



Supporting NASA missions with the GEOS Composition Forecast System

K. Emma Knowland

Morgan State University/GESTAR-II

NASA Global Modeling and Assimilation Office (GMAO)

Co-author: Christoph Keller (MSU/GESTAR-II, NASA GMAO)

In collaboration with:

NASA GMAO: Steven Pawson, Lesley Ott, Pamela Wales

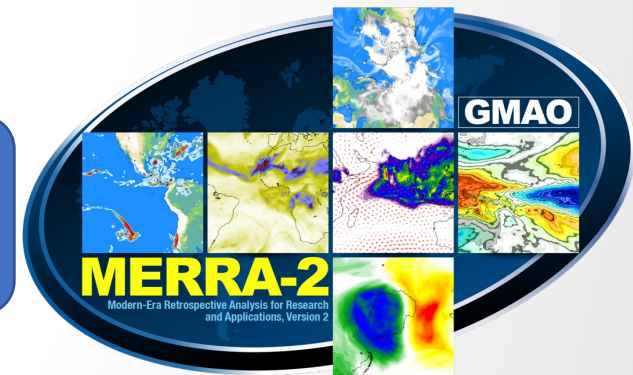
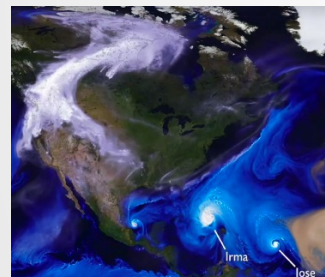
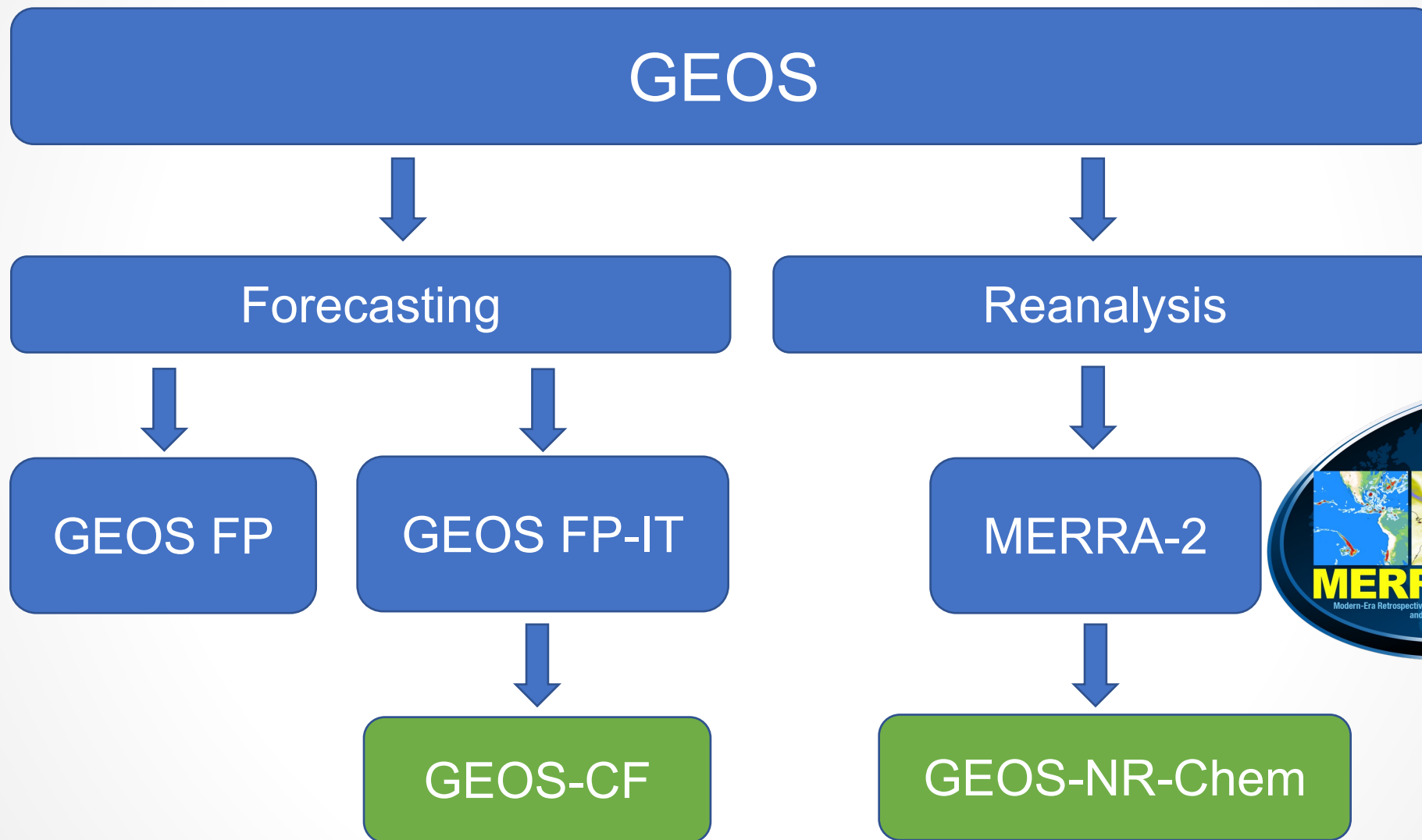
NASA Atmospheric Chemistry and Dynamics Lab: John Sullivan

NASA Ames: Matthew Johnson

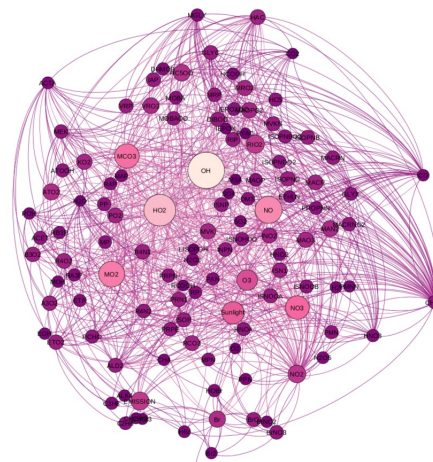
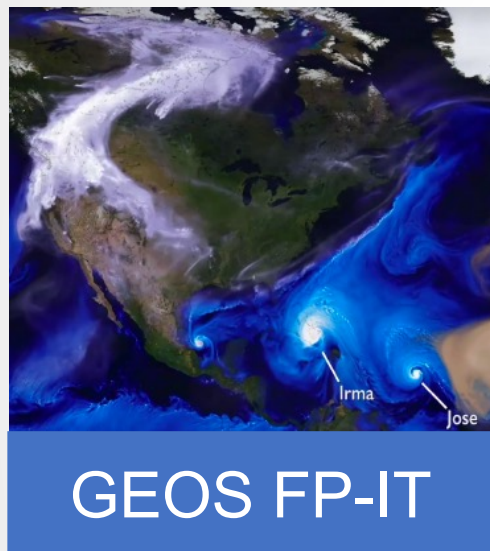
NASA Langley: Guillaume Gronoff, Tim Berkoff



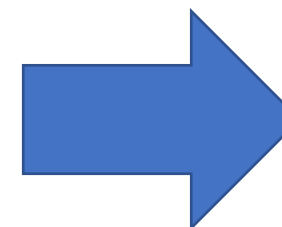
NASA GMAO global meteorology and chemistry products



GEOS Composition Forecast



GEOS-Chem



GEOS - CF

Version 12.0.1

Tropospheric and Stratospheric chemistry

same version as GEOS-Chem Classic

There are differences for emissions as GEOS-CF is run in near-real time, transport calculated directly within GEOS

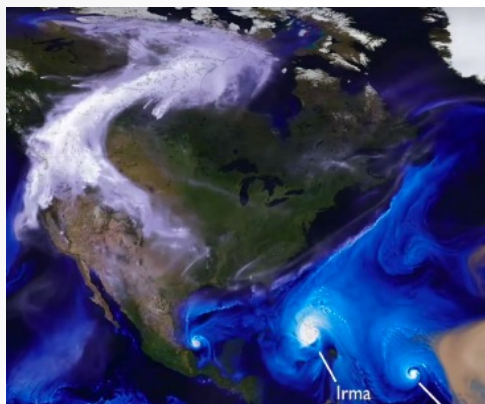
Keller, C. A., Knowland, K. E., et al. (2021). **Description of the NASA GEOS composition forecast modeling system GEOS-CF v1.0.** *Journal of Advances in Modeling Earth Systems*, 13, e2020MS002413. <https://doi.org/10.1029/2020MS002413>

GEOS Composition Forecast

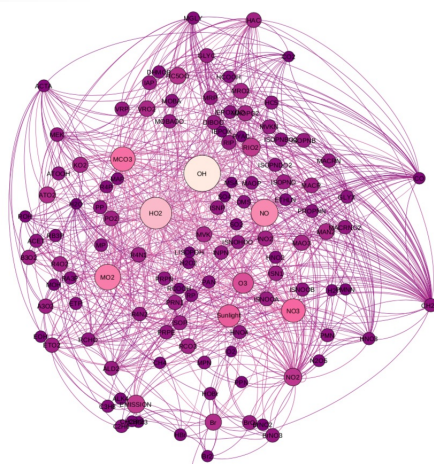
GEOS - CF

One **5-day forecast** per day

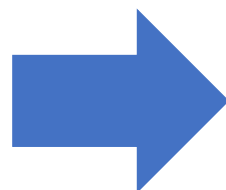
- 1-day replay
- 5-day forecast
- c360 (0.25° , **$\sim 25 \times 25 \text{ km}^2$**) resolution, 72 model layers



GEOS FP-IT



GEOS-Chem

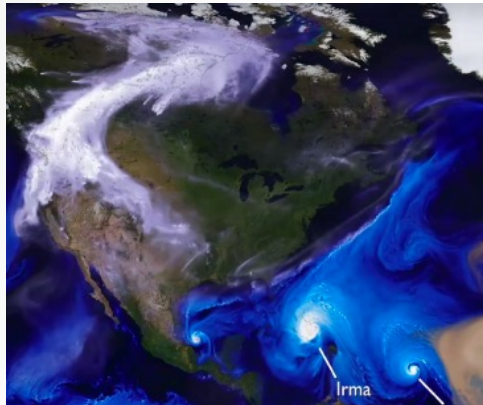


GEOS Composition Forecast

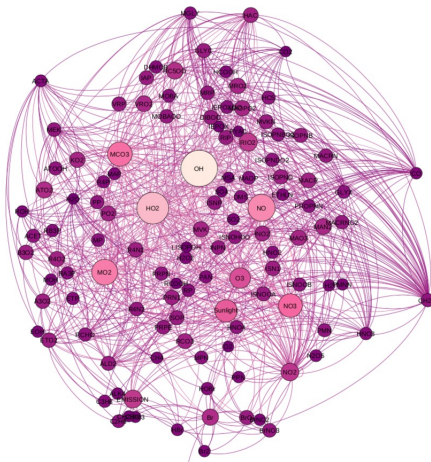
GEOS - CF

One **5-day forecast** per day

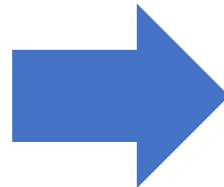
- 1-day replay
- 5-day forecast
- c360 (0.25° , $\sim 25 \times 25 \text{ km}^2$)
- **15 minute** “surface”
- **1-hour** average and instantaneous 2D & 3D



GEOS FP-IT



GEOS-Chem



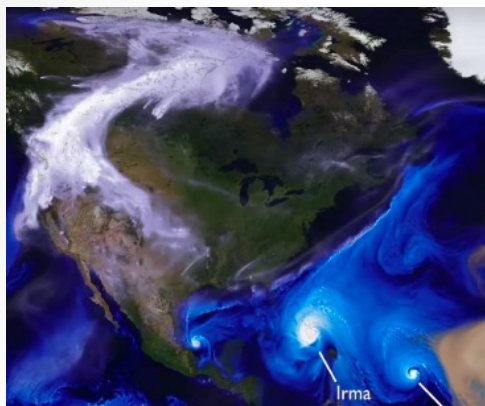
GEOS Composition Forecast

GEOS - CF

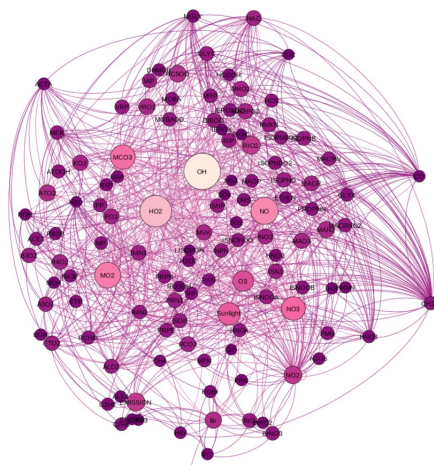
One **5-day forecast** per day

- 1-day replay
- 5-day forecast
- c360 (0.25° , $\sim 25 \times 25 \text{ km}^2$)

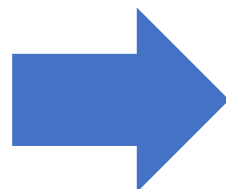
➤ **1 January 2018 - NRT**



GEOS FP-IT



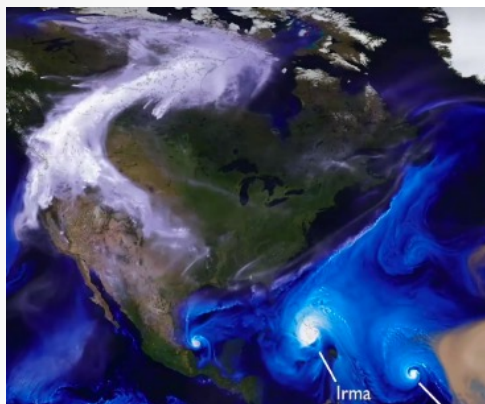
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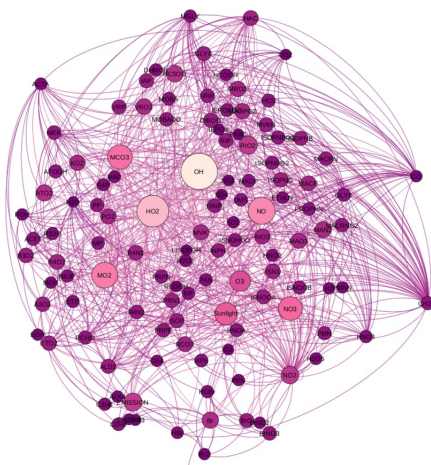
GEOS Composition Forecast

GEOS - CF

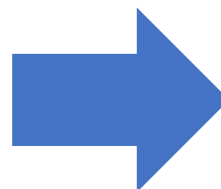
- Currently no direct data assimilation of constituents in GEOS-CF



GEOS FP-IT



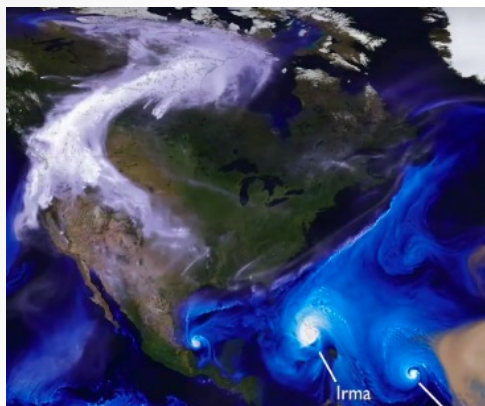
GEOS-Chem



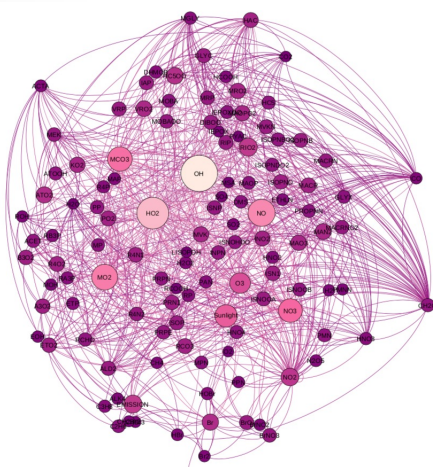
GEOS Composition Forecast

GEOS - CF

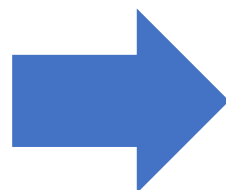
- Currently no direct data assimilation of constituents in GEOS-CF
- Biomass burning emissions from QFED
- Stratospheric O_3 weakly nudged to GEOS FP analyzed O_3



GEOS FP-IT



GEOS-Chem

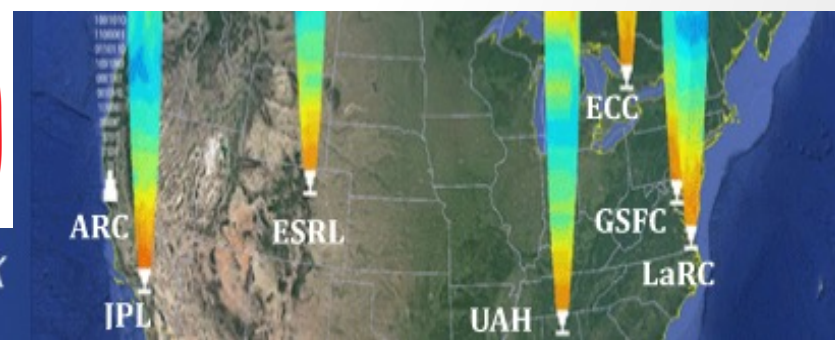
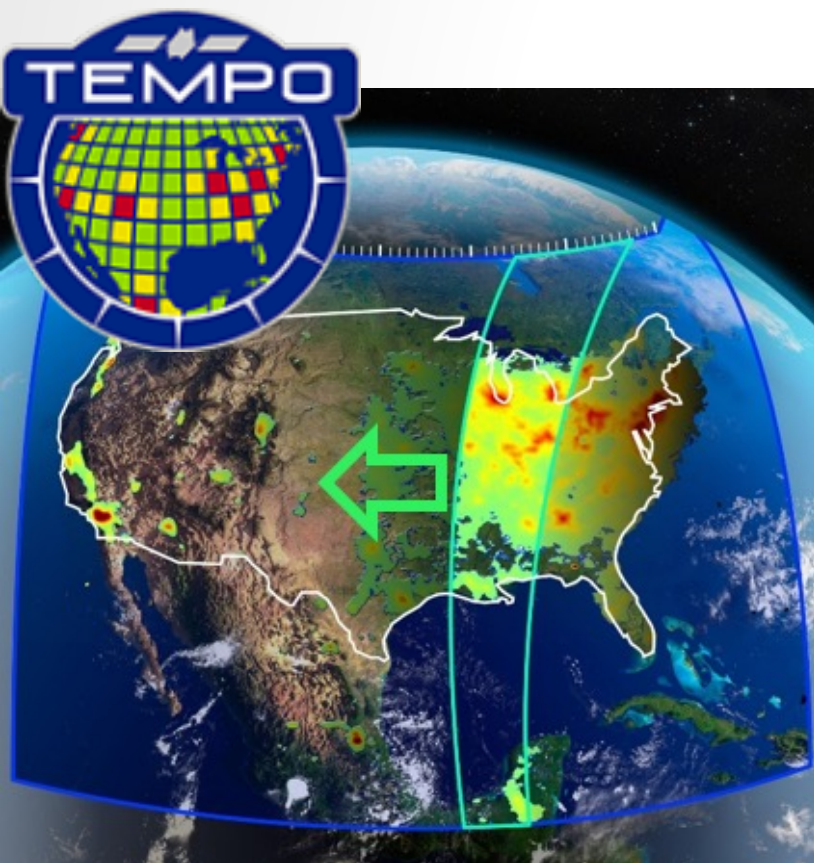


Support a broad range of NASA applications

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



GMAO Mission Support for Field Campaigns





Global Modeling and Assimilation Office

GMAO

<https://fluid.nccs.nasa.gov/missions/>

Weather | Mission Support | CF | Reanalysis | Carbon

Navigation

- » FLUID Overview
- » Contact

Active Missions

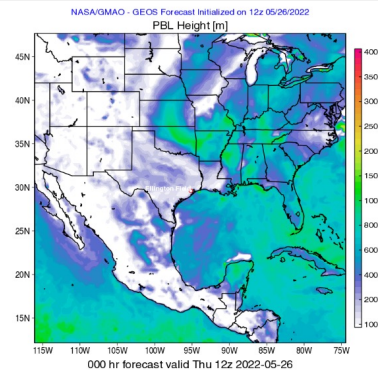
- » ACCLIP
- » BLUEFLUX
- » DCOTSS
- » PRDUST

Non-Active Missions

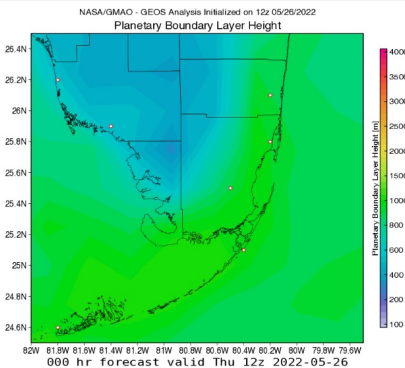
- » ABOVE
- » ACE-ENA
- » AEOLUS-CALVAL
- » ATOM
- » CAMP2EX
- » EPOCH
- » MOSAIC
- » ORACLES
- » SCOAPE
- » SOCRATES
- » TRACER-AQ

GMAO Active Mission Support

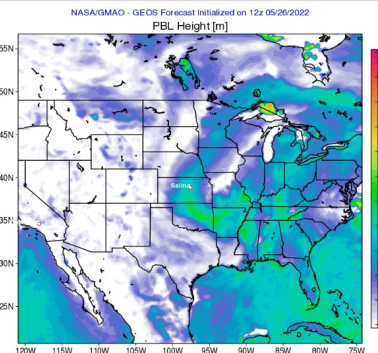
ACCLIP



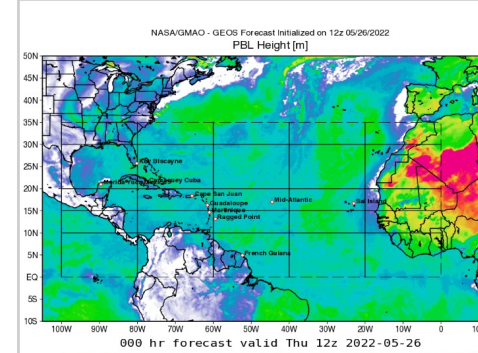
BLUEFLUX



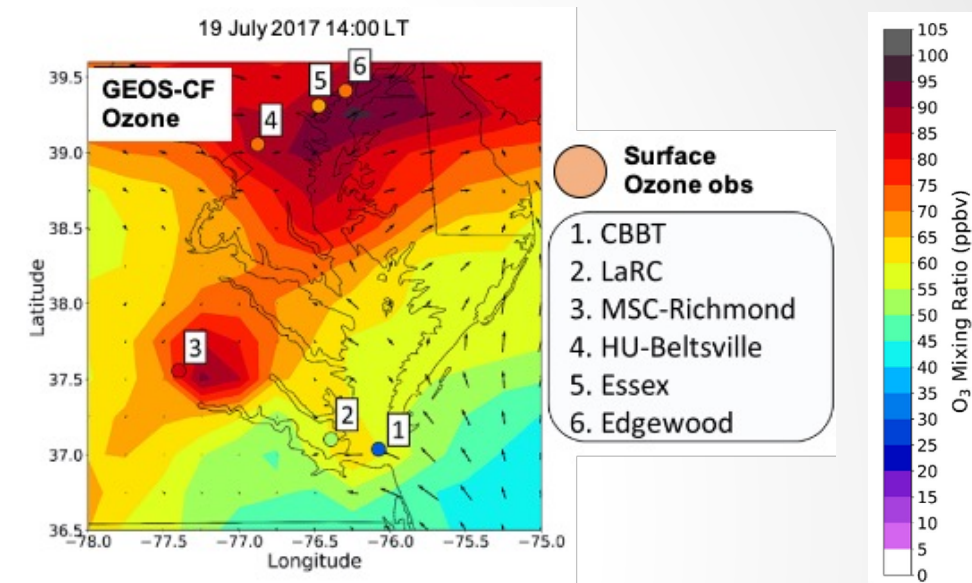
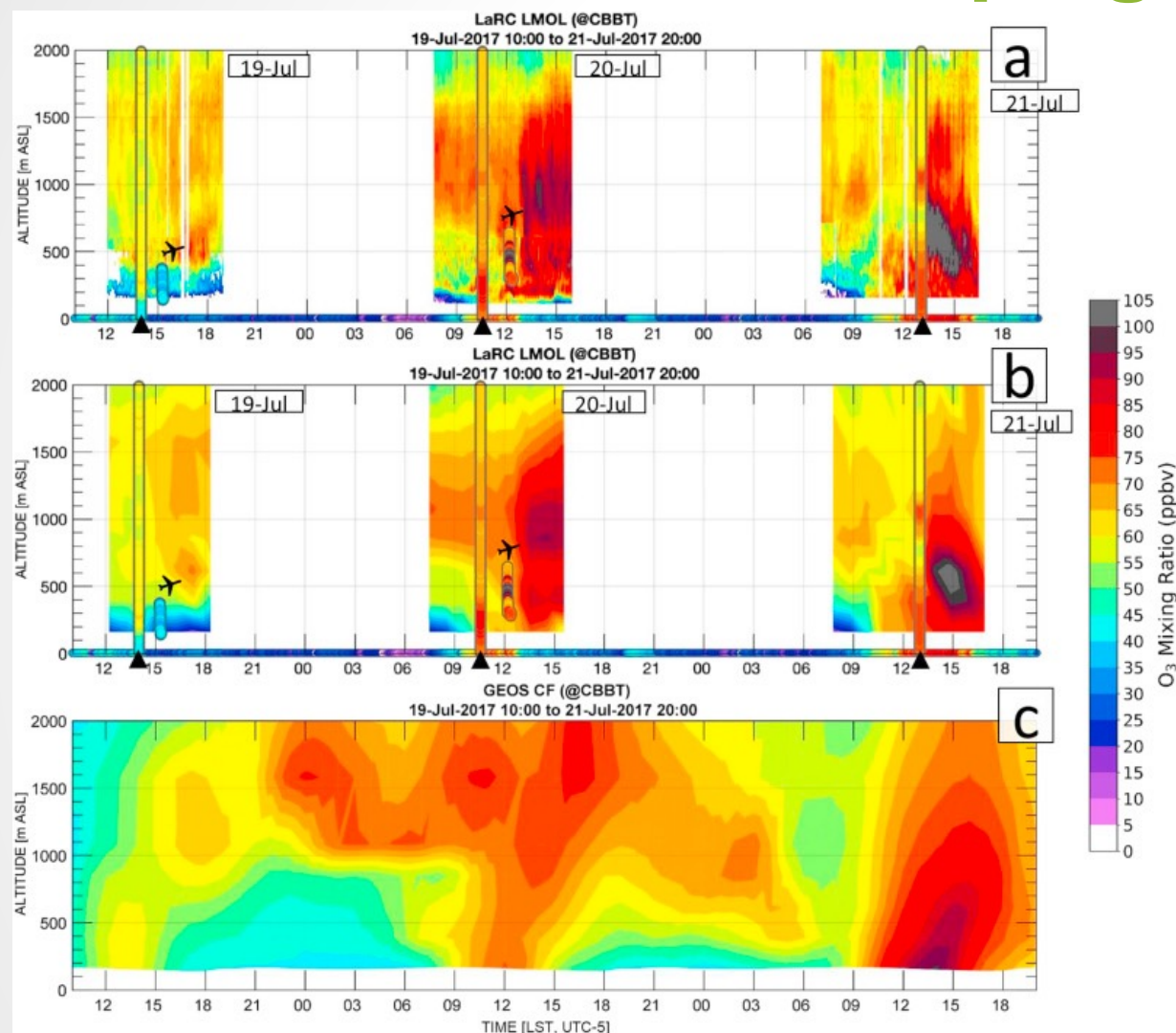
DCOTSS



PRDUST



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.

Long-range transport of Siberian biomass burning emissions to North America during FIREX-AQ campaign

- GEOS-CF and satellite observations characterized the long-range transport pathway of Siberian smoke over the AMOLITE location during FIREX-AQ.
- The long-range transport agreed with the timing of aerosol and ozone lamina measured by AMOLITE.
- GEOS-CF, AMOLITE, and in situ data suggest that while surface air quality impacts in western Canada were small, there were significant free tropospheric ozone (>20 ppb) and aerosol ($>30 \mu\text{g m}^{-3}$) enhancements.

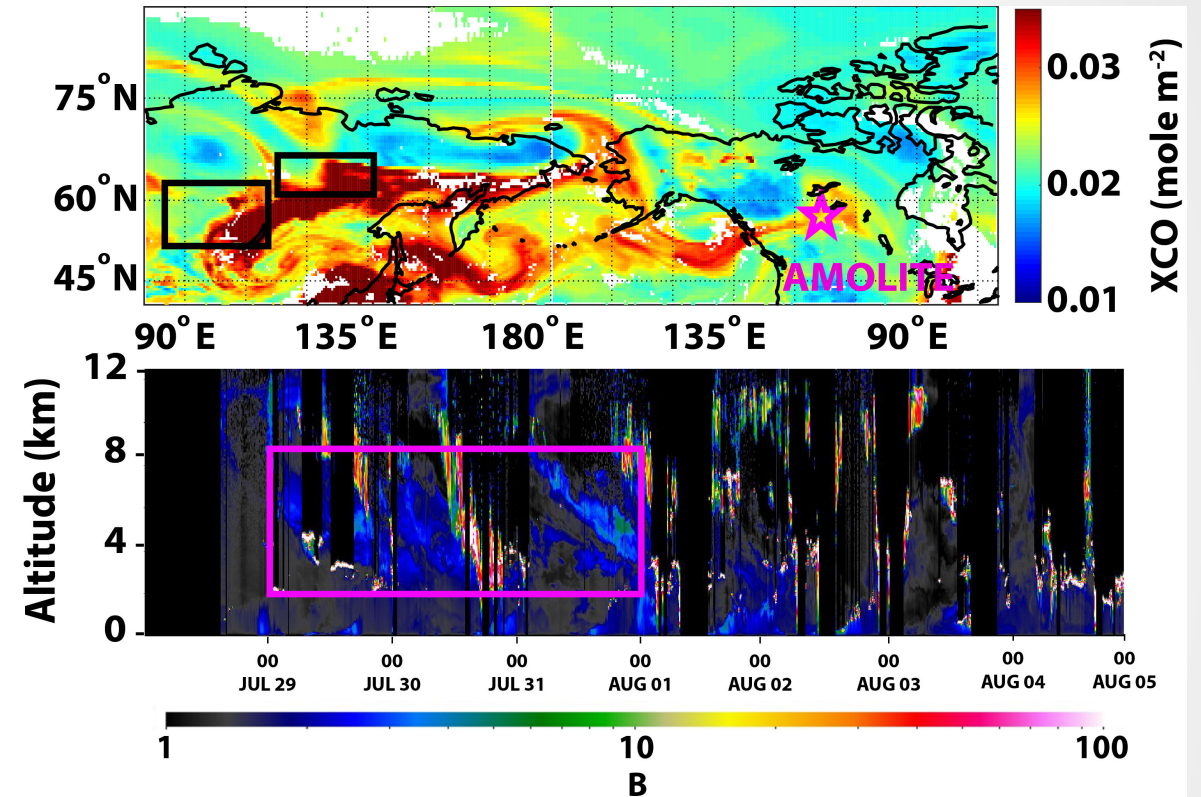


Figure 1. **GEOS-CF** XCO (mole m^{-2}) on July 29, 2019 (top) and AMOLITE aerosol backscatter ratio (B) between July 28 and August 5, 2019 (bottom). The magenta star and box highlight the location of **AMOLITE** and the large aerosol lamina observed by the system, respectively.

Johnson, M. S., Strawbridge, K., Knowland, K. E., et al., "Long-range transport of Siberian biomass burning emissions to North America during FIREX-AQ." *Atmos. Environ.*, 2021. DOI: 10.1016/j.atmosenv.2021.118241

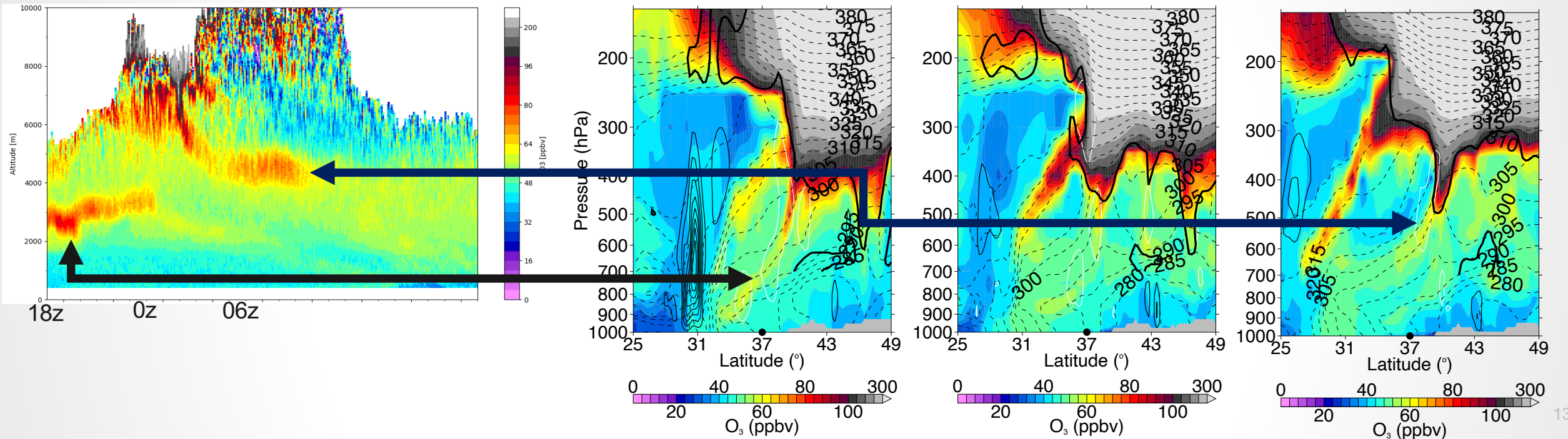
Stratosphere Troposphere Exchange

NASA LaRC Feb 13-14, 2019

GEOS-CF
Feb 13, 2019 18z

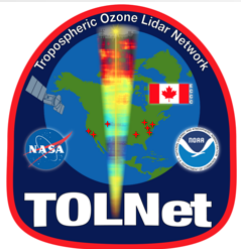
Feb 14, 2019 00z

Feb 14, 2019 06z



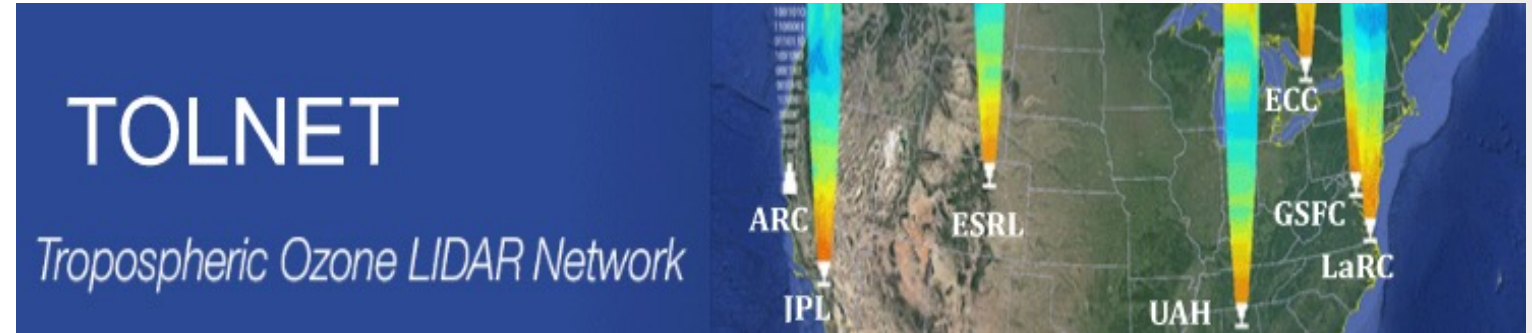
High ozone observed in the troposphere on February 13th and 14th of 2019 at LaRC have stratospheric origin, as indicated by the GEOS-CF curtain plots

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

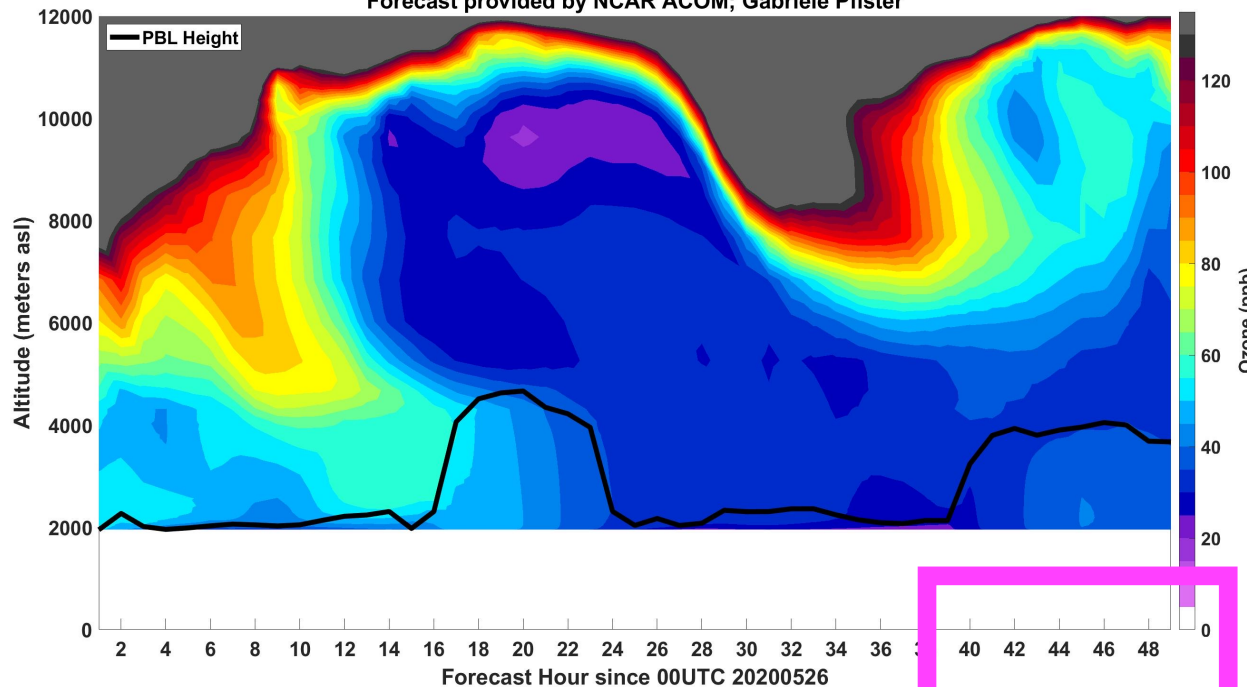


Daily alerts to NASA TOLNet Lidar teams sent by Matt Johnson, NASA AMES

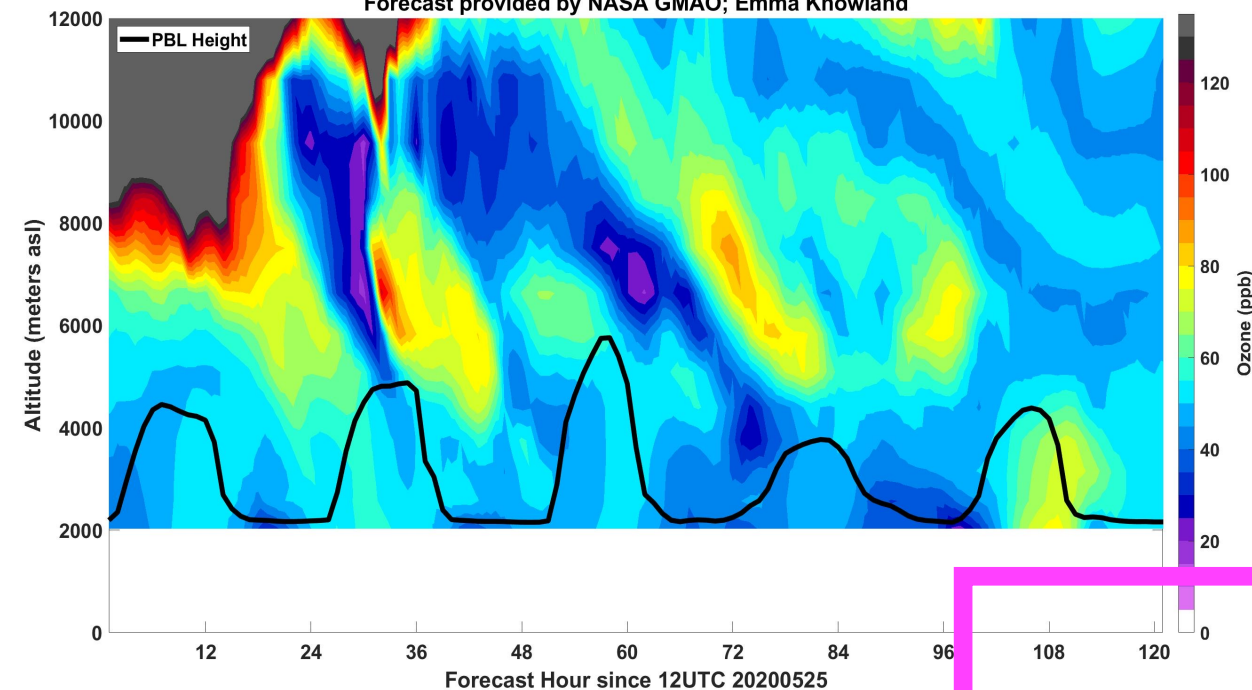
WRF-Chem 48-hour (left) and
GEOS-CF 120-hour (right) Ozone forecasts for
TOPAZ on May 26, 2020.



WRF-Chem Ozone (ppb) - TOPAZ - initialized 00UTC 20200526
Forecast provided by NCAR ACOM; Gabriele Pfister



GEOS-CF Ozone (ppb) - TOPAZ - initialized 12UTC 20200525
Forecast provided by NASA GMAO; Emma Knowland



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 0.25°*

longitude: 0° to -180°

latitude: 0° to 90°

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
FRSEACE	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 (CH ₂ O, MW = 30.00 g mol ⁻¹) volume mixing ratio dry air	mol mol ⁻¹
HNO ₂	tzyx	Nitrous acid (HNO ₂ , 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
NO ₂	tzyx	Nitrogen dioxide (NO ₂ , MW = 46.00 g mol ⁻¹) volume mixing ratio dry air	mol mol ⁻¹
O ₃	tzyx	Ozone (O ₃ , 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
SO ₂	tzyx	Sulfur dioxide (SO ₂ , 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



Summary of GEOS-CF Status

- GEOS-CF daily global composition forecasts at 25km resolution are generated in near-real time:
 - High-resolution historical estimates for fields are available since January 2018
 - Forecasts remain available on data servers for two weeks
 - The forecasts of the five most-requested surface pollutants (O_3 , NO_2 , CO , $PM_{2.5}$, and SO_2) remain accessible via data servers for January 2019-present
- Forecast visualizations and links to data available at: fluid.nccs.nasa.gov/cf
- Emerging applications users, including:
 - NASA field missions (SCOAPE, FIREX-AQ, ACT-America, TRACER-AQ, ACCLIP)
 - Daily alerts sent to NASA TOLNet lidar teams (Matt Johnson, NASA Ames)
 - TEMPO a priori for trace gas product

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>



Reference information

GEOS-CF are available online in near real-time

FLUID is a mobile-friendly website

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

Composition Forecast

CF Datagrams

NATIONAL

Select a Station

WORLD

Select a Station

AERONET

NORTH AMERICA

TMF

MEGACITIES

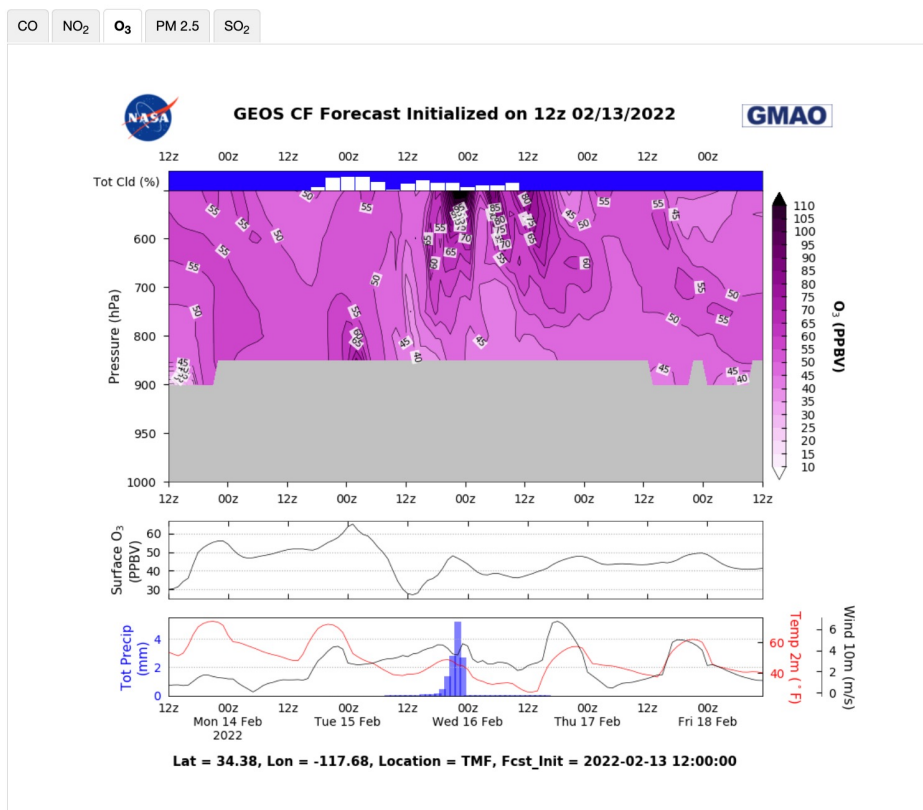
Select a Station

ACTIVE CAMPAIGNS

Select a Station

GMAO GEOS CF Datagrams

O₃ at TMF (34.38, -117.68)



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

GODDARD SPACE FLIGHT CENTER

[+ NASA HomePage](#)
[+ NASA Center for Climate Simulation](#)

NCCS Dataportal - Datashare

Name	Last modified	Size	Description
Parent Directory		-	
das/	26-Aug-2019 10:41	-	
forecast/	22-Mar-2019 13:49	-	

[+ Privacy Policy and Important Notices](#)

Curator: Corey D Jones
 NASA Official: Dan Duffy
 Last Updated: 03/13/2019

<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: -180.0000000000°E to 179.7500000000°E (1440 points, avg. res. 0.25°)
Latitude: -90.0000000000°N to 90.0000000000°N (721 points, avg. res. 0.25°)
Altitude: 72.0000000000 to 72.0000000000 (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 peroxyntiric 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



Thank you!

Referred

Knowland, K. E., C. A. Keller, P. A. Wales, et al. (2022). NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0: Stratospheric composition. *Journal of Advances in Modeling Earth Systems*, 14, e2021MS002852. <https://doi.org/10.1029/2021MS002852>

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>

Gladson, L. A., K. R. Cromar, M. Ghazipura, et al. (2022). Communicating respiratory health risk among children using a global air quality index. *Environment International*, 159: 107023 [10.1016/j.envint.2021.107023]

Bi, J., K. E. Knowland, C. A. Keller, and Y. Liu. 2022. "Combining Machine Learning and Numerical Simulation for High-Resolution PM2.5 Concentration Forecast." *Environmental Science & Technology*, 56 (3): 1544-1556 [10.1021/acs.est.1c05578]

Duncan, B. N., C. A. Malings, K. E. Knowland, et al. 2021. "Augmenting the Standard Operating Procedures of Health and Air Quality Stakeholders With NASA Resources." *GeoHealth*, 5 (9): [10.1029/2021gh000451]

Lee, J. D., F. A. Squires, T. Sherwen, et al. 2021. "Ozone production and precursor emission from wildfires in Africa." *Environmental Science: Atmospheres*, (Accepted) [10.1039/d1ea00041a]

Gronoff, G., T. Berkoff, K. Knowland, et al. 2021. "Case study of stratospheric Intrusion above Hampton, Virginia: lidar-observation and modeling analysis." *Atmospheric Environment*, 118498 [10.1016/j.atmosenv.2021.118498]

Malings, C., K. E. Knowland, C. A. Keller, and S. E. Cohn. 2021. "Sub-City Scale Hourly Air Quality Forecasting by Combining Models, Satellite Observations, and Ground Measurements." *Earth and Space Science*, 8 (7): [10.1029/2021ea001743]

Johnson, M. S., K. Strawbridge, K. E. Knowland, C. Keller, and M. Travis. 2021. "Long-range transport of Siberian biomass burning emissions to North America during FIREX-AQ." *Atmospheric Environment*, 252: 118241 [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>

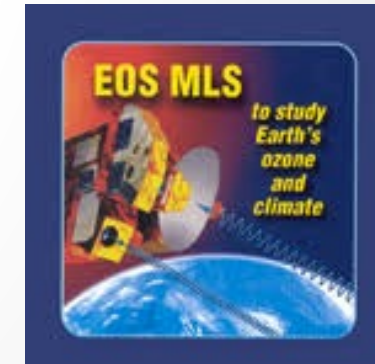
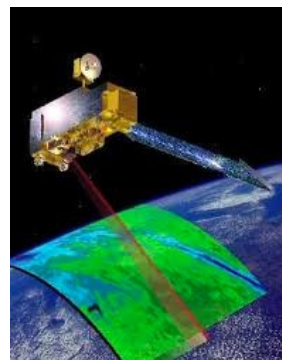
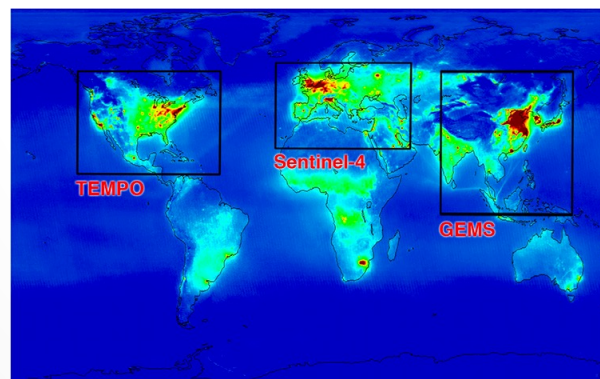
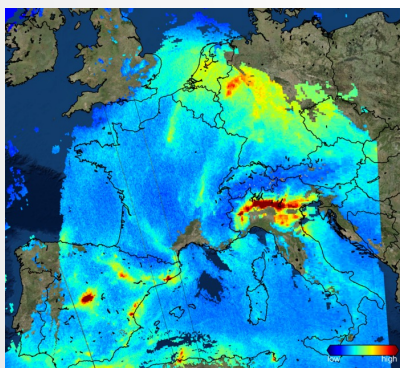
Dacic, N., Sullivan, J. T., Knowland, K. E., Wolfe, G. M., Oman, L. D., Berkoff, T. A., and Gronoff, G. P. (2020). Evaluation of NASA's high-resolution global composition simulations: Understanding a pollution event in the Chesapeake Bay during the summer 2017 OWLETS campaign. *Atmospheric Environment*,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

Non-Refereed

Knowland, K. E., Keller, C. A. and Lucchesi, R. A. (2022), "File Specification for GEOS-CF Products." *GMAO Office Note No. 17 (Version 1.2)*, 54pp, available from http://gmao.gsfc.nasa.gov/pubs/office_notes

Planned upgrades for GEOS-CF

- Model update to GEOS-Chem v13
 - Improvements to ozone deposition
 - Updates to NO_3 washout → likely reduce $\text{PM}_{2.5}$ bias
- GEOS AGCM update
- CEDS emission inventory (latest release through 2019)
- Constituent Data Assimilation System (CoDAS)
 - Multi-constituent assimilation with O_3 , CO , NO_2



GEOS NWP with Coupled GEOS-Chem chemistry

GEOS-CF v1.0

One **5-day forecast** per day

- Initialized at 12z
- 1-day meteorological replay (“analysis”)
- 5-day forecast
- c360 (0.25°, ~**25x25 km²**)
- GEOS-Chem v12.0.1

Data distributed via OpenDAP and HTTPS:

- 2D output at 15 minute and hourly frequency
- 3D output at hourly and three hourly frequency, 1-hour 2D & 3D output, **including specific TEMPO file for trace-gas 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

Emissions:

- HTAP (global bottom-up) for anthropogenic
- Near real-time fires (QFED)
- Online dust, sea salt, plant emissions

Observation-constraints

- Currently no direct data assimilation of constituents in GEOS-CF
- GOCART aerosols constrained by satellite measurements of AOD
- Biomass burning emissions from QFED