NASA GEOS Composition Forecast System, “GEOS-CF”

K. Emma Knowland

USRA/GESTAR

NASA Global Modeling and Assimilation Office (GMAO)

In collaboration with:

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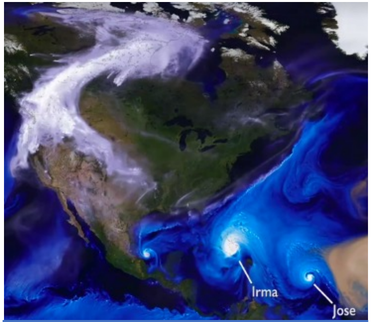
Atmospheric Chemistry and Dynamics Lab: Bryan Duncan, Sarah Strode, Junhua Liu, Julie Nicely, Dan Anderson, Eric Fleming

USRA GESTAR

2 June 2021

GEOS Composition Forecast



GEOS NWP

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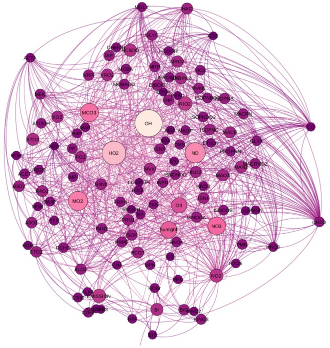

GEOS-Chem

GEOS - CF

Version 12

Tropospheric and Stratospheric chemistry

- 250 Chemical Species
- 725 Chemical Reactions

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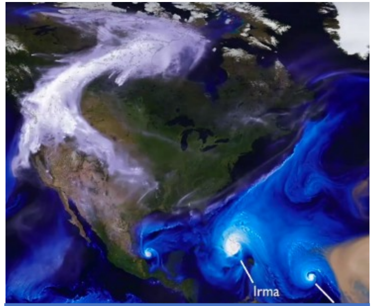
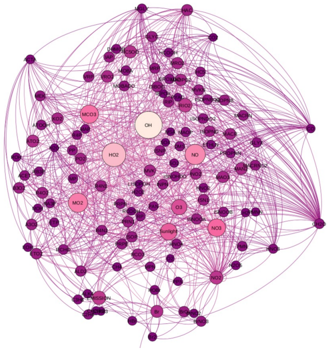
Daily composition forecast



GEOS NWP



GEOS-Chem

GEOS - CF

One **5-day forecast** per day

- 1-day meteorological replay ("analysis")
- 5-day forecast
- 0.25° resolution, **~25x25 km^2**, Global
- 72 model layers, surface to 0.01 hPa
- Chemistry: O_3, NO_x, CO, VOCs, PM, …
- Meteorology: T, U, V, RH ....
- **15 minute** "surface"
- **1-hour** average and instantaneous 2D & 3D
- **Available since 1 January 2018**

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

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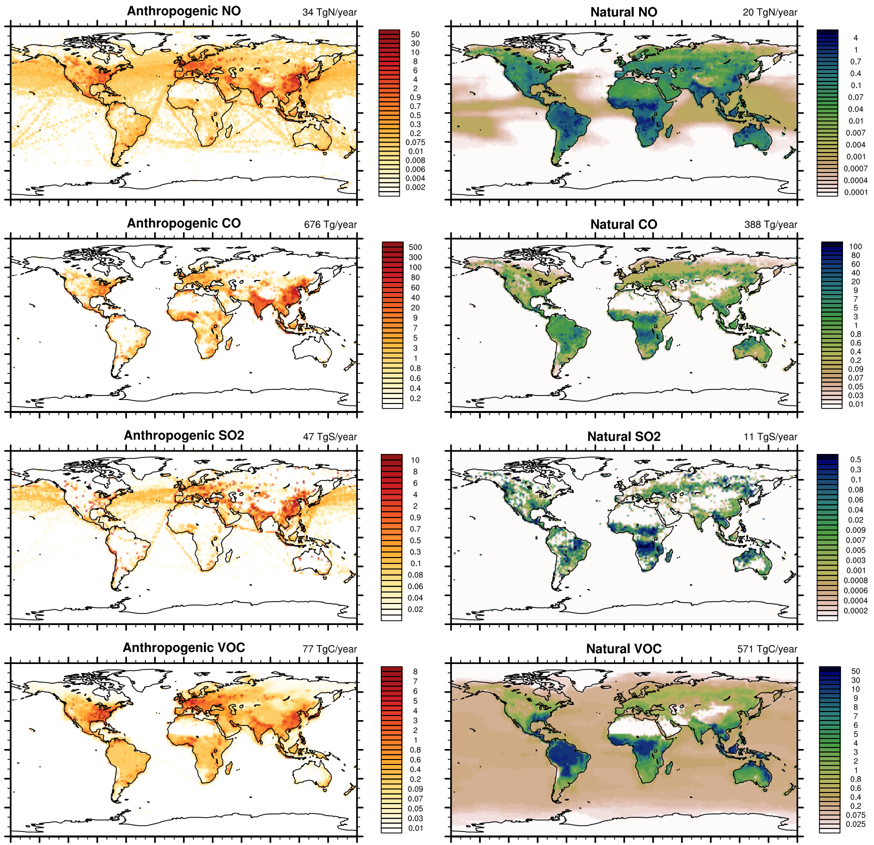
GEOS-Chem emissions



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

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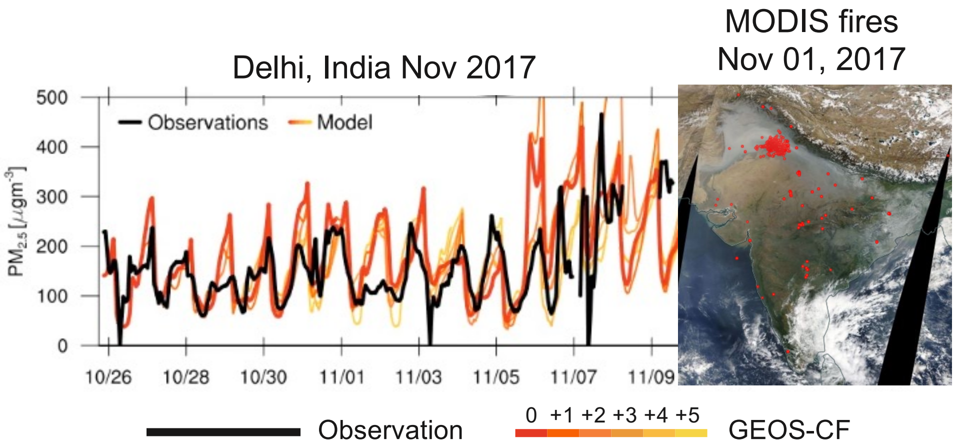
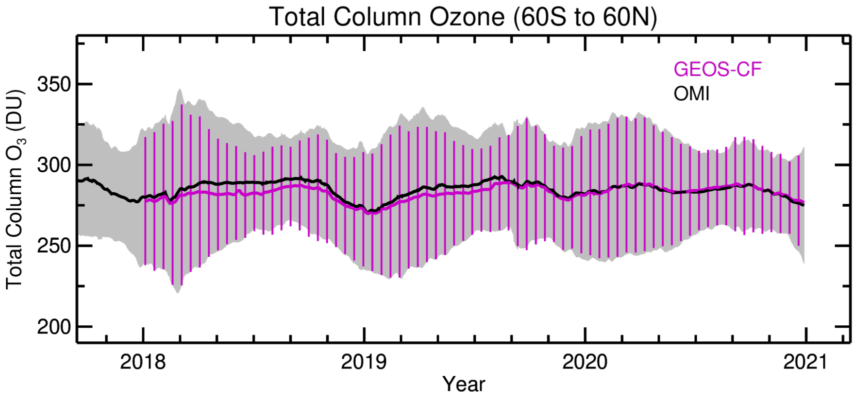
Near-real time updates from satellite data

- Biomass burning emissions from near-real time QFED v2.5
- GEOS-CF Stratospheric O_3 is weakly nudged to the GEOS FP assimilated O_3

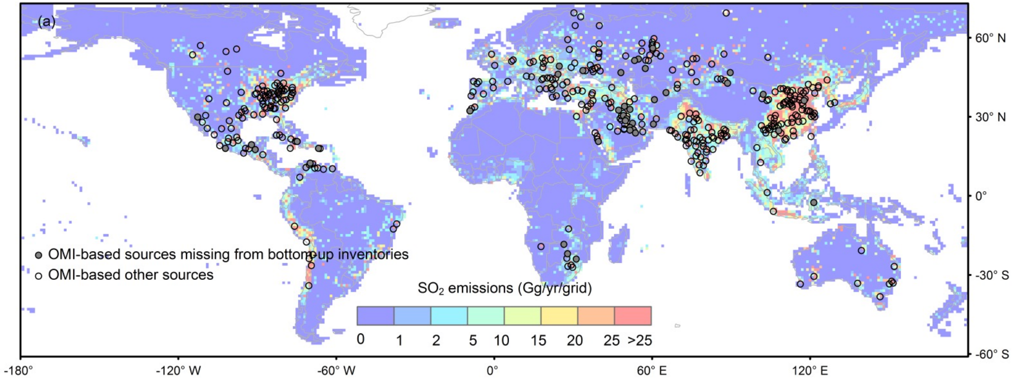




Daily composition forecast

GEOS - CF

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

- 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).

<u>"Business-as-usual" assumed for 2020 and 2021</u>

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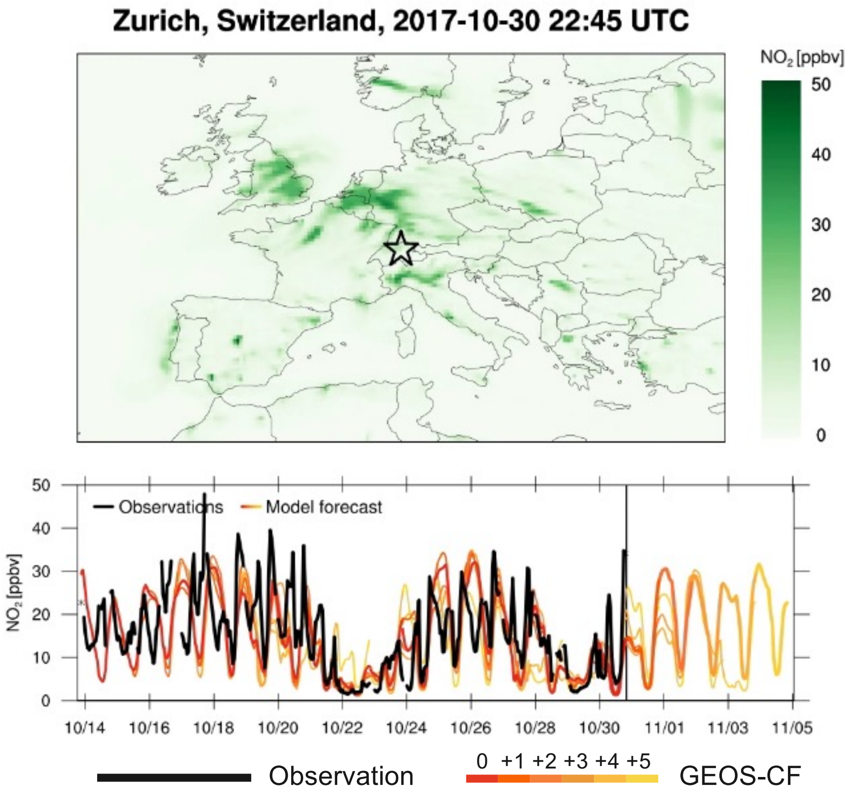
Daily variations of emissions



- 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 through emerging connection to OpenAQ (openaq.org)

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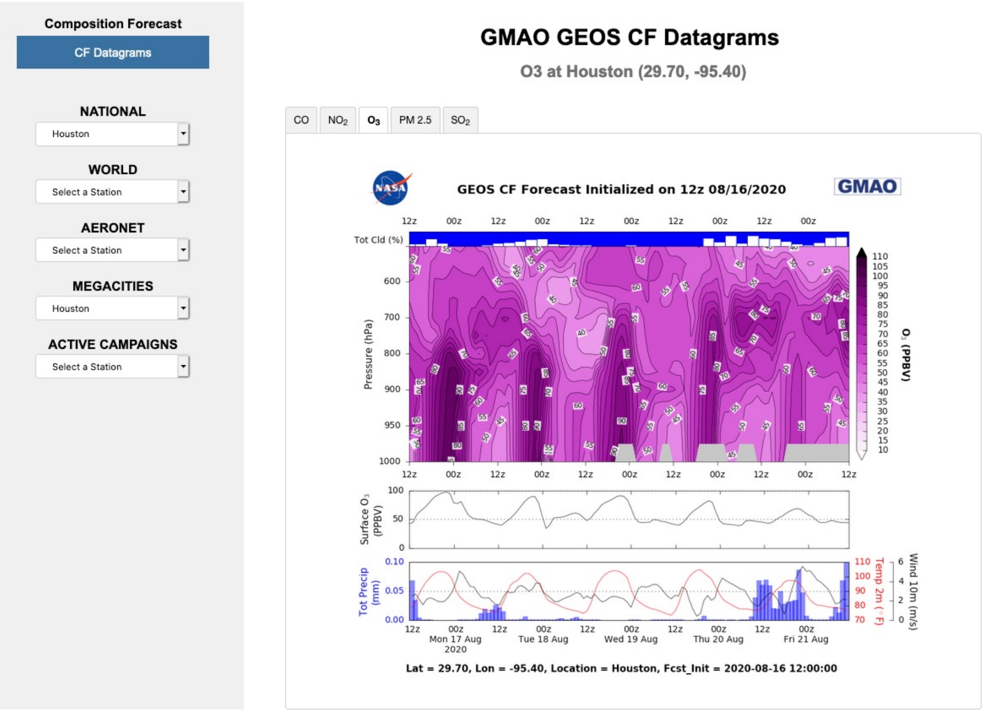
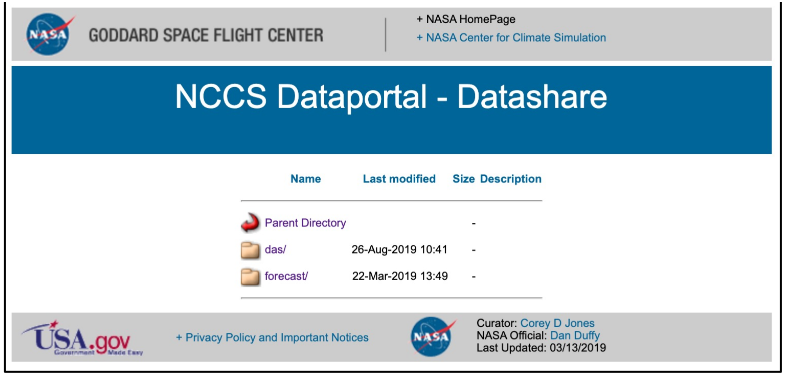
GEOS-CF are available online in near real-time

FLUID is a mobile-friendly website

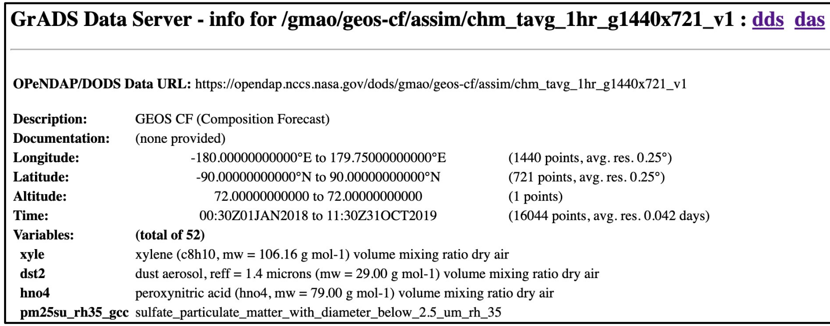
https://fluid.nccs.nasa.gov/cf/



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



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



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

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

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

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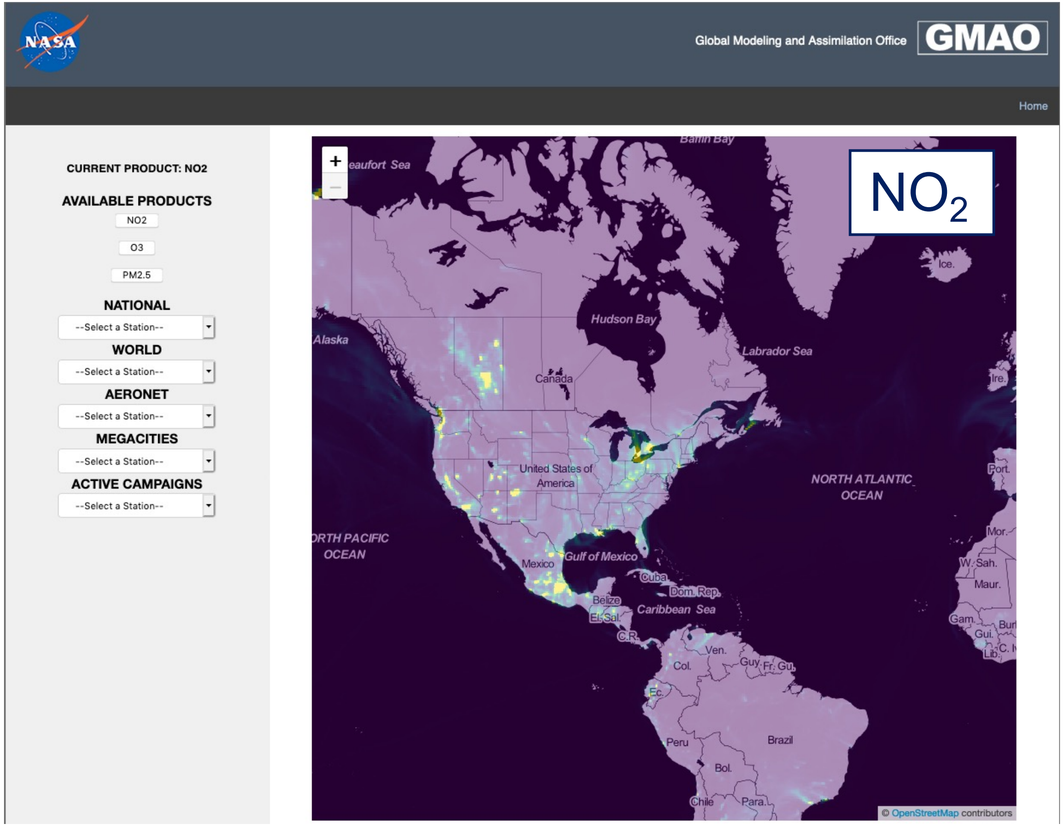
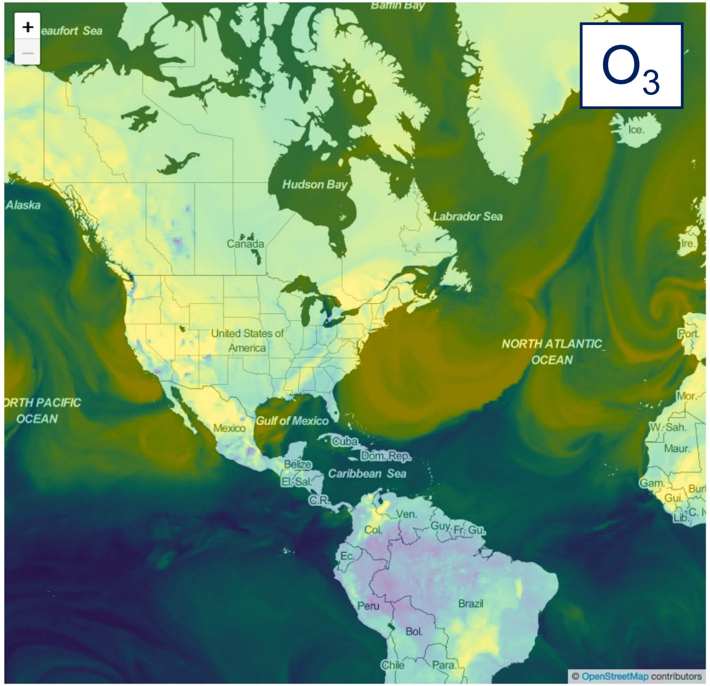
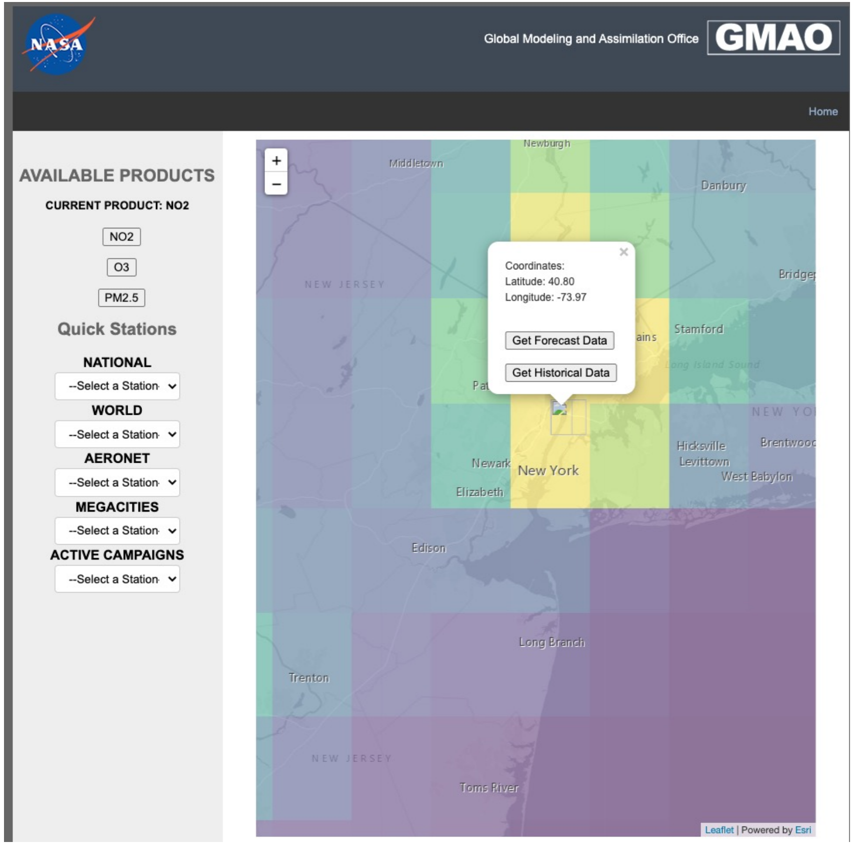
Emerging FLUID Features *in Development*



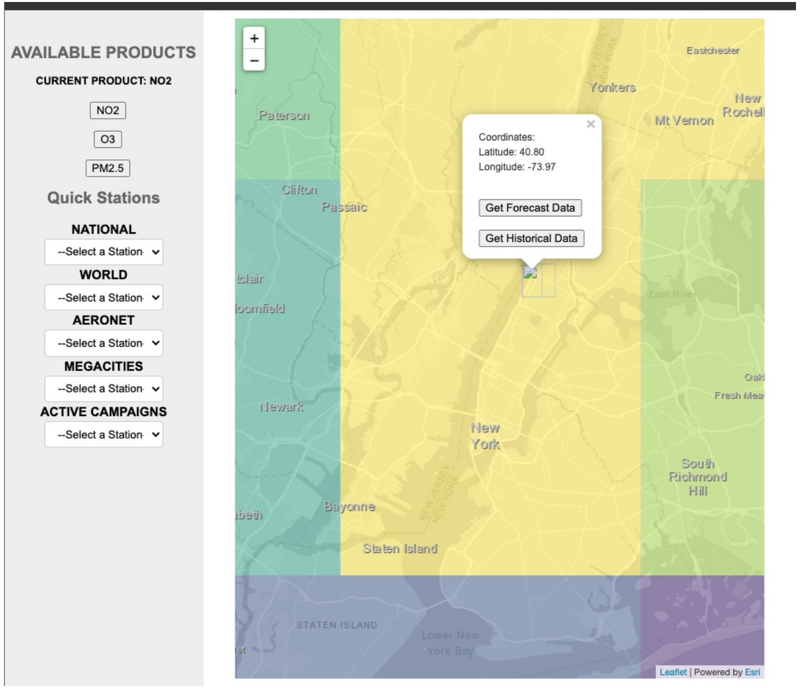
Support from NASA HQ Applied Sciences and Army Public Health Center



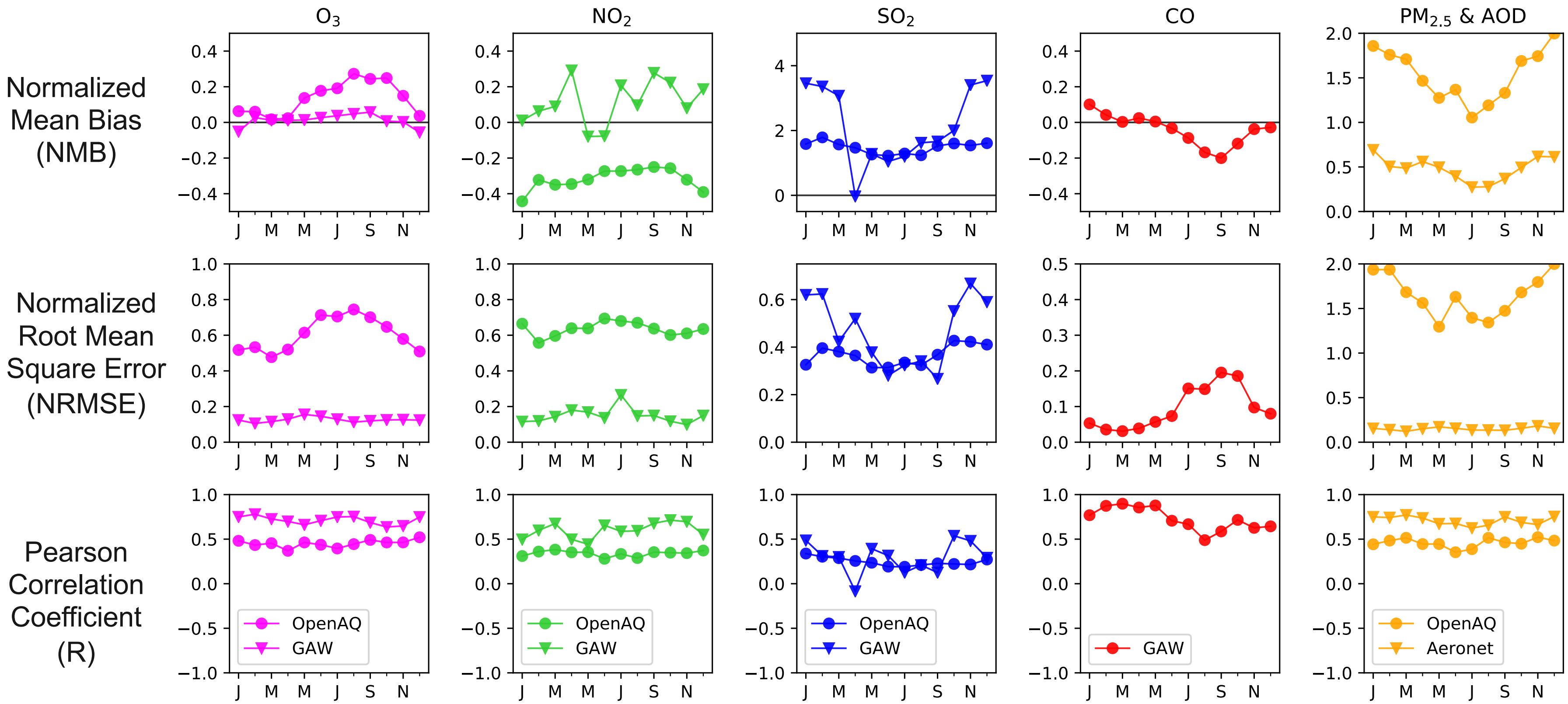
Emerging FLUID Features *in Development*



Capability to zoom in and select data for any grid box

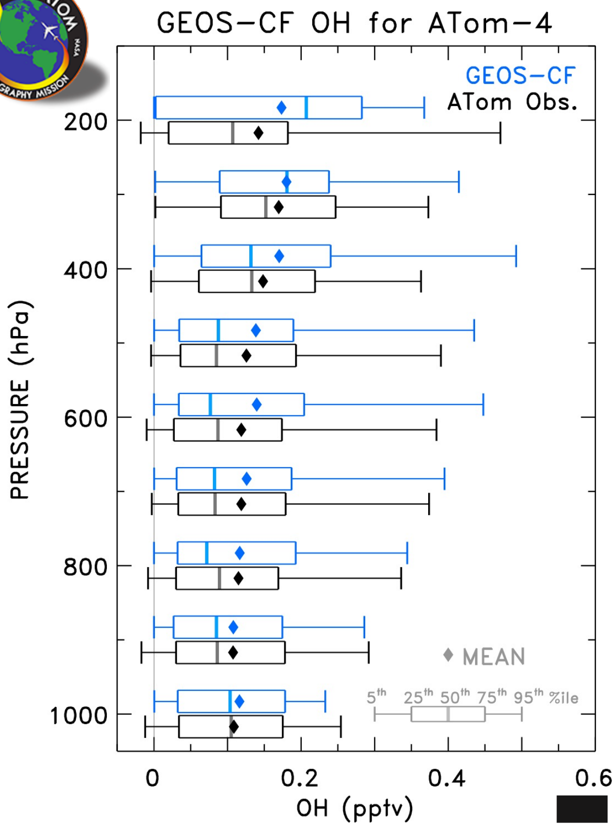


Global surface comparisons - monthly



Keller et al., 2021, JAMES

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

Observations GEOS-CF

Figure courtesy of Julie Nicely

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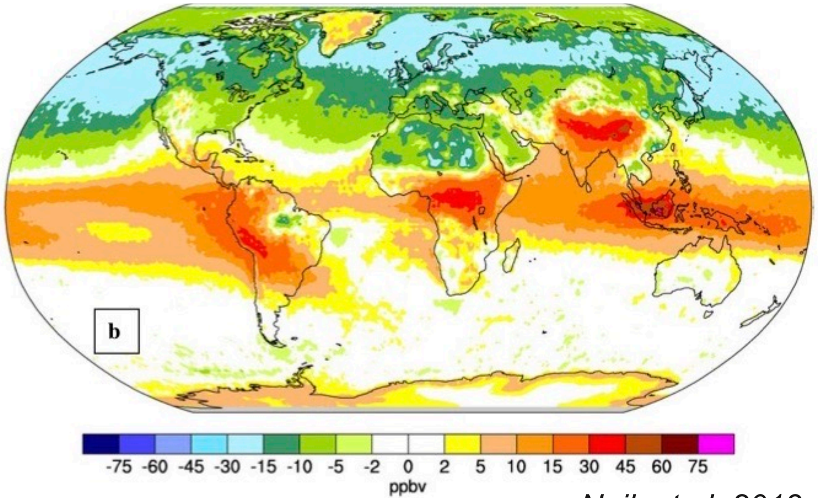
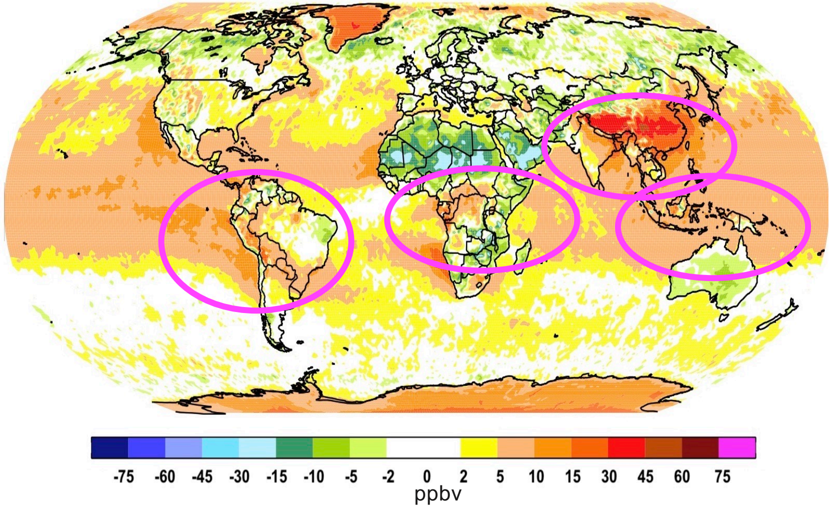
GEOS-CF shows significant improvements in CO simulation, especially over NH

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



Naik et al. 2013, ACP

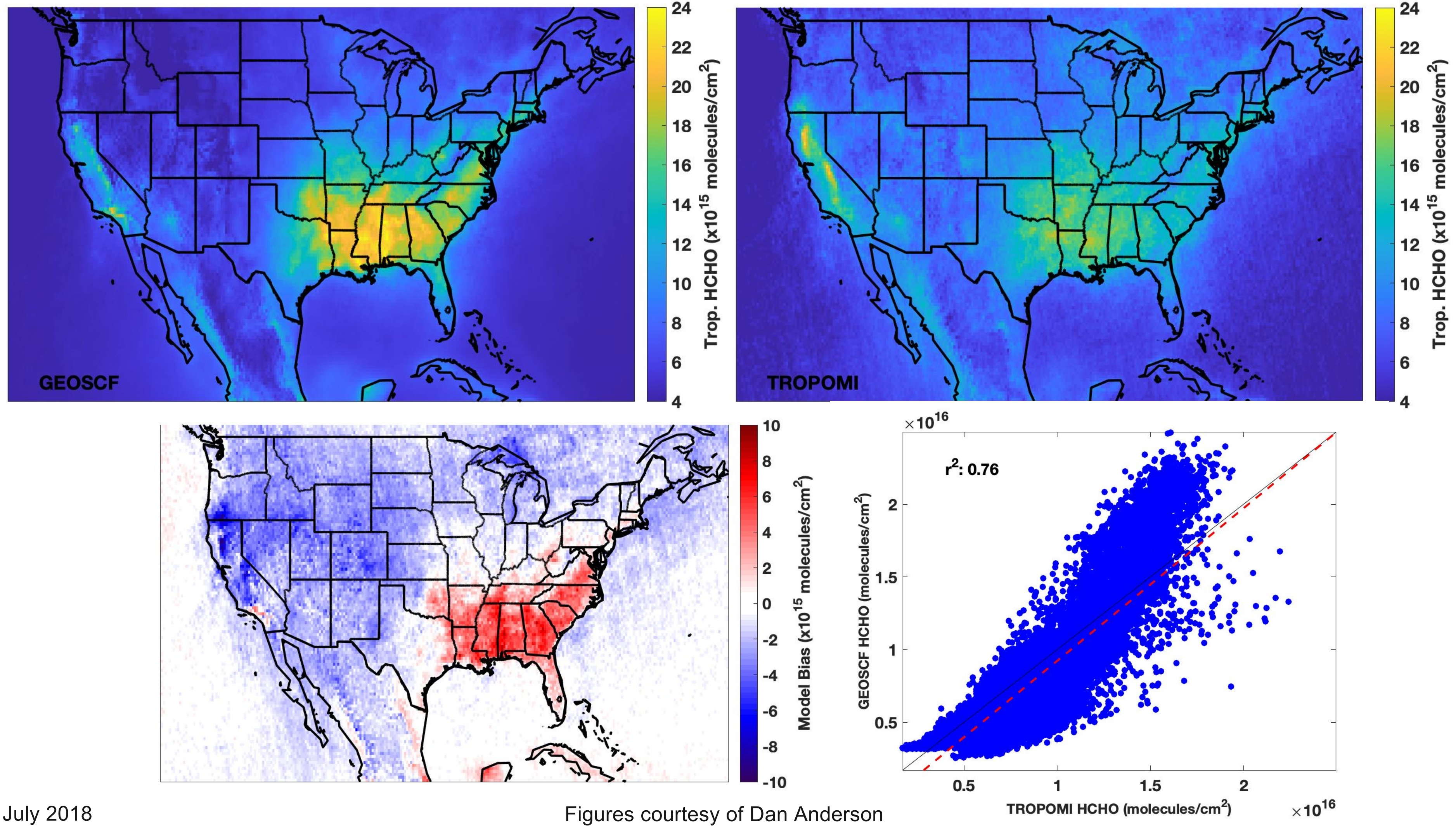
GEOS-CF – MOPITT
(500 hPa, 2018-2019)



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.

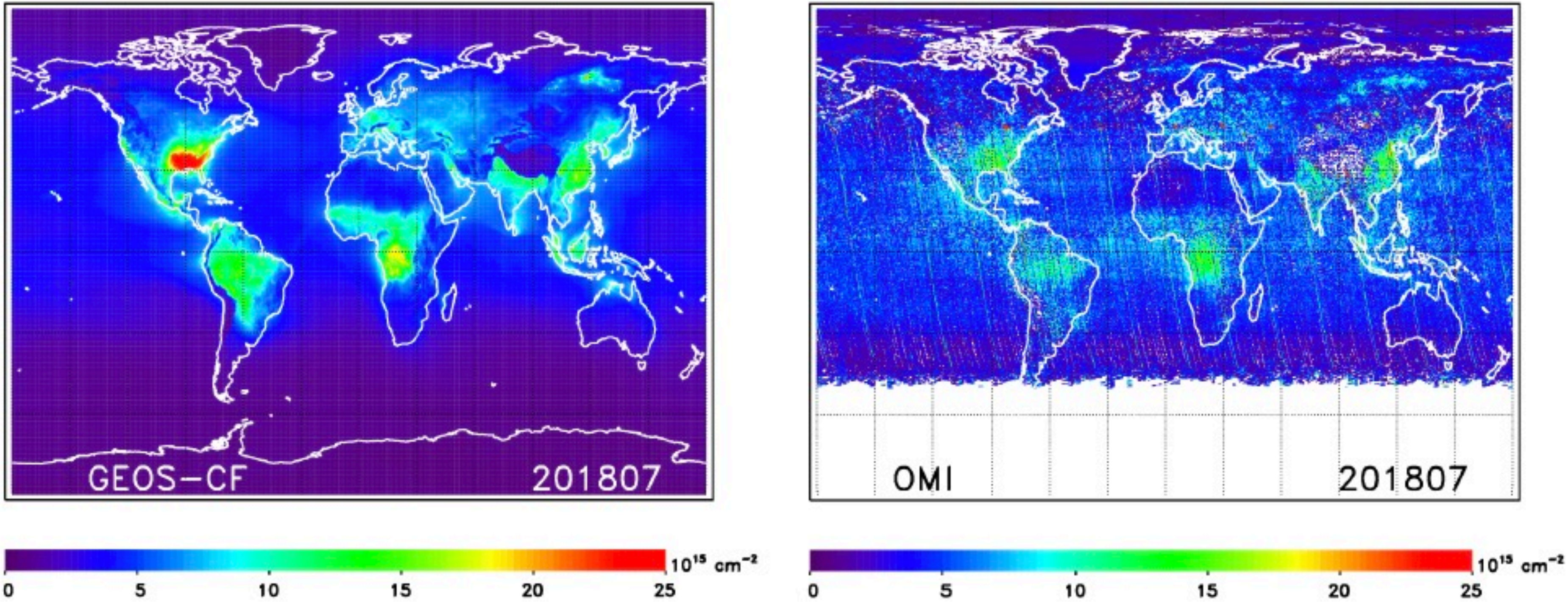
GEOS-CF shows **significant improvements in CO simulation** except over south-central China:

Figures courtesy of Junhua Liu



July 2018

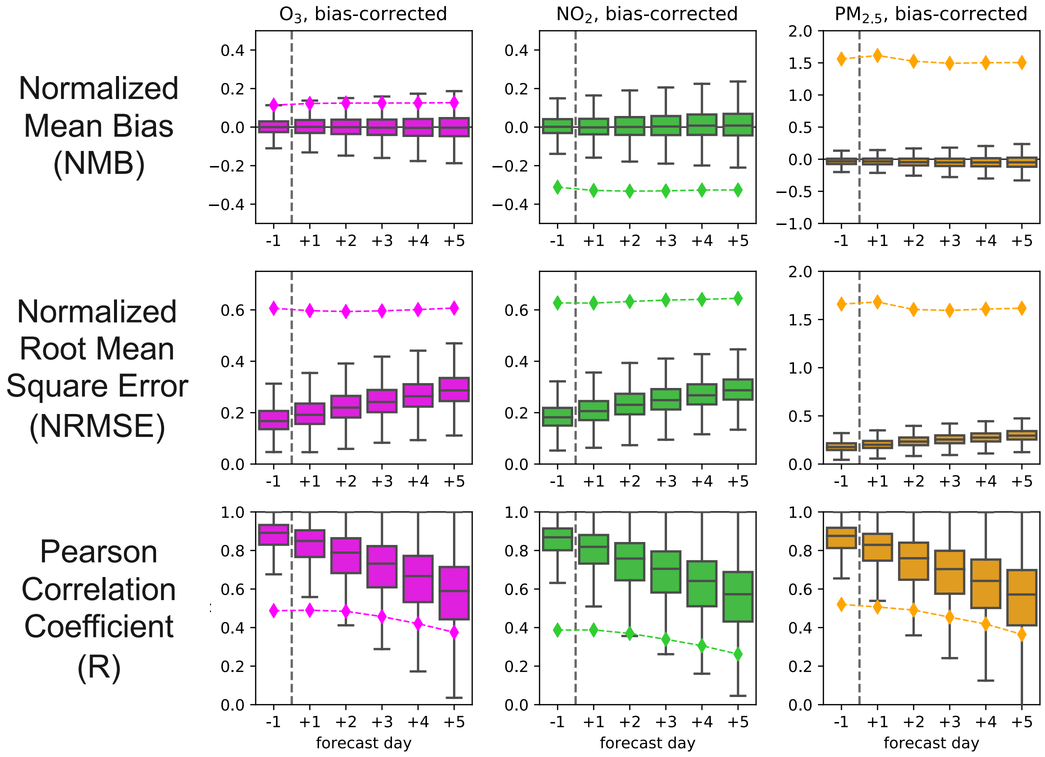
Figures courtesy of Dan Anderson



Using L3 OMI HCHO product, averaging kernel *not* incorporated

Figure courtesy of Julie Nicely

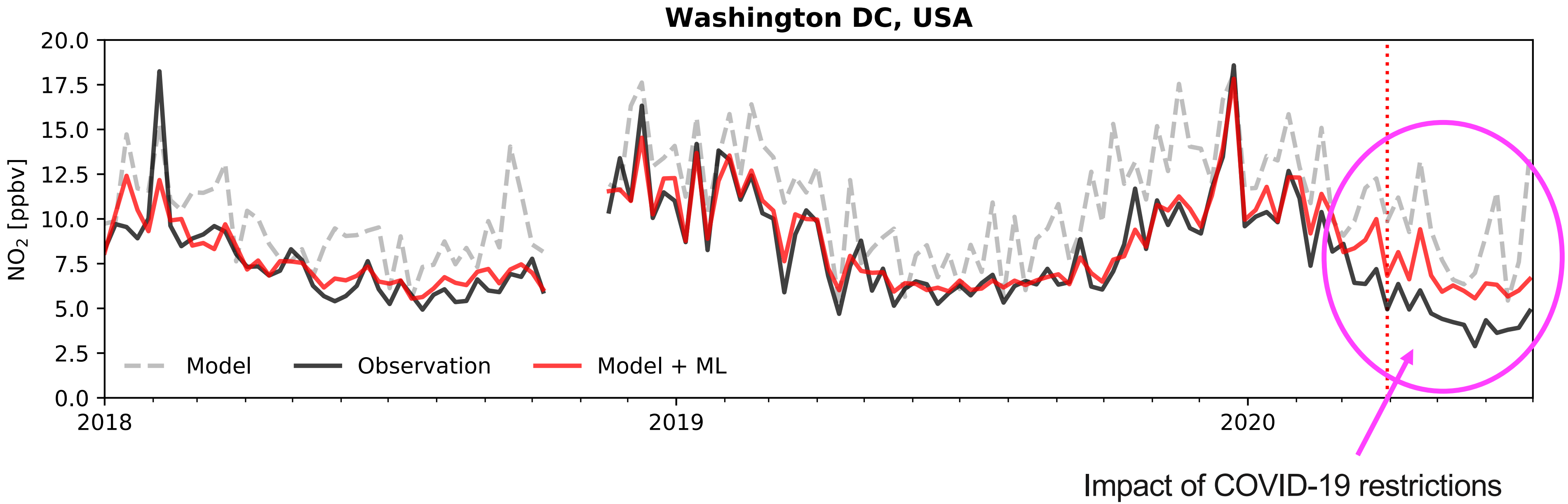
GEOS CF Forecast skill



- ✓ 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

New application of the GEOS-CF ML algorithm



Keller et al., 2021 ACP

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

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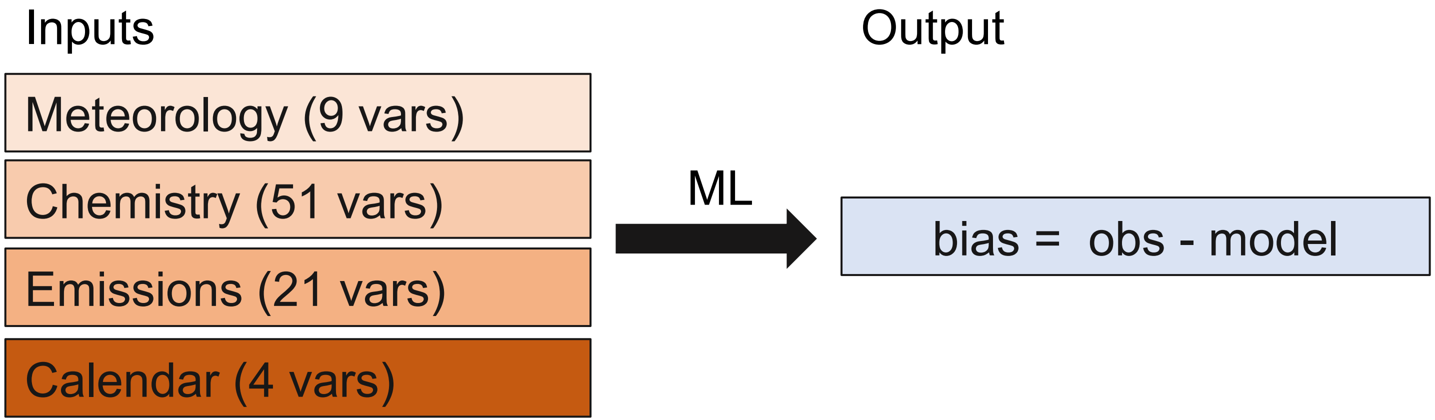
Apply bias-correction to model output using machine learning (using historical observation-model comparisons)



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

Keller et al., 2021 ACP

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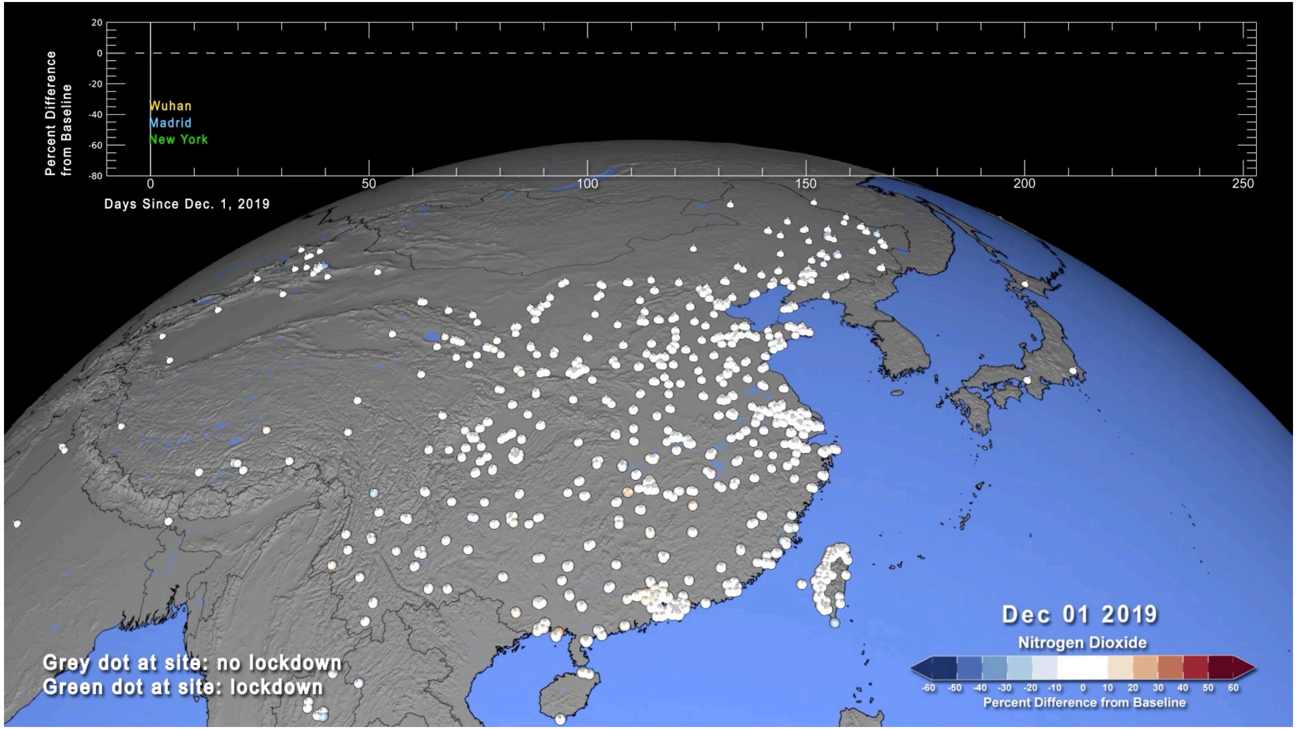
Apply analysis to 5756 sites worldwide



openaq

European Environment Agency

RIO PREFEITURA

QUITO ALCALDÍA

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

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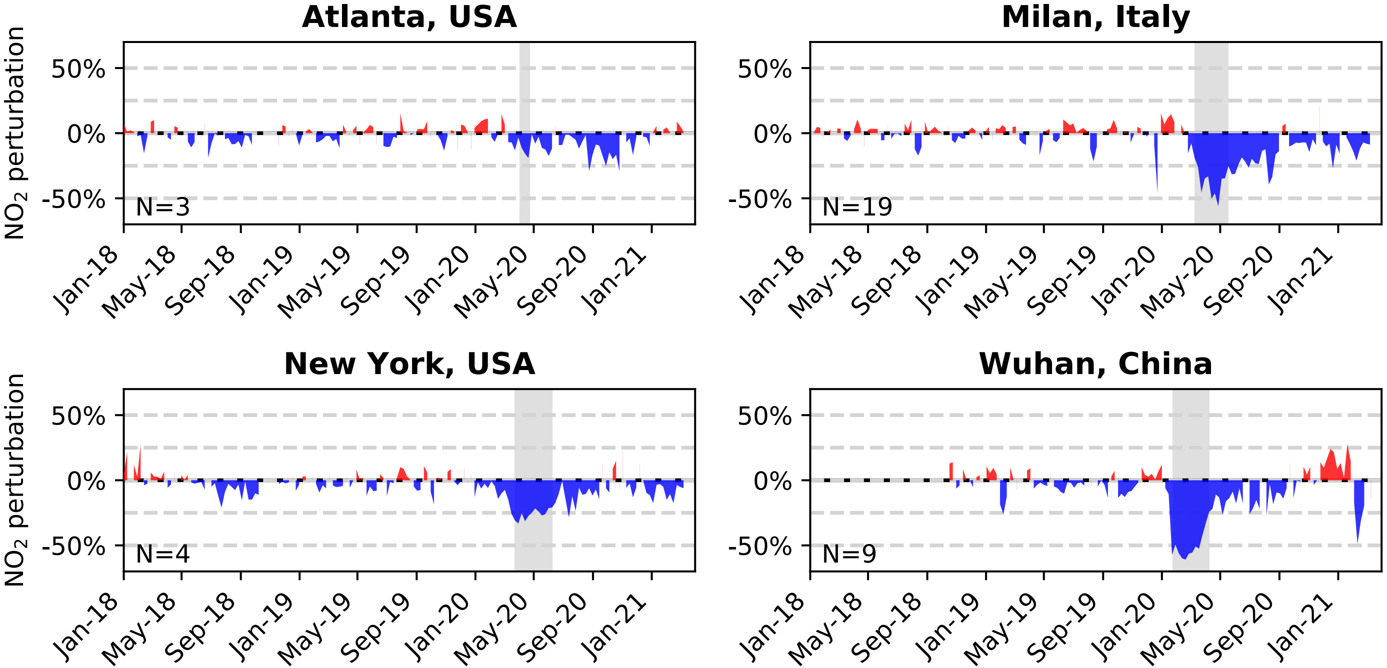
Observation-model differences indicate city-wide NO_2 declines of up to 50% early on and a halting recovery since then



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

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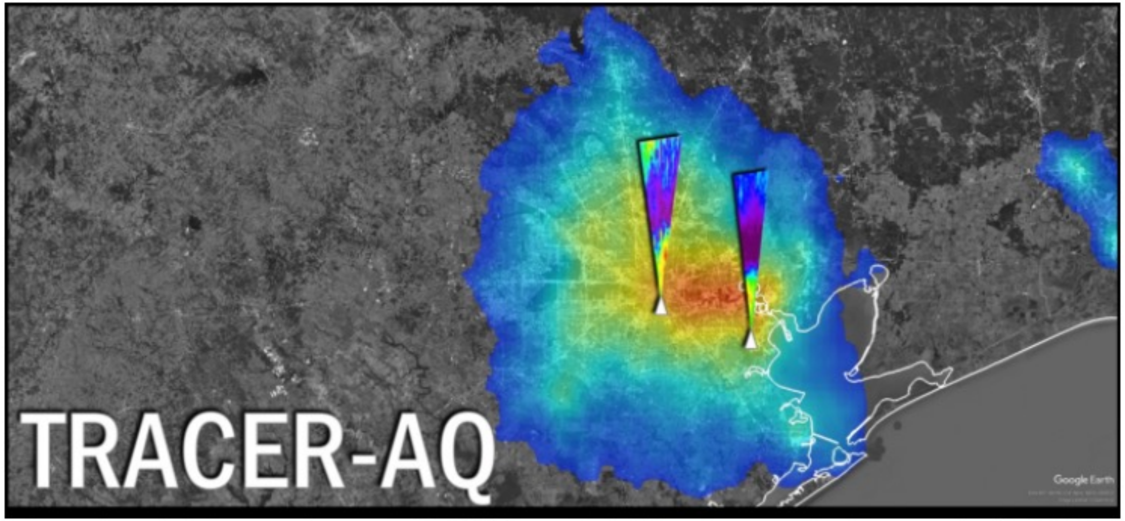
Future missions

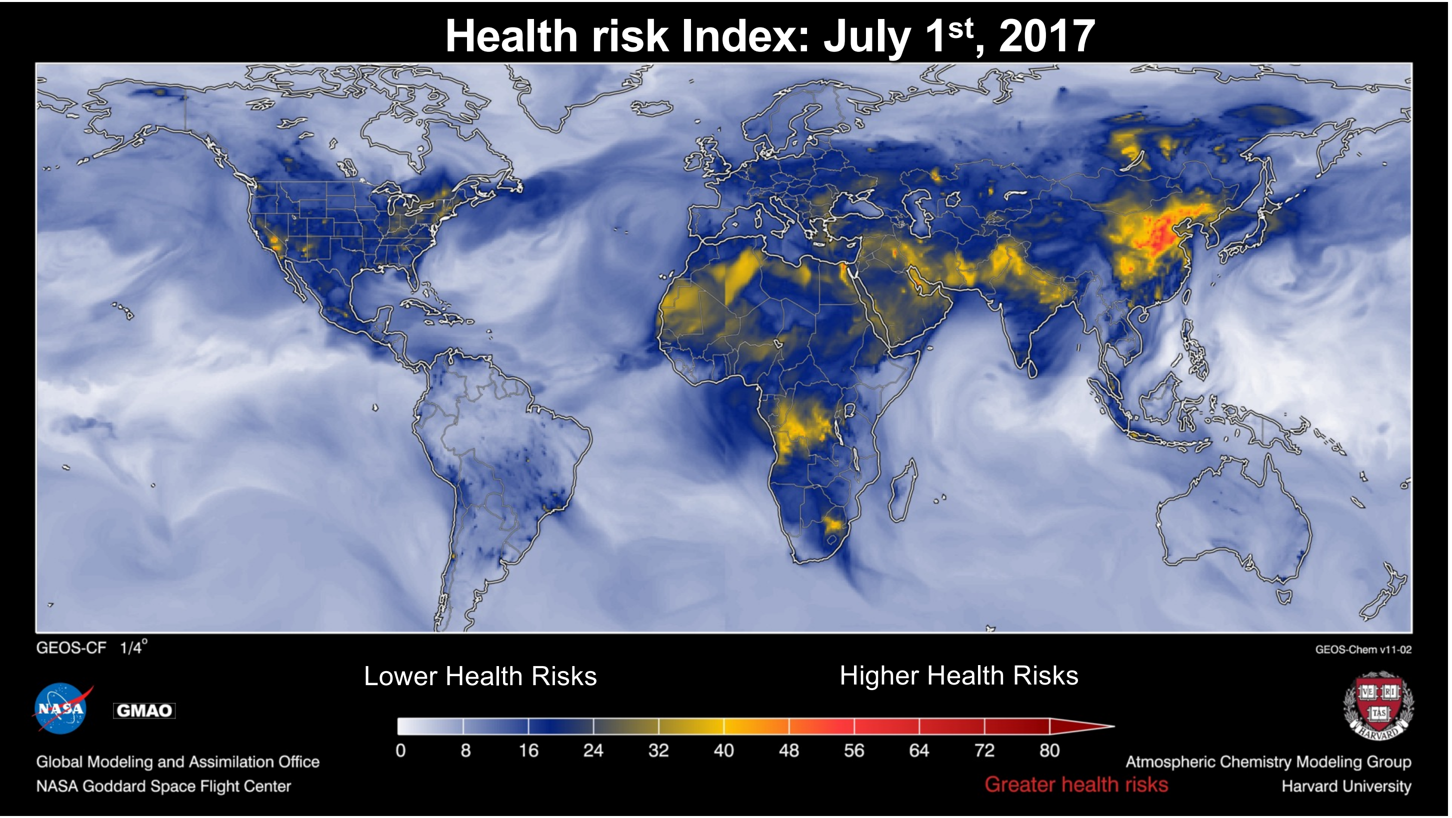


Banner image includes annual average TROPOMI Tropospheric NO_2 columns over the Houston region (April 2019-March 2018) with the approximate proposed locations for TOLNET lidars illustrating their capability for ozone profiling.

https://www-air.larc.nasa.gov/missions/tracer-aq/

GEOS products to support the upcoming TRACER-AQ campaign September 2021

Forecast Application: Multi-pollutant Health Risk Index

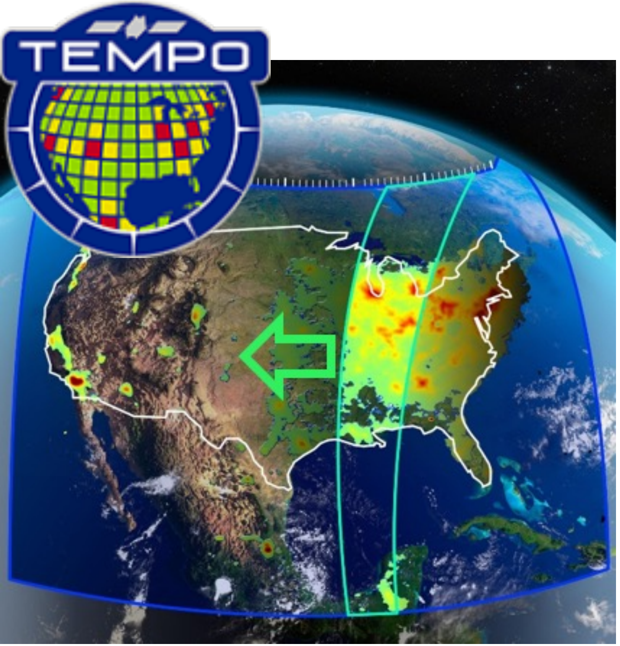


Multi-pollutant index, developed by Kevin Cromar and NYU team (Gladson et al. *in prep*)

- Maximum daily 8-hour average (MDA8) O_3
- 24-hour-average NO_2
- 24-hour-average $PM_{2.5}$

Daily *atmospheric composition* forecast

GEOS - CF

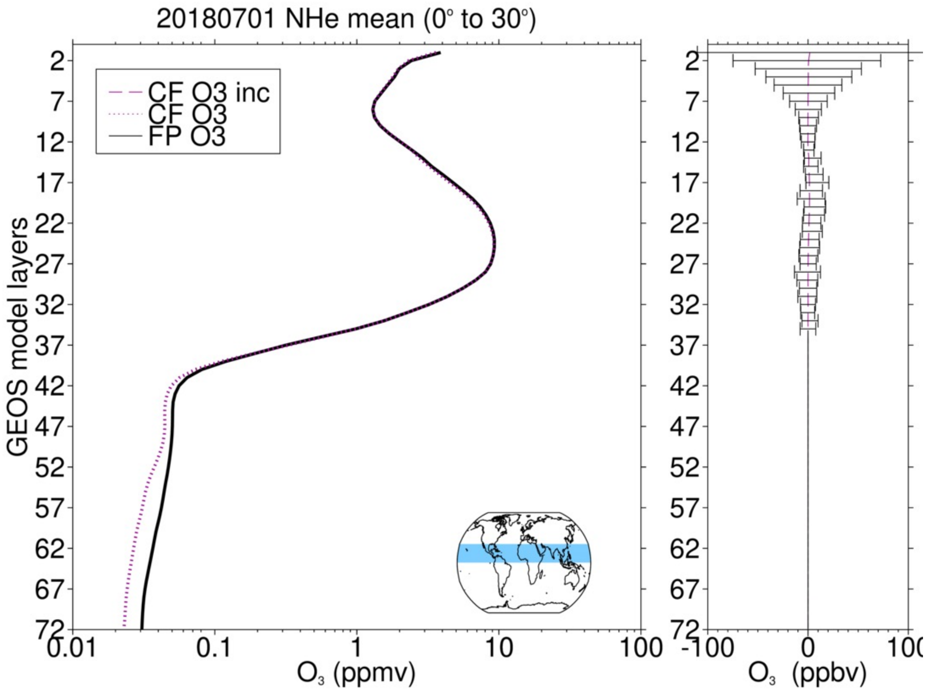


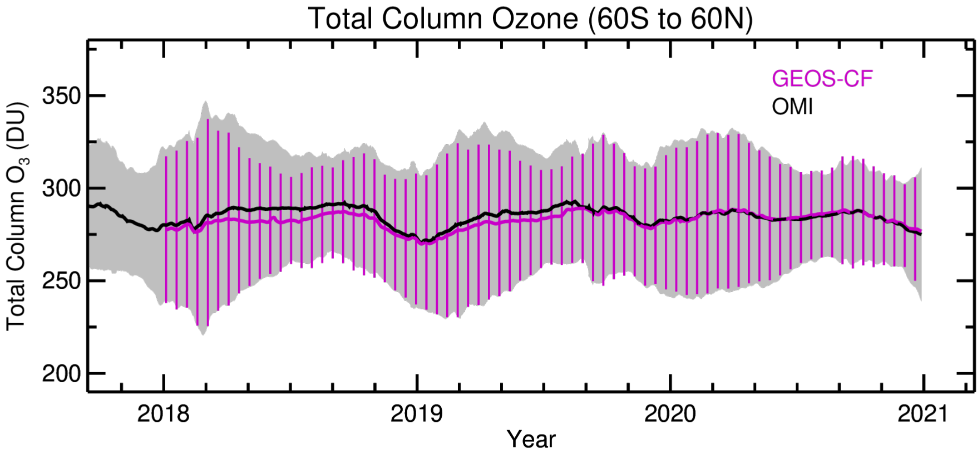
A realistic stratosphere in GEOS-CF is essential to support a broad range of NASA applications, including:

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

Near-real time updates from satellite data

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





GEOS-CF captures the spread of OMI column O_3

Knowland et al., 2021 in prep

GEOS-CF has realistic stratospheric ozone forecasts

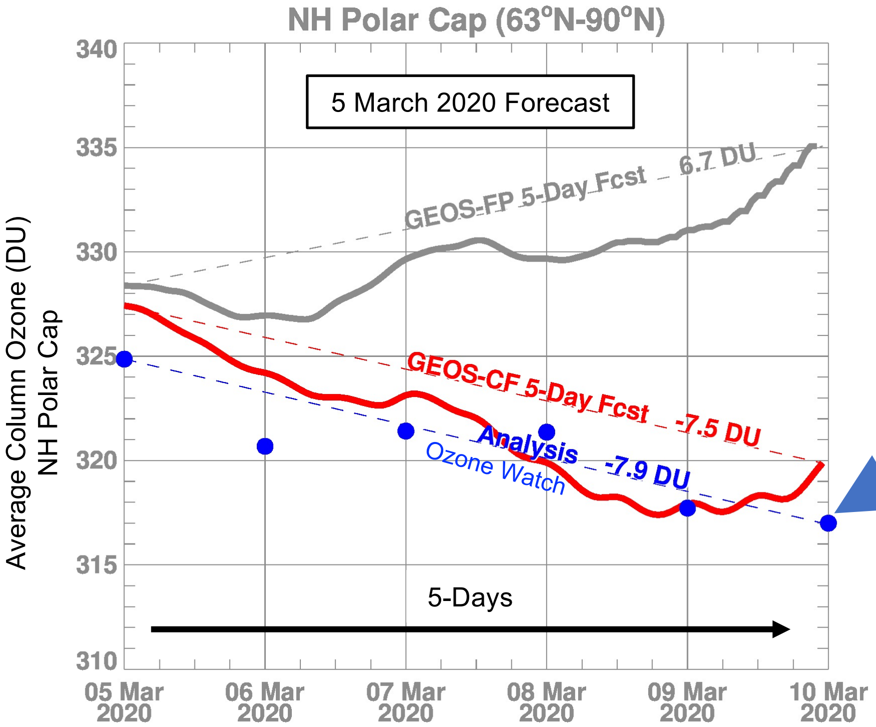
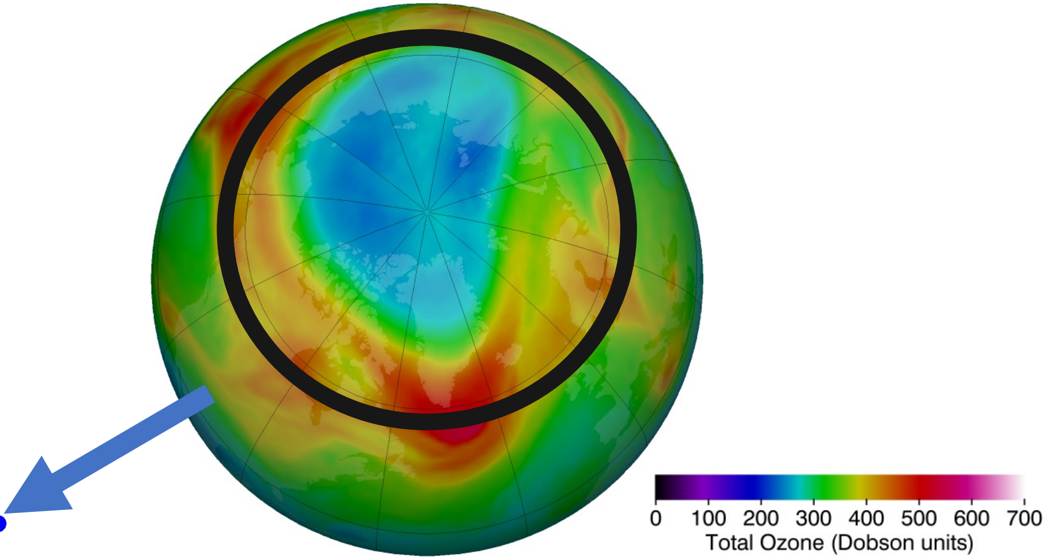


Figure courtesy of Larry Coy



March 10, 2020: Ozonewatch.gsfc.nasa.gov

The GEOS-CF with stratospheric chemistry is responsible for the improved ozone forecasts adding realistic near-real-time stratospheric ozone forecasting capability to the NASA GMAO.

Knowland et al., 2021 in prep

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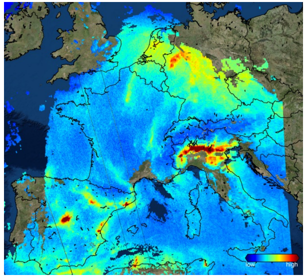
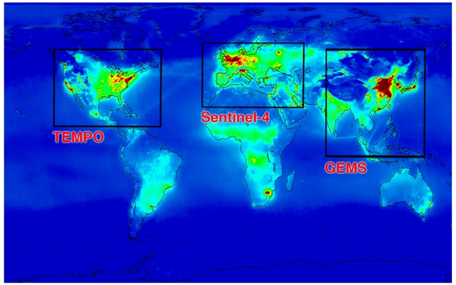
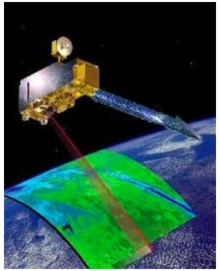
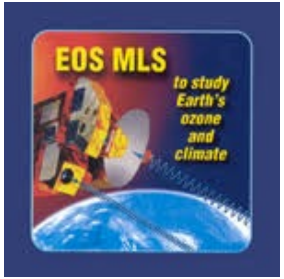
Planned upgrades for GEOS-CF

- Model update to GEOS-Chem v13.0
  - Improvements to ozone deposition
  - Updates to NO_3 washout ⇢ likely reduce PM2.5 bias
- GEOS AGCM update
- Meteorology update to GEOS-FP or GEOS-IT
- CEDS emission inventory (latest release through 2019); new emission scale factors
- Constituent Data Assimilation System (CoDAS)
  - Multi-constituent assimilation with O_3, CO, NO_2
  - Satellite-based emission scale factors









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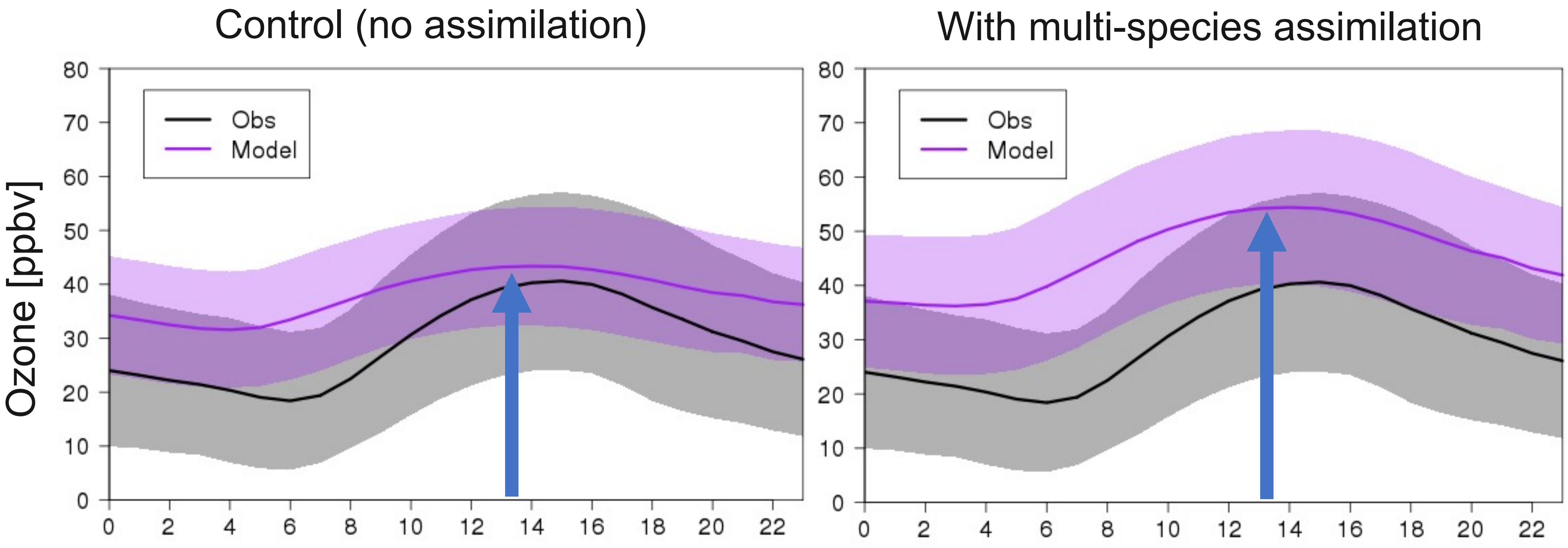
Assimilation of NO_x and CO exacerbates tropospheric ozone bias



- ➢ Improved diurnal cycle, most likely due to improved afternoon NO_2

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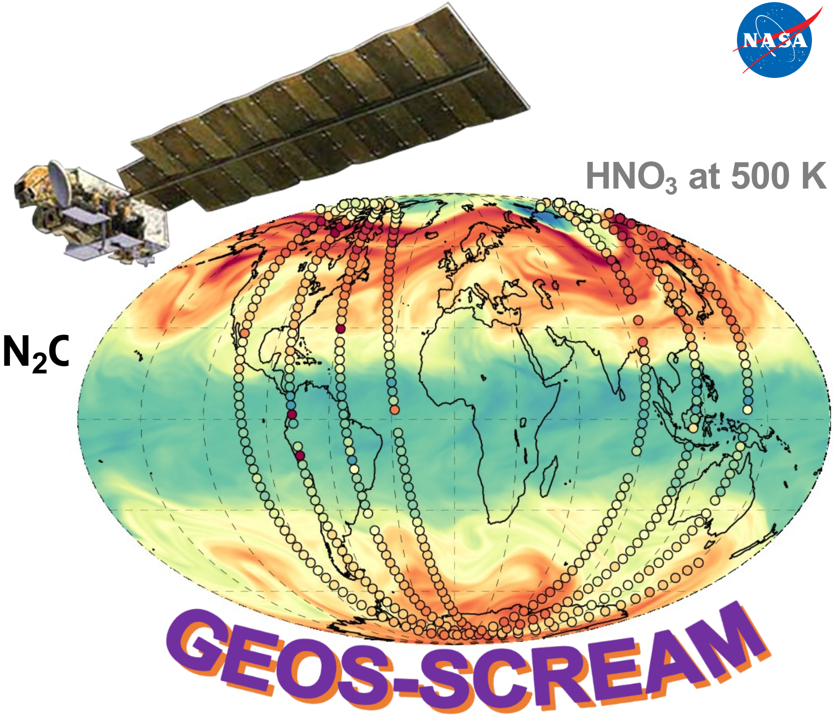
GEOS Stratospheric Composition Reanalysis with Aura MLS (GEOS-SCREAM)

Kris Wargan, Brad Weir, Gloria L. Manney, Stephen E. Cohn, Nathaniel J. Livesey and JPL colleagues



- ❑ Assimilating MLS v4.2 **ozone, H_2O, HCl, HNO_3,** & **N_2O** and **total ozone** from OMI
- ❑ Replay to MERRA-2
- ❑ GEOS “StratChem” stratospheric-only chemistry
- ❑ Period: September 2004 – December 2020+

- ✓ Close agreement with ACE-FTS and GLORIA data and the BRAM2 reanalysis
- ➢ GMAO Reanalysis of the 21st Century (R21C, ~2022) with chemistry

Wargan, K., Weir, B., Manney, G. L., Cohn, S. E., & Livesey, N. J. (2020). The anomalous 2019 Antarctic ozone hole in the GEOS Constituent Data Assimilation System with MLS observations. *Journal of Geophysical Research: Atmospheres*, 125, e2020JD033335. https://doi.org/10.1029/2020JD033335

Thank you!

Referred

Keller, C. A., Knowland, K. E., Duncan, B. N., Liu, J., Anderson, D. C., Das, S., 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

Johnson, M. S., Strawbridge, K., Knowland, K. E., Keller, C., and Travis, M. (2021), Long-range transport of Siberian biomass burning emissions to North America during FIREX-AQ, *Atmos. Environ.,* 252, https://doi.org/10.1016/j.atmosenv.2021.118241.

Keller, C. A., Evans, M. J., Knowland, K. E., Hasenkopf, C. A., Modekurty, S., Lucchesi, R. A., Oda, T., Franca, B. B., Mandarino, F. C., Díaz Suárez, M. V., Ryan, R. G., Fakes, L. H., and Pawson, S. (2021), Global impact of COVID-19 restrictions on the surface concentrations of nitrogen dioxide and ozone, *Atmos. Chem. Phys.,* 21, 3555–3592, https://doi.org/10.5194/acp-21-3555-2021.

Dacic, N., Sullivan, J. T., Knowland, K. E., Wolfe, G. M., Oman, L. D., Berkoff, T. A., and Gronoff, G. P. (2020), Evaluation of NASA's high-resolution global composition simulations: Understanding a pollution event in the Chesapeake Bay during the summer 2017 OWLETS campaign, *Atmospheric Environment*, 117133, https://doi.org/10.1016/j.atmosenv.2019.117133.

Non-Refereed

Knowland, K. E., Keller, C. A. and Lucchesi, R. A. (2020), "File Specification for GEOS-CF Products." *GMAO Office Note No. 17 (Version 1.1), 37pp, available from http://gmao.gsfc.nasa.gov/pubs/office_notes*

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