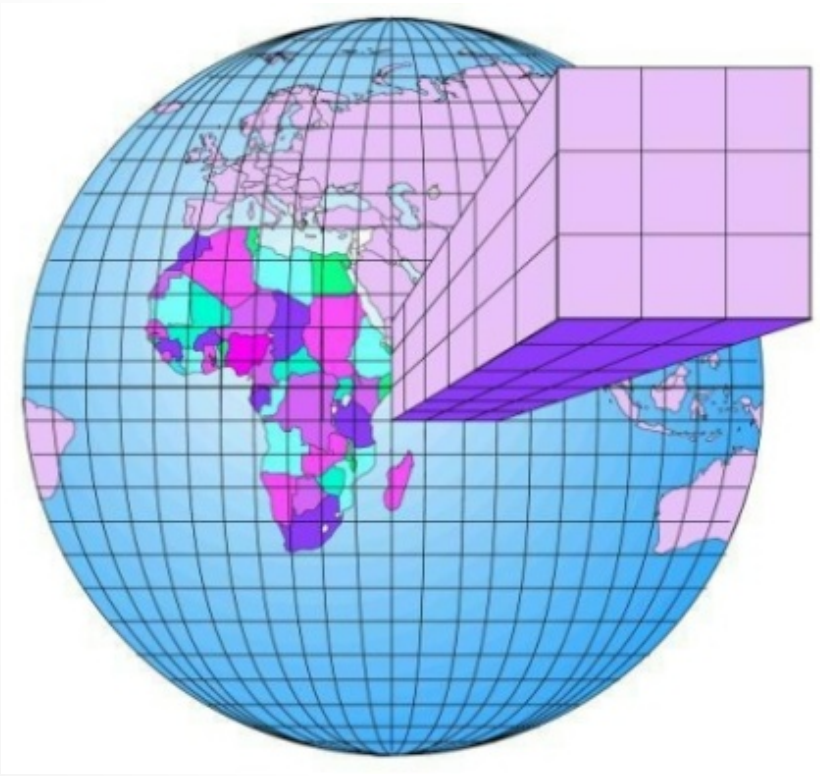
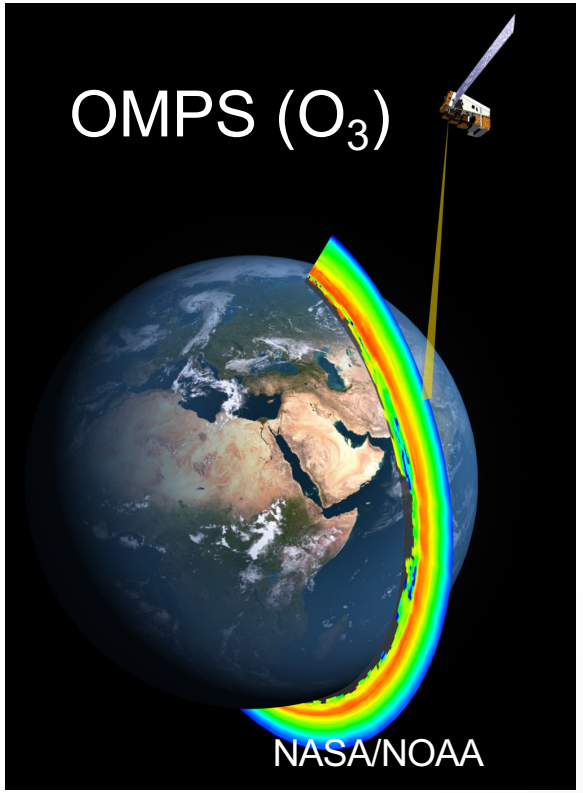
Harvard University: Daniel Jacob, Mike Long

University of Montana: Lu Hu

NASA GMAO global meteorology and chemistry products

GEOS





www.nasa.gov

NASA GMAO global meteorology and chemistry products

GEOS

Forecasting

Reanalysis

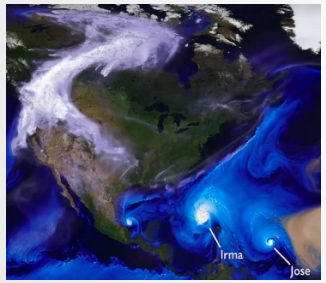
GEOS FP

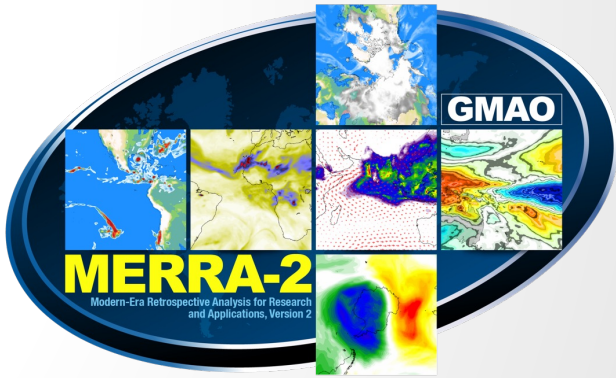
GEOS FP-IT

MERRA-2

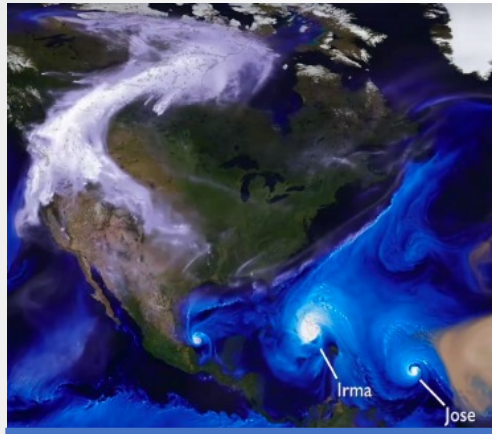
GEOS-CF

GEOS-NR-Chem

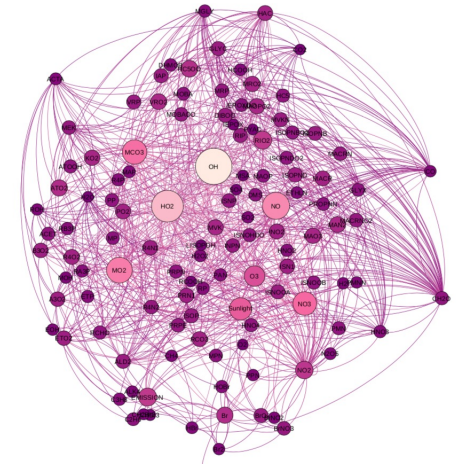




GEOS with Coupled GEOS-Chem chemistry



GEOS NWP



GEOS-Chem

G5NR - Chem

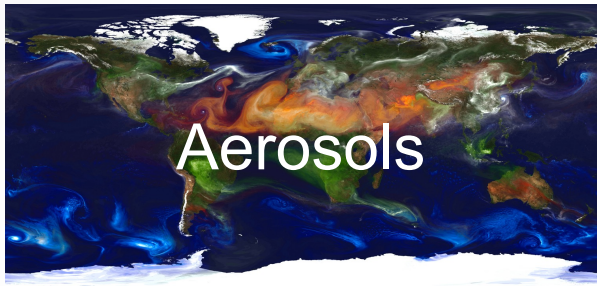
GEOS - CF

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.

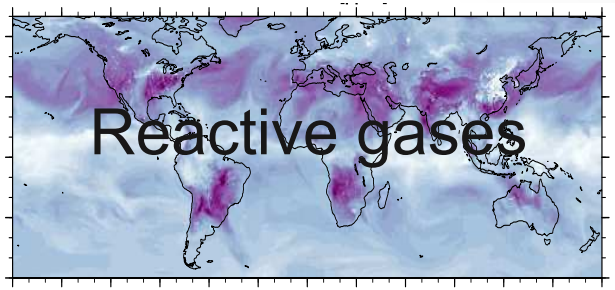
Keller, C. A., Knowland, K. E., et al. (2021). **Description of the NASA GEOS composition forecast modeling system GEOS-CF v1.0**. *Journal of Advances in Modeling Earth Systems*, 13, e2020MS002413. https://doi.org/10.1029/2020MS002413

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

Aerosol and Gas Phase Chemistry



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

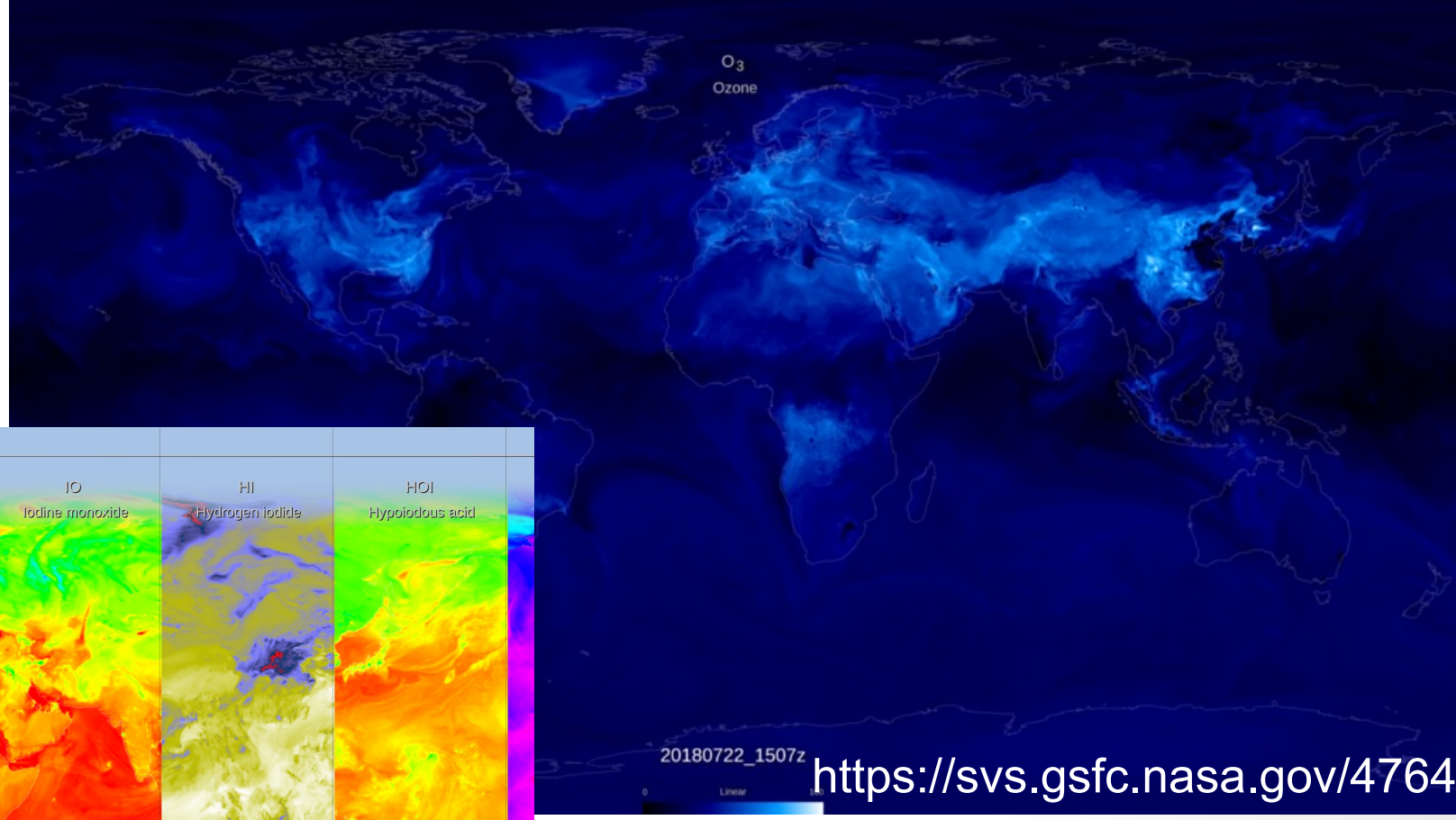


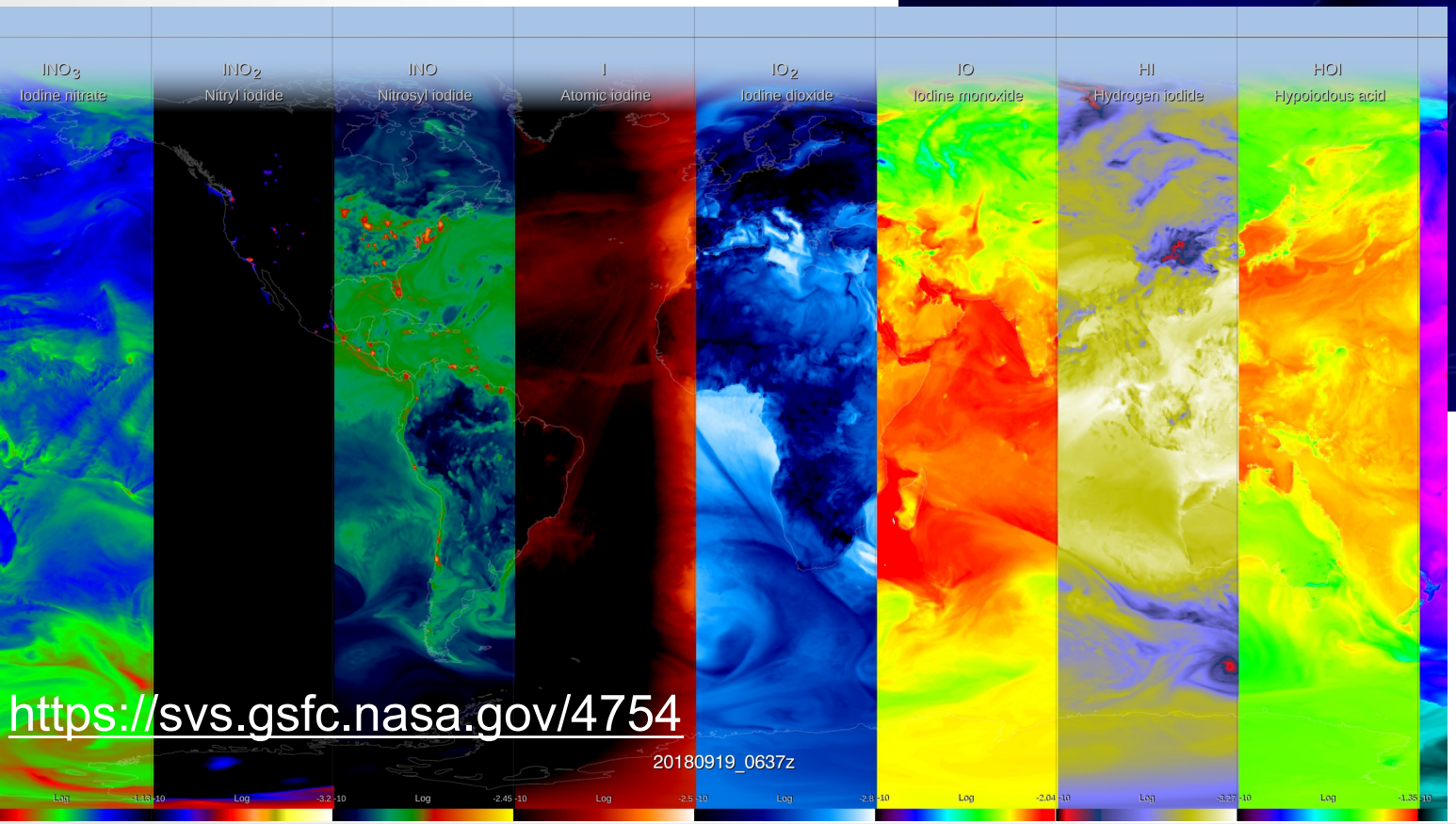
- Ozone (O_3)
- Nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Volatile organic compounds (VOCs):
  - Formaldehyde
  - Benzene / Toluene
  - And many more!

GOCART

GEOS-Chem

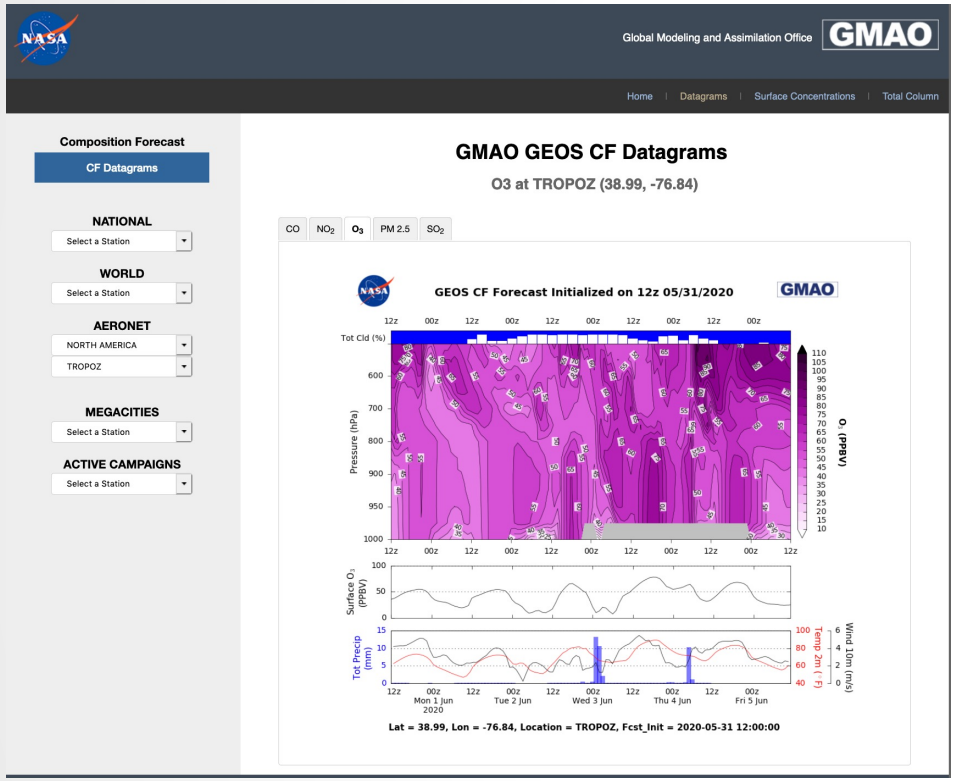
GEOS - CF





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

GEOS-CF Products



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

One **5-day global forecast** per day:

- 1-day meteorological replay ("analysis")
- 5-day forecast, initiated at 12Z
- c360L72 resolution (0.25°), ~25x25 km^2, 72 layers
- Chemistry: O_3, NO_x, CO, VOCs, PM, …
- Meteorology: T, U, V, RH ....

Data distributed via OpenDAP and web link:

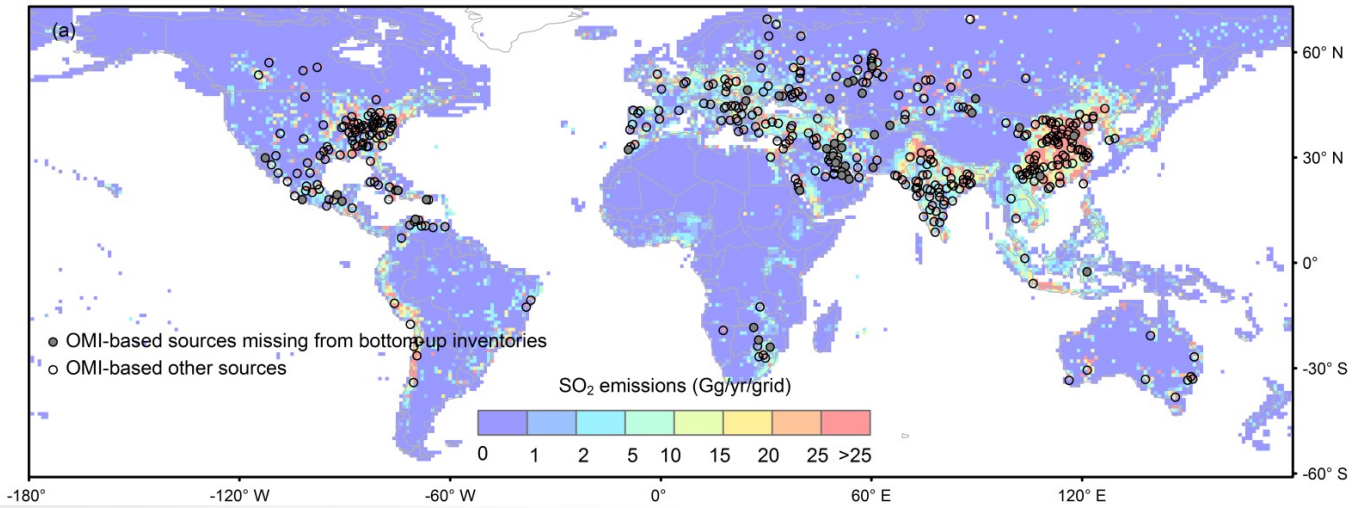
- **15 minute** "surface" fields
- **1-hour** average and instantaneous 2D & 3D
- Summary plots on "FLUID" website
- Documentation in GMAO Office Note #17

Year-to-year emissions changes

Emissions:

- HTAP (global bottom-up) for anthropogenic.
- Online dust, sea salt, plant emissions
- 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

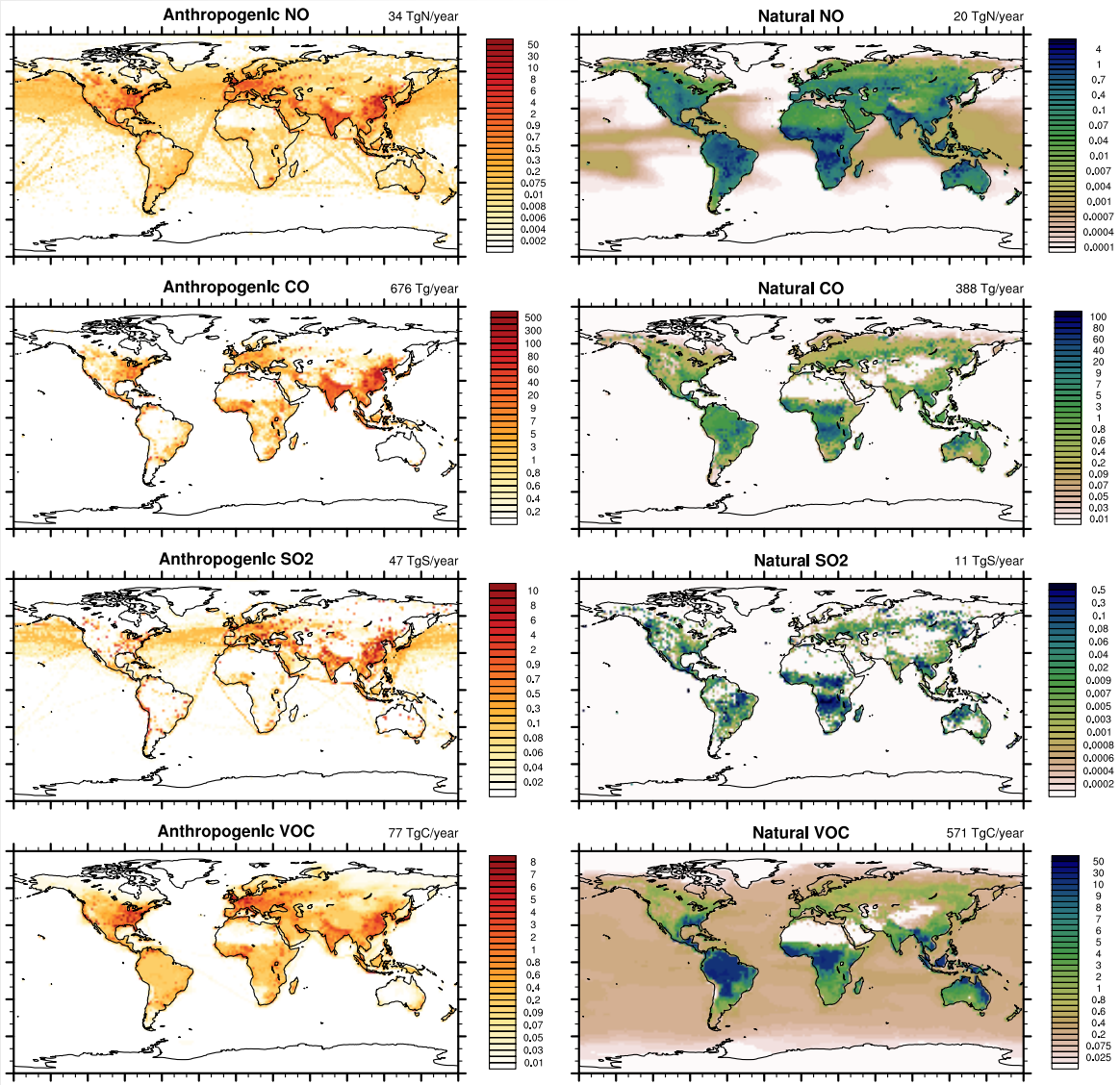
SO_2 emissions in the OMI-HTAP inventory



A new emission inventory, OMI-HTAP, combines OMI-based SO_2 emissions for large sources and the bottom-up inventory, HTAP, for smaller sources.

Liu, F., et al., *Atmos. Chem. Phys., 18*, 2018

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)

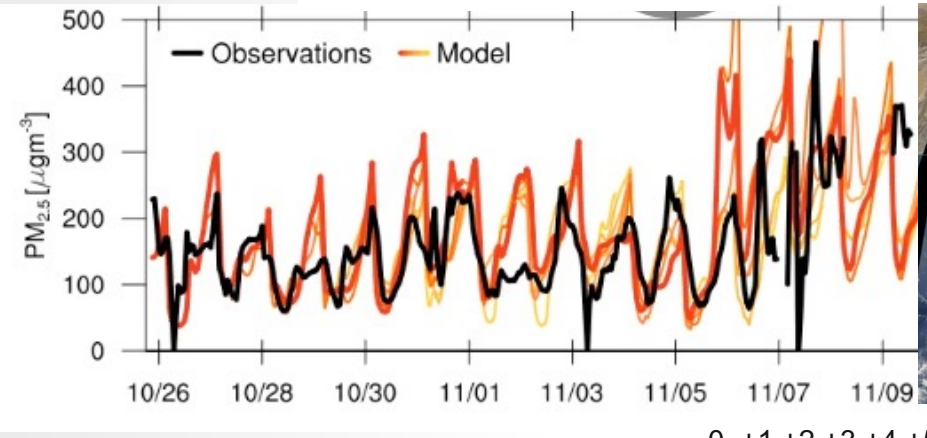
Ocean: online: sea salt, DMS, acetone, acetaldehyde, HOI, I_2

Prescribed: CFCs, VSLS, CH_4, CO_2

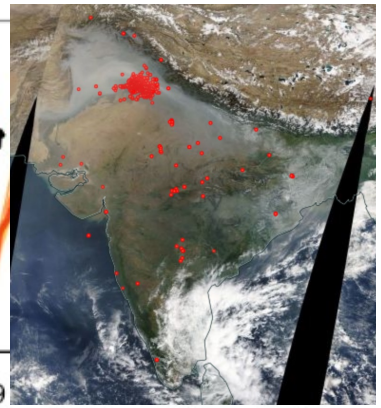
Near-real time updates from satellite data

- Biomass burning emissions from near-real time QFED v2.5

Delhi, India Nov 2017



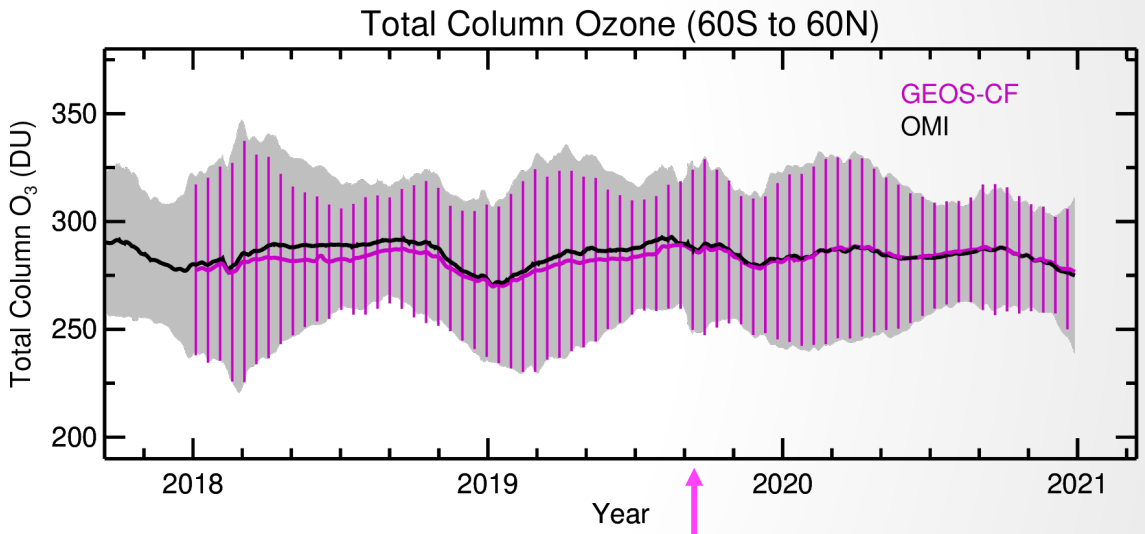
MODIS fires Nov 01, 2017



Observation

0 +1 +2 +3 +4 +5 GEOS-CF

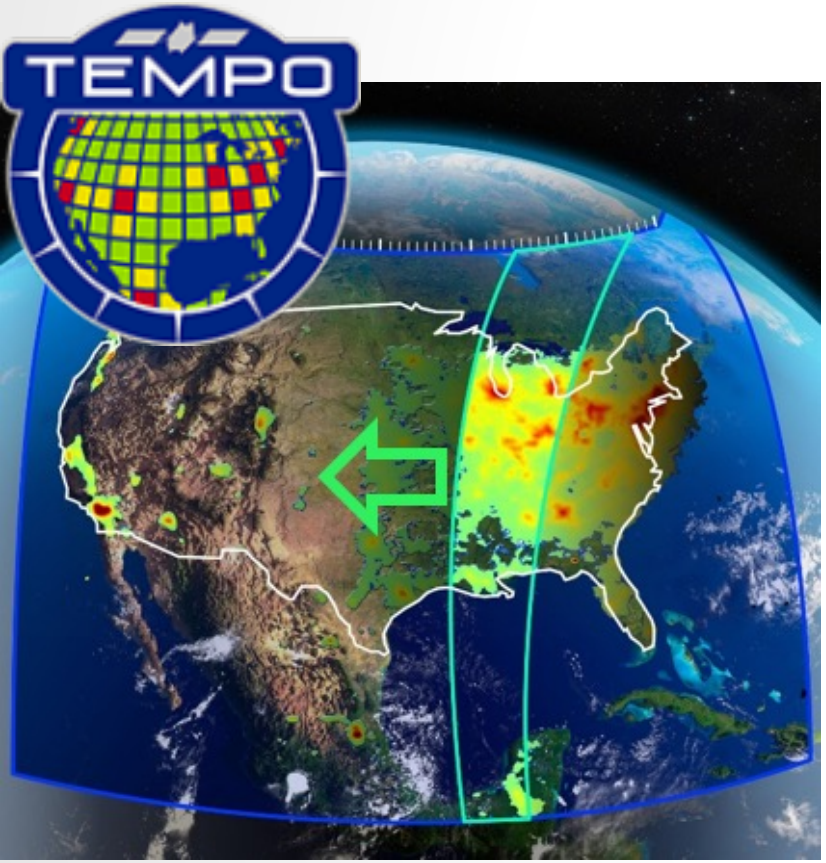
- GEOS-CF Stratospheric O_3 is weakly nudged to the GEOS FP assimilated O_3



Updates were made to GEOS-Chem in GEOS-CF based on experience from the GSFC Chemistry Climate Modeling (CCM) group with GMI

Support a broad range of NASA applications

GEOS - CF

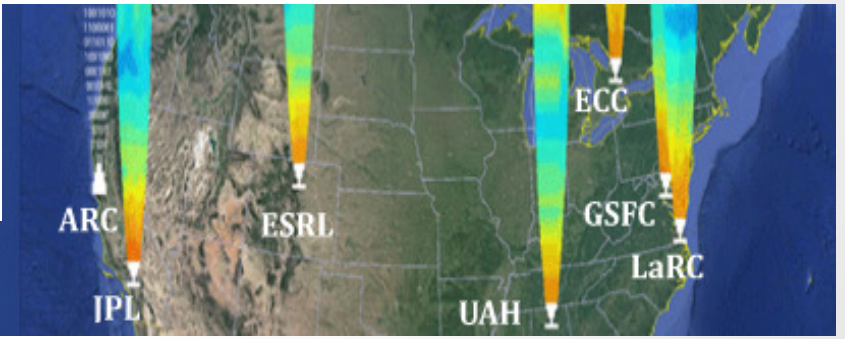


Realistic atmospheric composition in the troposphere **and** stratosphere in GEOS-CF is essential to support a broad range of NASA applications measuring trace gases and aerosols, including:

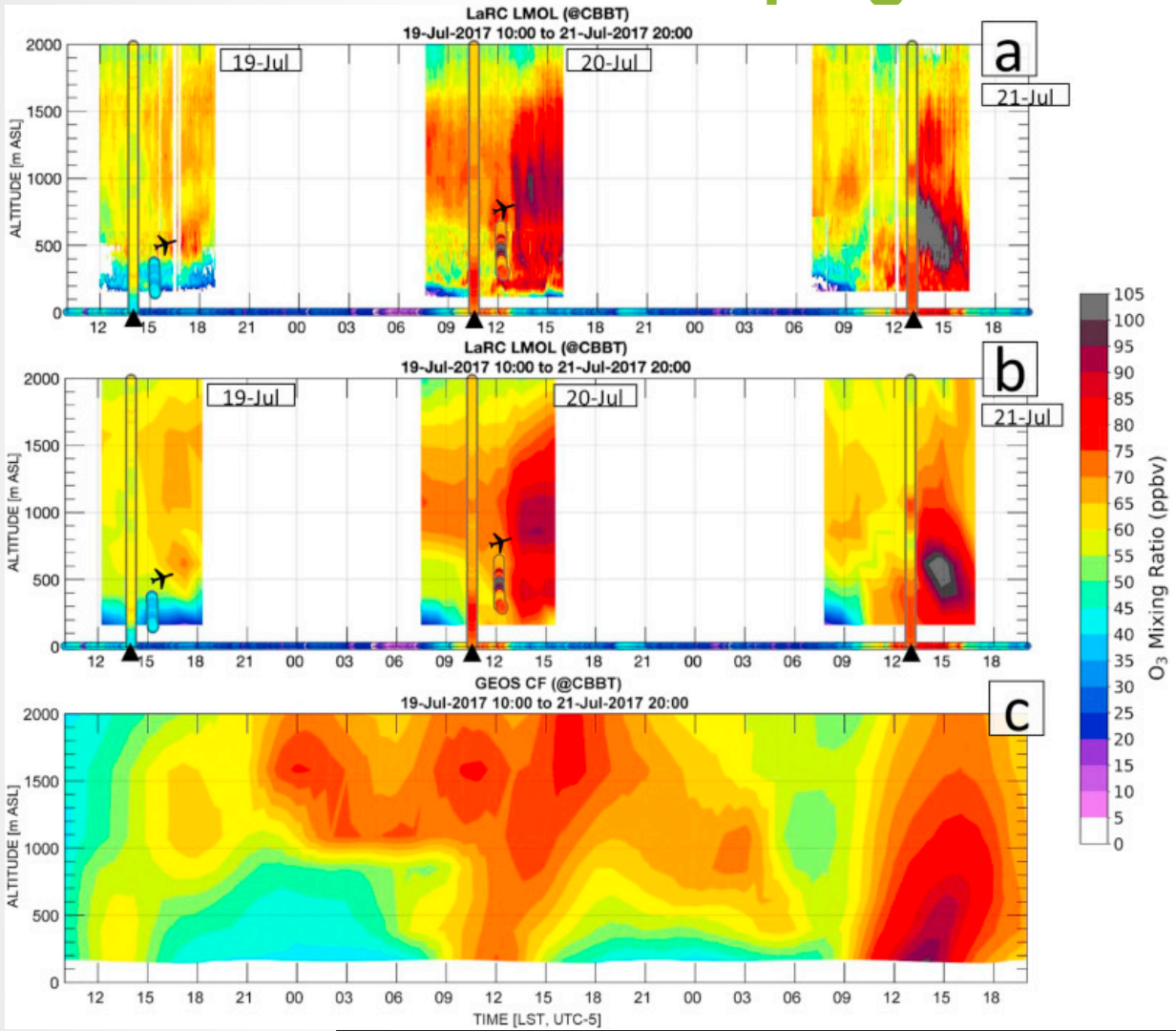
- Airborne campaigns
- Satellite retrievals of trace gases
- Stratosphere-troposphere exchange

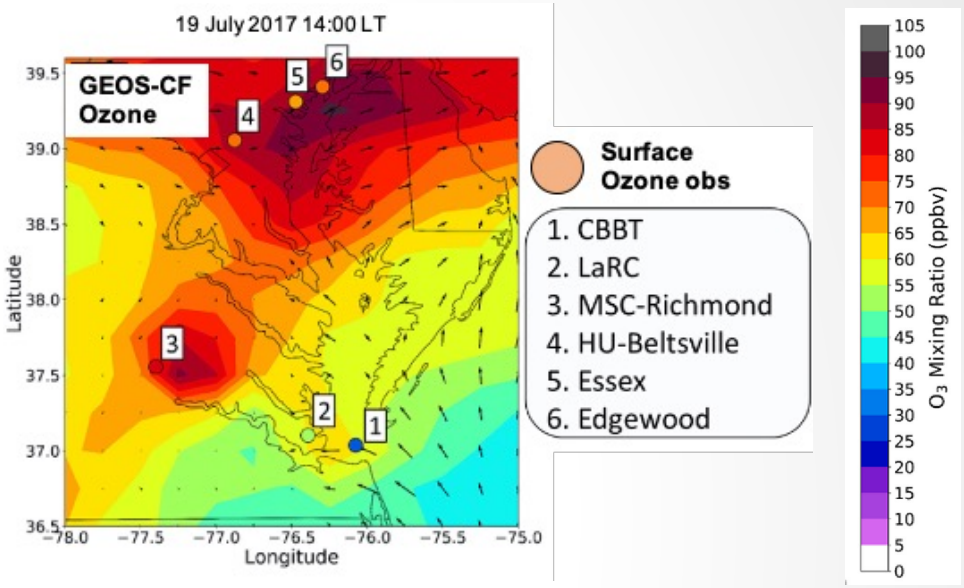
TOLNET

Tropospheric Ozone LIDAR Network



NASA's OWLETS campaign

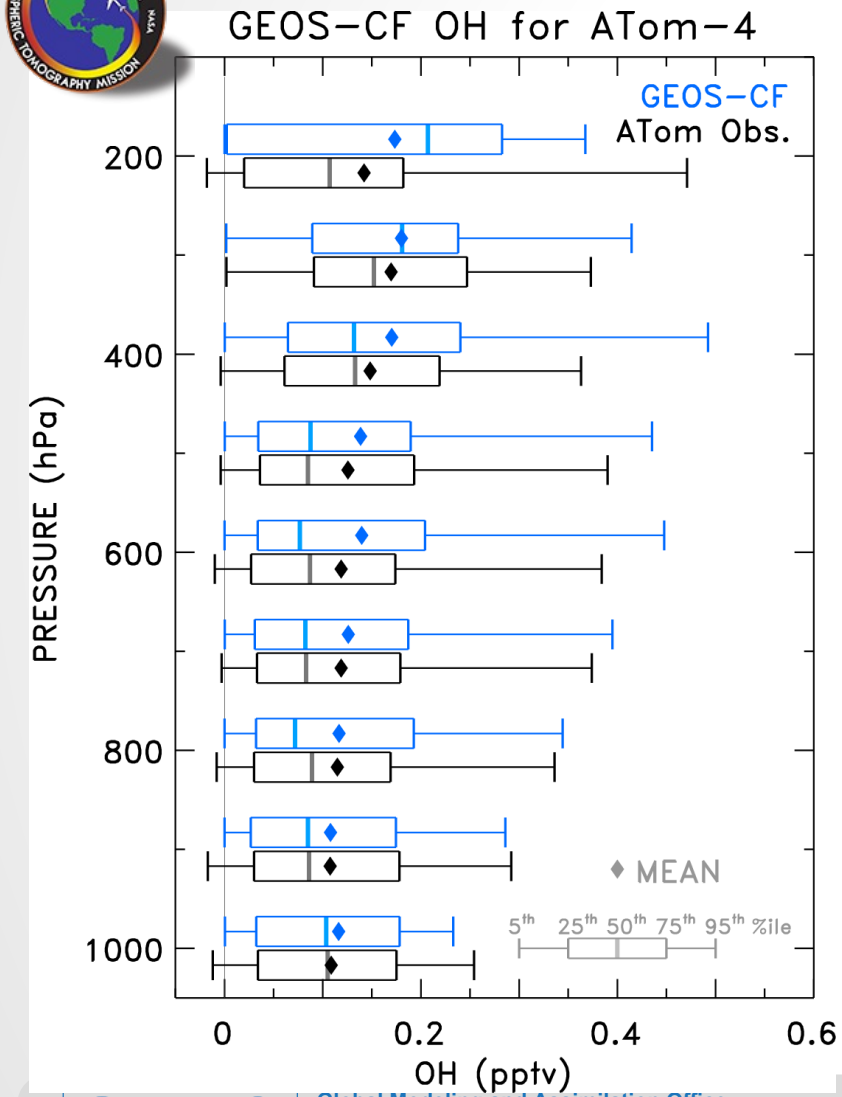




Dacic et al. (2020) used the GEOS-CF simulated ozone to put the OWLETS observations in 'the big picture', using the combined meteorology and chemistry to represent the synoptic conditions that lead to the observed ozone exceedances at surface observation sites.

Dacic, N., Sullivan, J. T., Knowland, K. E., et al., "Evaluation of NASA's high-resolution global composition simulations: Understanding a pollution event in the Chesapeake Bay during the summer 2017 OWLETS campaign", Atmos. Environ, 2020.

GEOS-CF oxidizing capacity of remote atmosphere compares well to ATom



- The hydroxyl radical (OH) is the main tropospheric oxidant, controlling lifetimes of greenhouse gases including methane and initiating formation of secondary pollutants like ozone and aerosols
- OH is difficult to measure; the NASA Atmospheric Tomography Mission (ATom) airborne campaign conducted global-scale *in situ* measurements of OH
- The ATHOS instrument measured OH by laser-induced fluorescence on four deployments of the DC-8 aircraft, primarily over remote Pacific, Atlantic oceans
- GEOS-CF hourly model output was sampled along the flight tracks of the fourth deployment (ATom-4) for April-May 2018.
- Despite OH being difficult to model, distributions of OH compare well between GEOS-CF and observations from the surface to 300 hPa

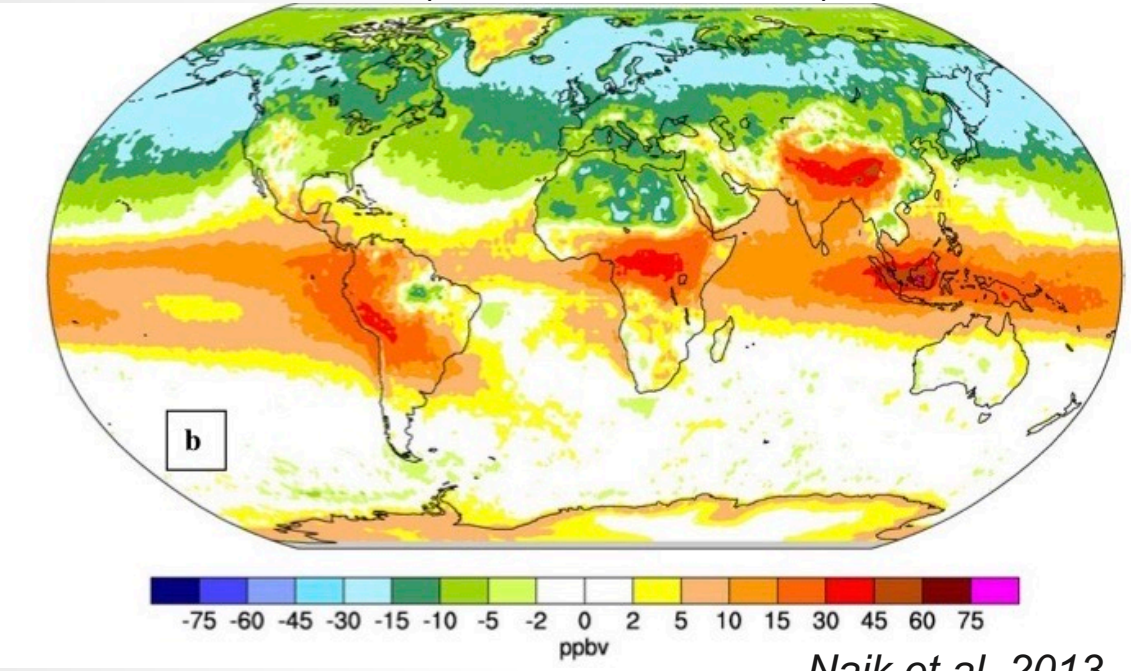
Courtesy of Julie Nicely
ESSIC, NASA GSFC

GEOS-CF shows significant improvements in CO simulation, especially over NH

Courtesy of Junhua Liu,
USRA/GESTAR NASA/GSFC

CO Difference (MOD – OBS)

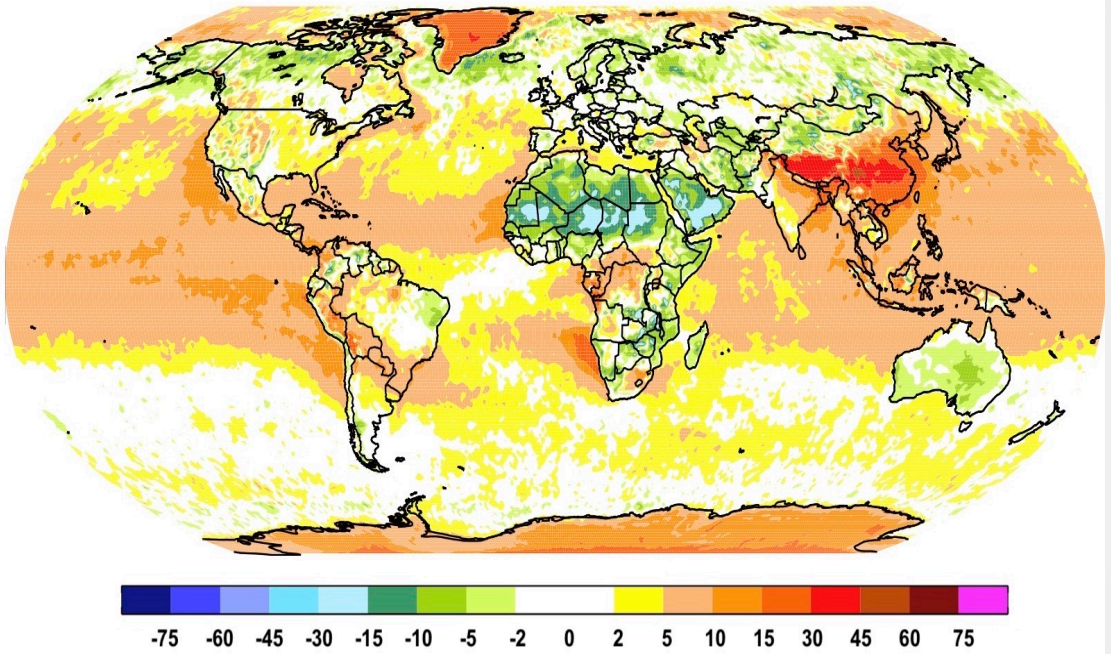
ACCMIP multi-model mean – MOPITT
(500 hPa, 2000-2006)



Naik et al. 2013, ACP

The ACCMIP multi-model mean underestimates the MOPITT CO at 500 hPa in the NH mid-high latitudes (up to 45 ppb), except over northern India and south-central China; similar to the earlier multi-model results of Shindell et al. 2006.

GEOS-CF – MOPITT
(500 hPa, 2018-2019)



GEOS-CF shows **significant improvements in CO simulation** except over south-central China:

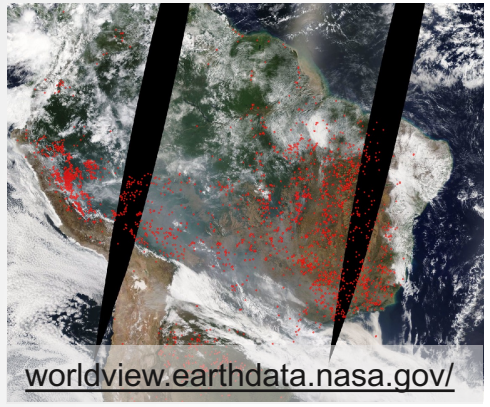
- Much lower negative biases in the NH mid-high latitudes (<10 ppb)
- Lower positive biases over northern India, South America, central Africa and Indonesia.

GEOS-CF Captures the 2019 Increase in Amazon Fires

Courtesy of Sarah Strode, USRA/GESTAR NASA/GSFC

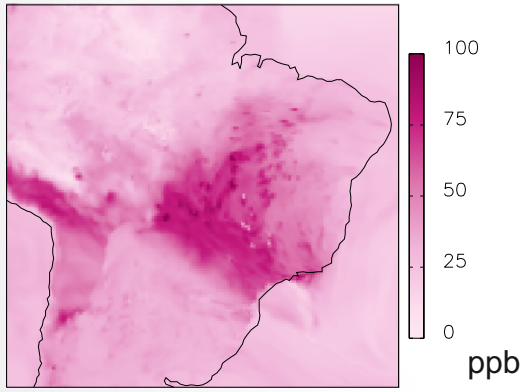
a) Sept. 18, 2019 Amazon Fires

Satellite



GEOS-CF Surface Ozone (O_3)

Model

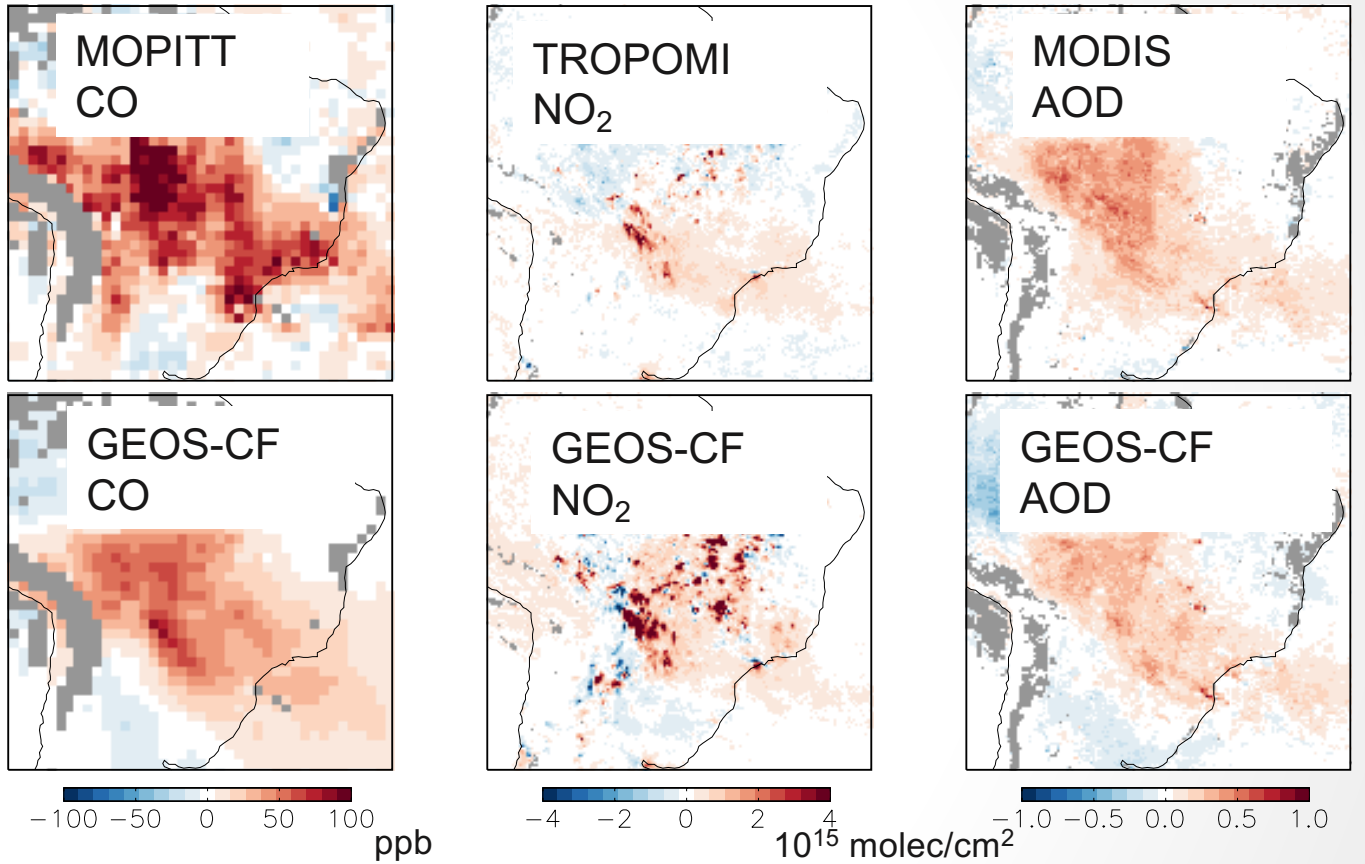


- Fire and smoke from MODIS (**a**: top) along with the GEOS-CF simulation of elevated surface O_3 (**a**: bottom) on Sept. 18, 2019. O_3 forms downwind of fires.

b) September difference (2019-2018) in CO, NO_2, and aerosol

Satellite

Model



- Increased biomass burning occurred in the Amazon in Aug.-Sept. 2019.
- Comparison of GEOS-CF to satellite observations (**b**) of MOPITT CO, TROPOMI NO_2, and MODIS aerosol optical depth (AOD) shows that GEOS-CF captures the observed differences in biomass burning pollutants between 2018 and 2019.

Planned upgrades for GEOS-CF

- Model update to GEOS-Chem v13.0
- GEOS AGCM update
- CEDS emission inventory (latest release through 2019)
- Constituent Data Assimilation System (CoDAS)
  - Multi-constituent assimilation with O_3, CO, NO_2
- We will provide new climatology to TEMPO retrieval team

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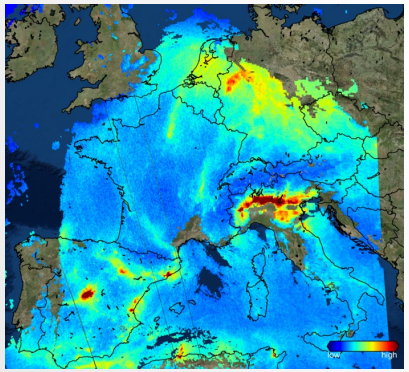
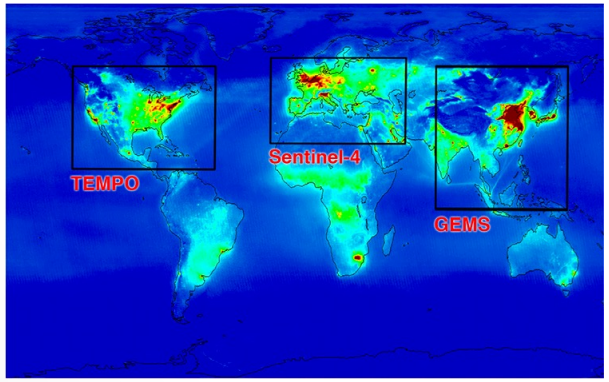
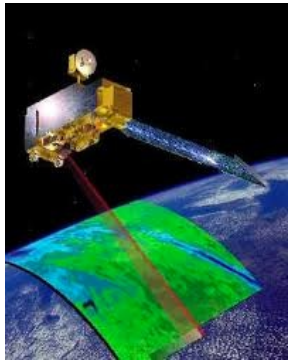
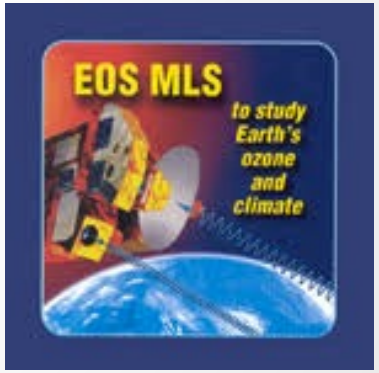








GEOS with Coupled GEOS-Chem chemistry

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 UCX Tropospheric & Stratospheric
- HTAP v2.2
- 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 1.2), 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

Knowland et al., 2022. "File Specification for GEOS-CF Products." *GMAO Office Note No. 17 (Version 1.2), 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
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

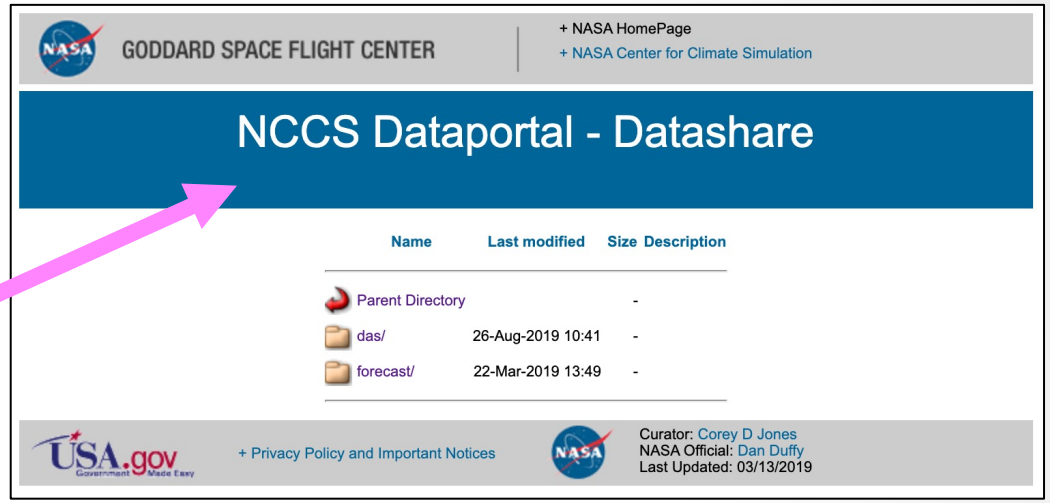
TEMPO specific collection: “sat_inst_1hr_r721x361_v72”

Regional Chemistry and Meteorology Diagnostics to support TEMPO satellite

Mode: Replay only; Forecasts available based on mission requirements

- Forecast test period with TEMPO retrieval team in February-March 2022
- Files were accessed by the TEMPO team from the NCCS Dataportal
  e.g., https://portal.nccs.nasa.gov/datashare/gmao/geos-cf/v1/forecast/Y2022/M01/D23/H12/GEOS-CF.v01.rpl.sat_inst_1hr_r720x361_v72*.nc4
- The replay files are still available since January 1, 2022
  e.g., https://portal.nccs.nasa.gov/datashare/gmao/geos-cf/v1/das/Y2022/M01/D01/GEOS-CF.v01.rpl.sat_inst_1hr_r720x361_v72*.nc4

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/sat_inst_1hr_r721x361_v72 : dds das

OPeNDAP/DODS Data URL: https://opendap.nccs.nasa.gov/dods/gmao/geos-cf/assim/sat_inst_1hr_r721x361_v72

Description:	GEOS CF (Composition Forecast)	
Documentation:	(none provided)	
Longitude:	-180.00000000000°E to 0.00000000000°E	(721 points, avg. res. 0.25°)
Latitude:	0.00000000000°N to 90.00000000000°N	(361 points, avg. res. 0.25°)
Altitude:	1.00000000000 to 72.00000000000	(72 points, avg. res. 1.0)
Time:	00Z01JAN2022 to 12Z25MAY2022	(3469 points, avg. res. 0.042 days)
Variables:	**(total of 21)**	
bro	bromine monoxide (bro, mw = 96.00 g mol-1) volume mixing ratio dry air	
snomas	total_snow_storage_land	
hcho	formaldehyde (ch2o, mw = 30.00 g mol-1) volume mixing ratio dry air	
so2	sulfur dioxide (so2, mw = 64.00 g mol-1) volume mixing ratio dry air	