National Aeronautics and Space Administration

NASA GEOS Composition Forecast System, GEOS-CF: Overview, Applications, and Future Directions

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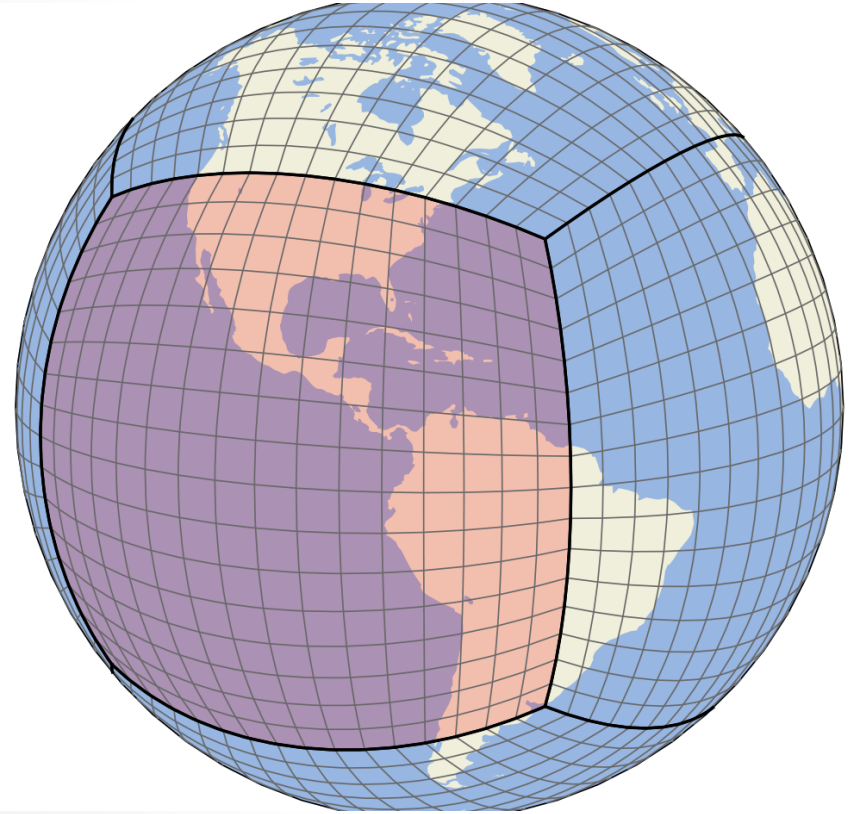
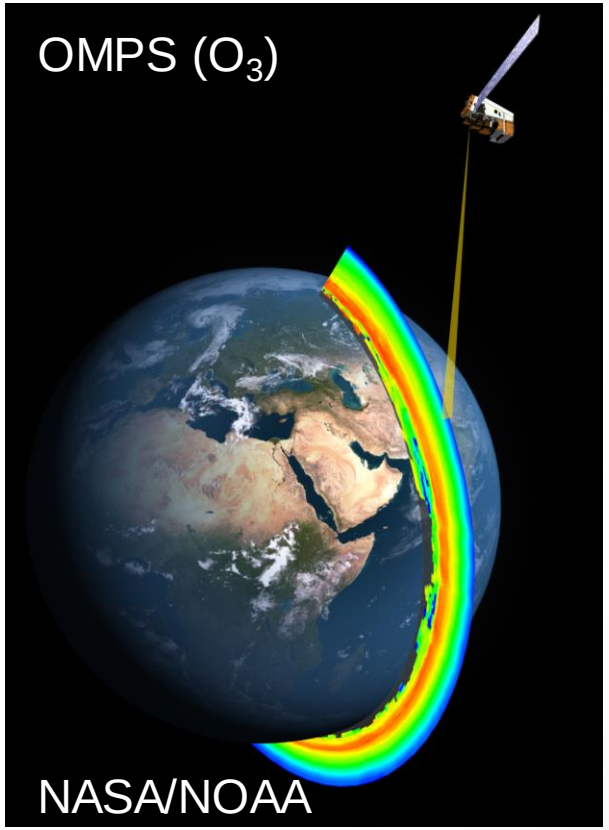
NASA GMAO global meteorology and chemistry products

GEOS

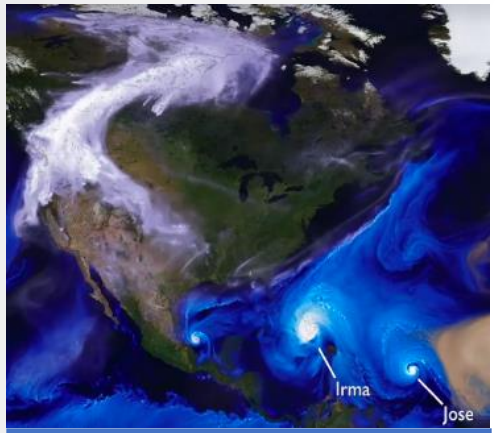


Bindle et al., 2021 GMD

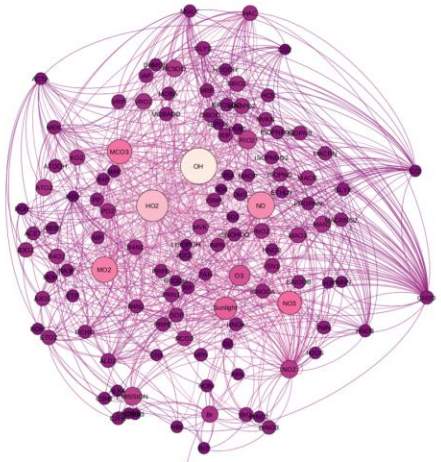


www.nasa.gov

GEOS Composition Forecast



GEOS NWP



GEOS-Chem

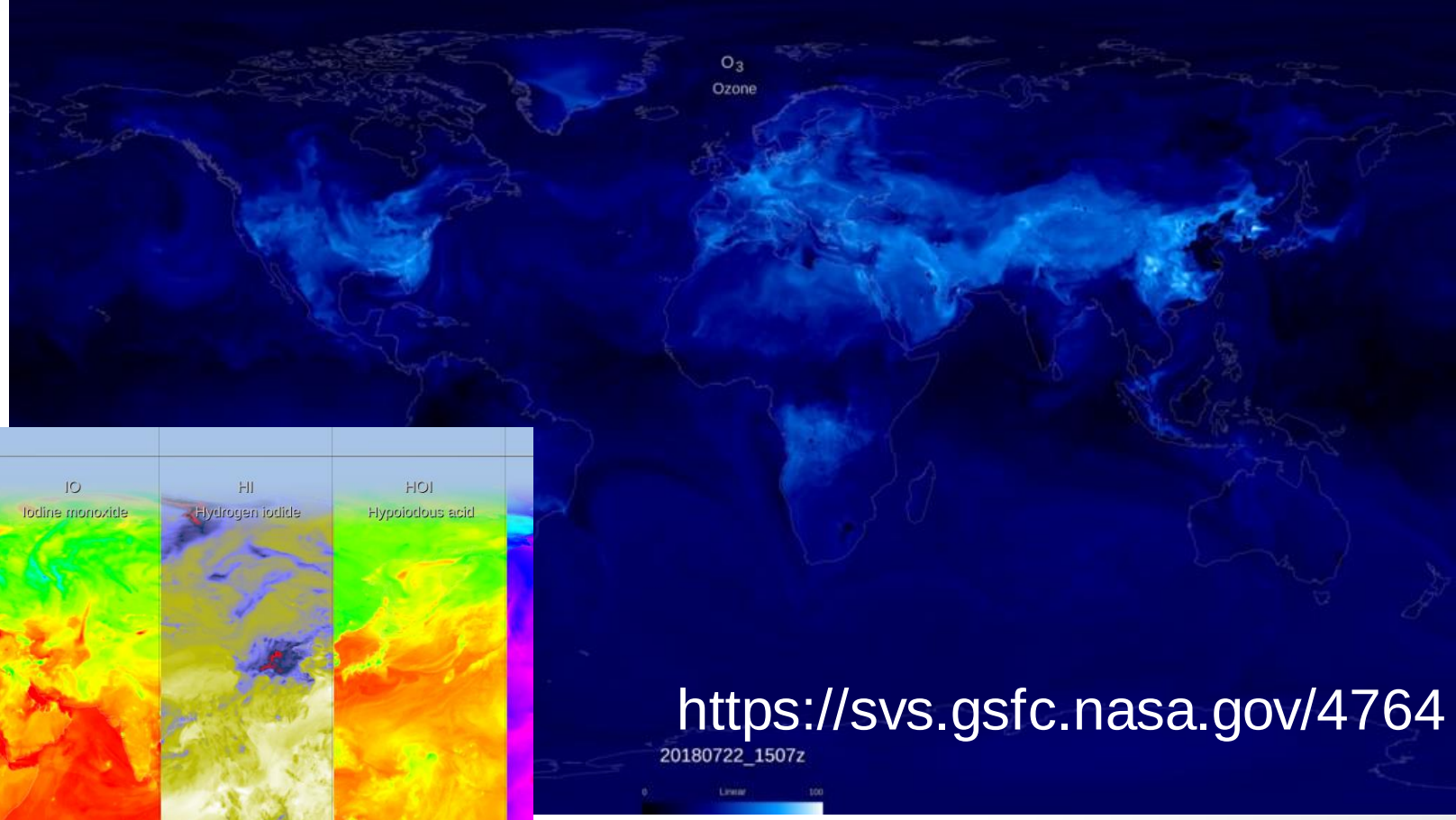
GEOS - CF

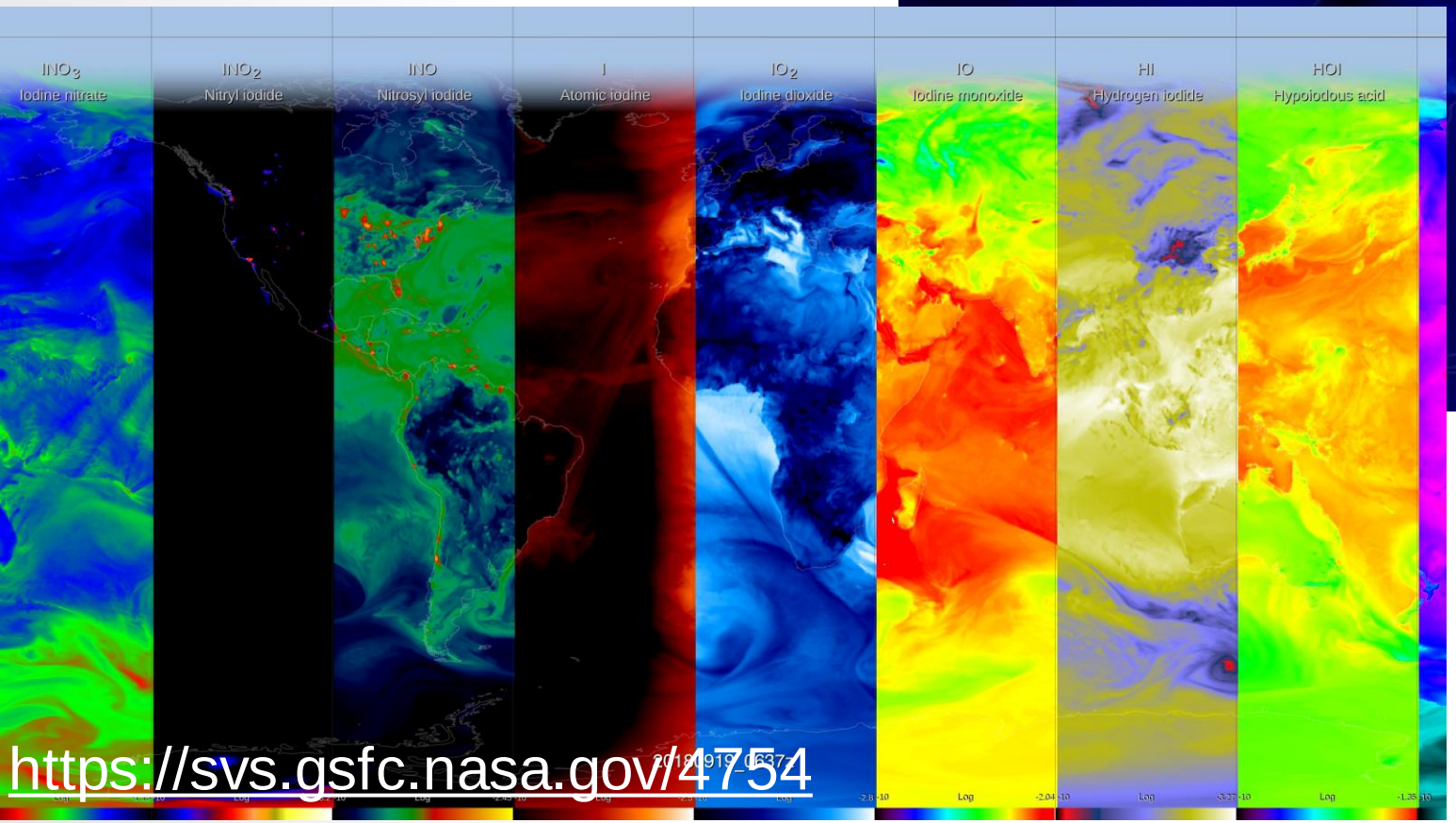
Version 12.0.1

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

GEOS - CF

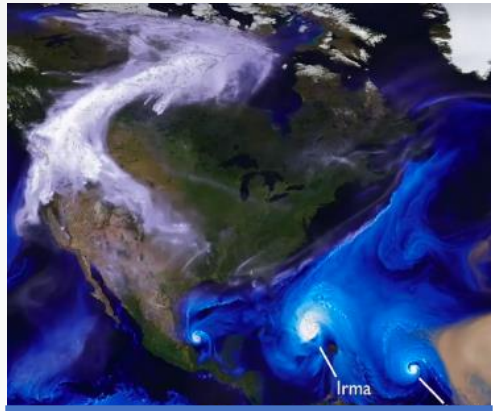




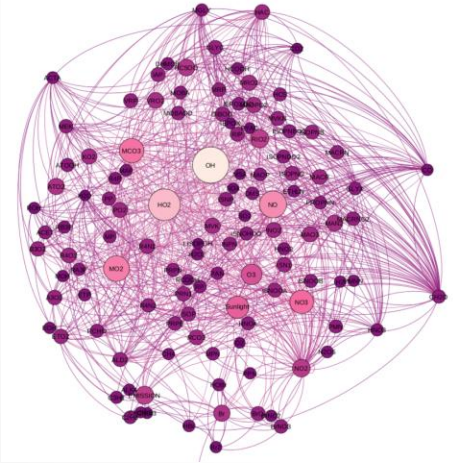
GEOS-Chem v12.0.1

- Tropospheric and Stratospheric chemistry
- 250 Chemical Species
- 725 Chemical Reactions

GEOS Composition Forecast



GEOS NWP



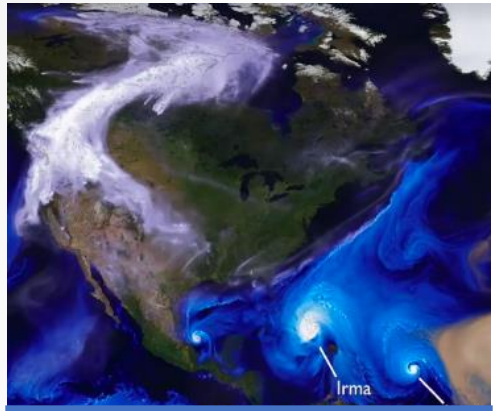
GEOS-Chem

GEOS - CF

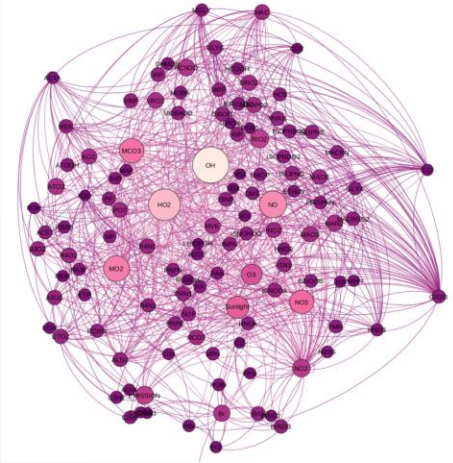
One **5-day forecast** per day

- 1-day replay
- 5-day forecast
- c360 (0.25°, ~**25x25 km²**) resolution, 72 model layers
- Run on **NASA's** Center for Climate Simulation (NCCS) **supercomputer**

GEOS Composition Forecast



GEOS NWP



GEOS-Chem

GEOS - CF

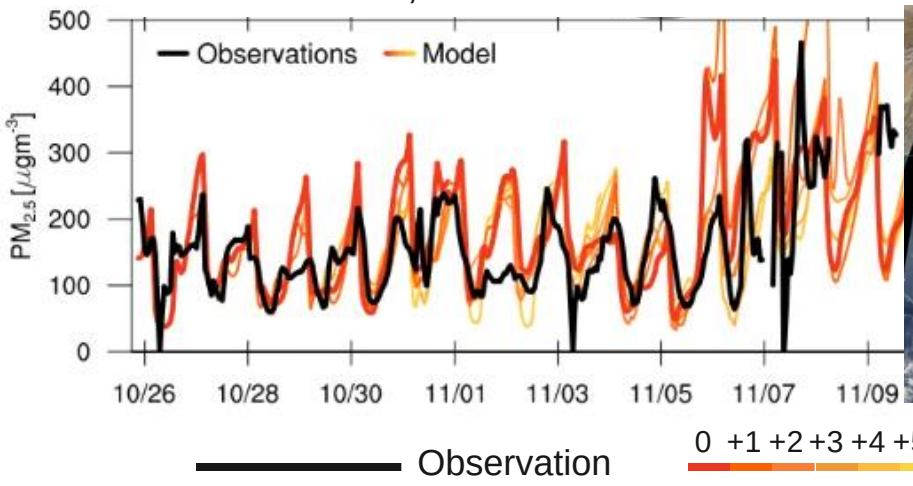
One **5-day forecast** per day

- 1-day replay
- 5-day forecast
- c360 (0.25°, ~25x25 km^2)
- **15 minute** "surface"
- **1-hour** average and instantaneous 2D & 3D
- **1 January 2018 - NRT**

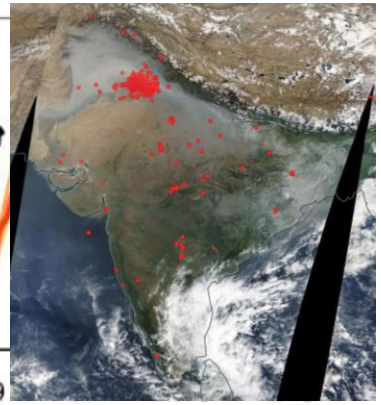
Near-real time updates from satellite data

- 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

Delhi, India Nov 2017

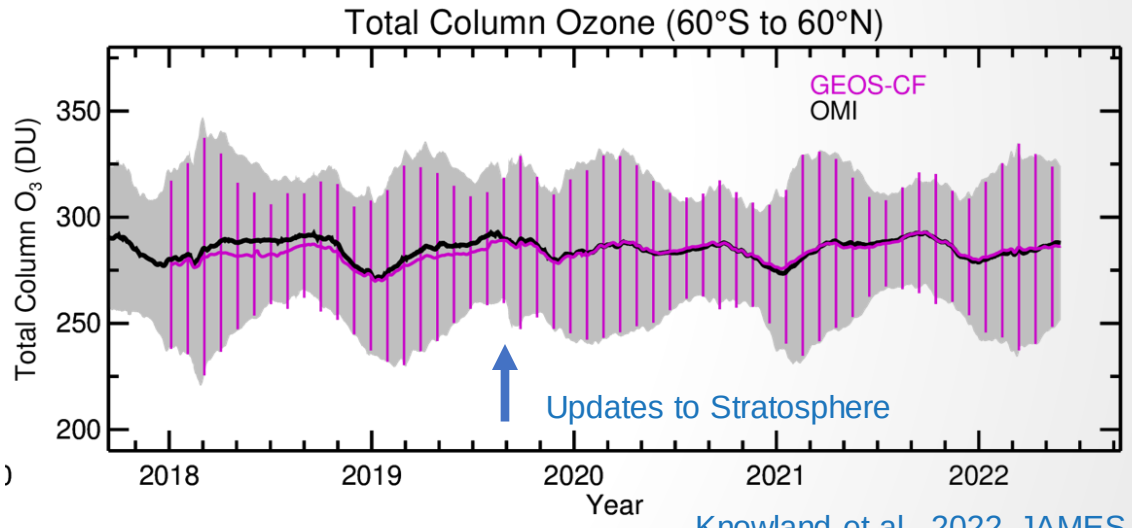


MODIS fires Nov 01, 2017



Observation

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



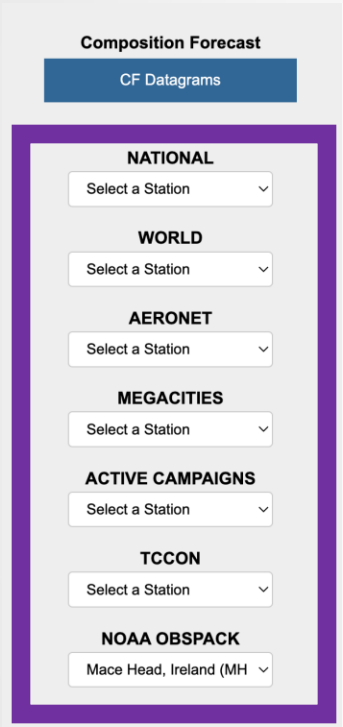
Knowland et al., 2022, JAMES

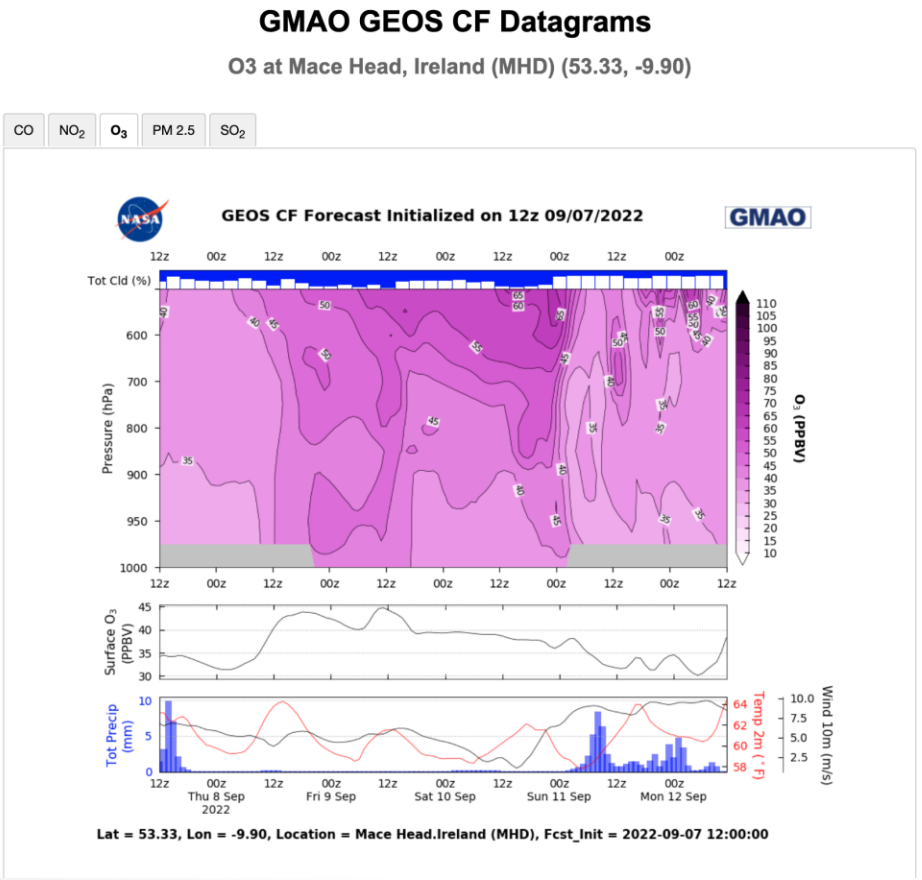
Currently developing direct data assimilation of tropospheric constituents into GEOS

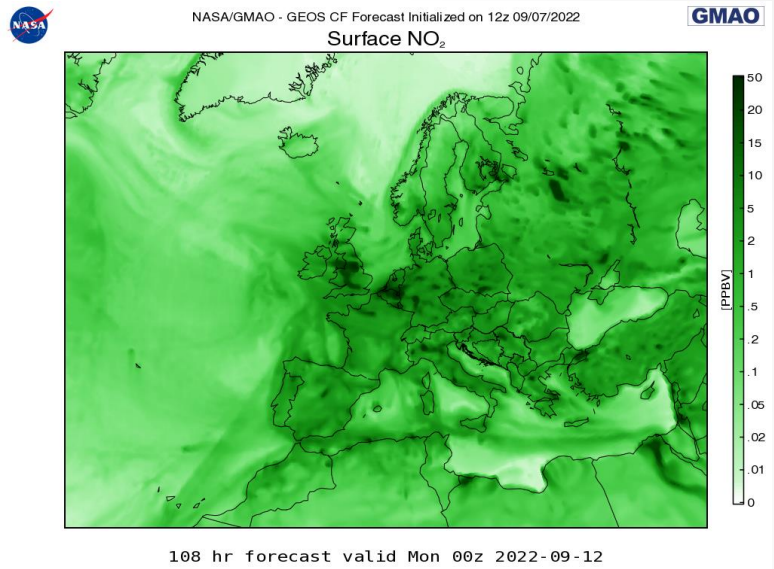
GEOS-CF output is available online in near real-time

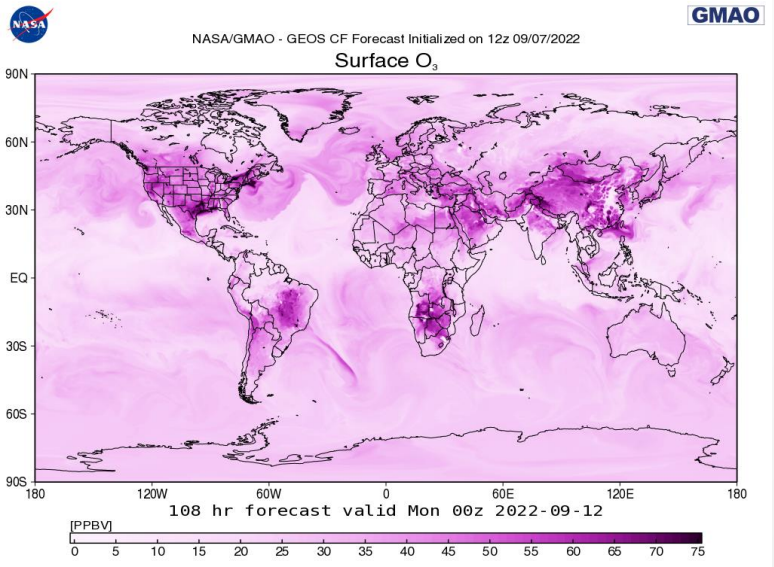
Fluid is a mobile-friendly website

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









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National Aeronautics and Space Administration

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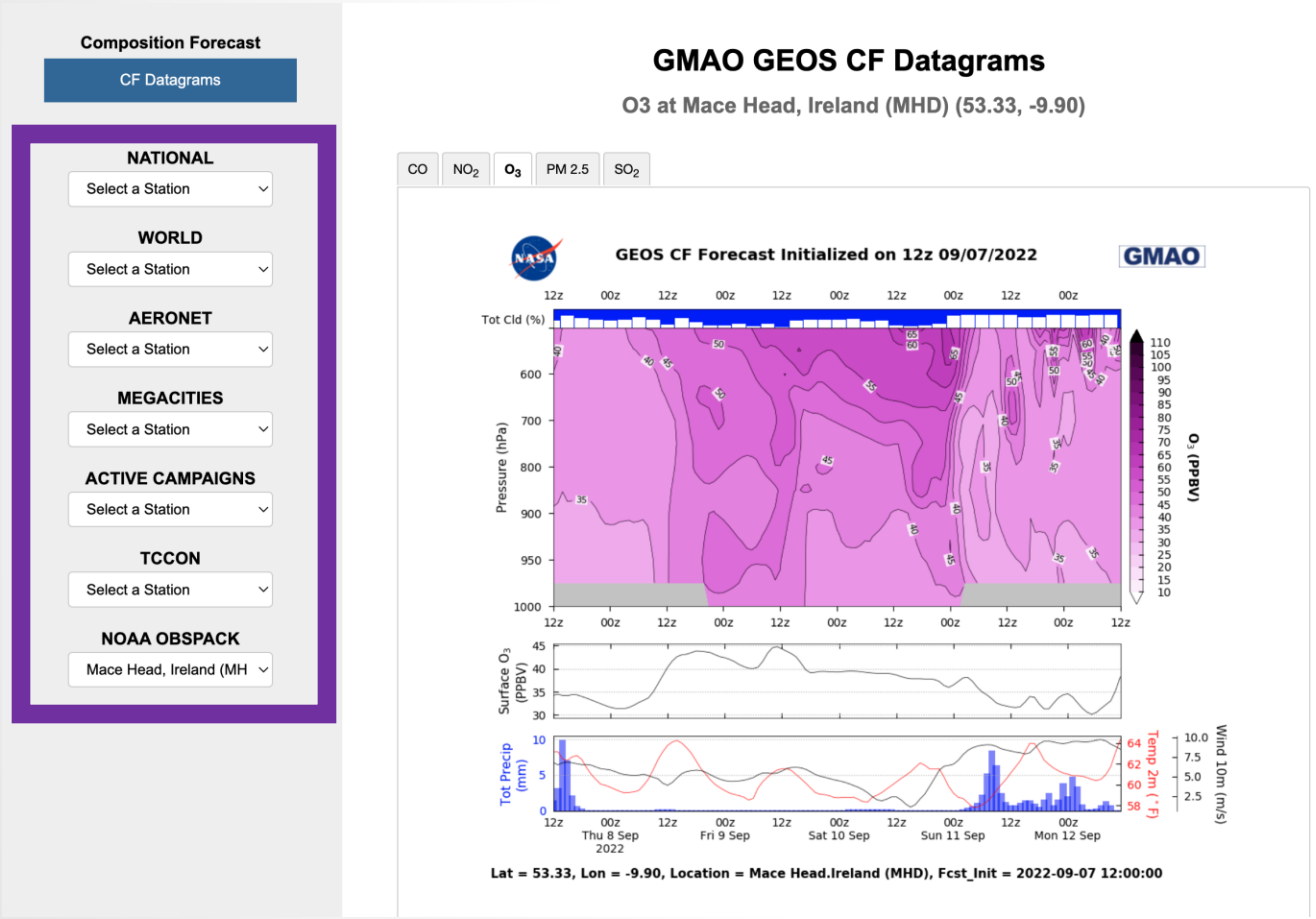
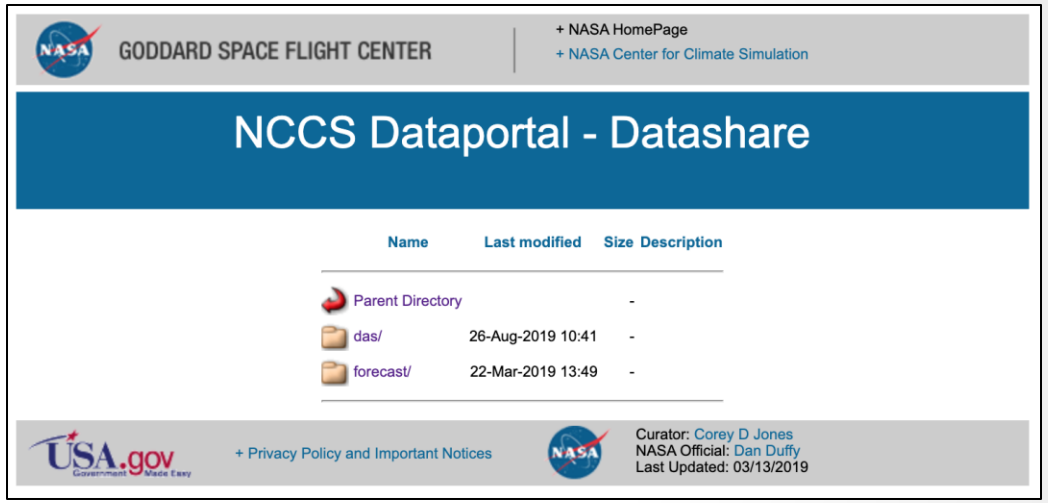


https://portal.nccs.nasa.gov/datashare/gmao/geos-cf/v1/



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

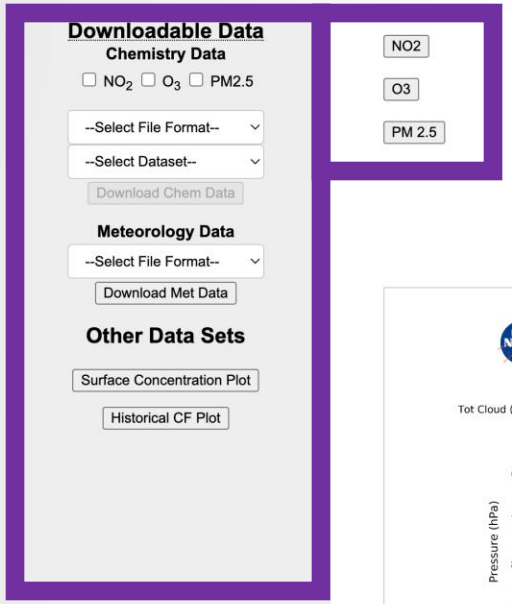
OPeNDAP/DODS Data URL: https://opendap.nccs.nasa.gov/dods/gmao/geos-cf/assim/chm_tavg_1hr_g1440x721_v1

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	

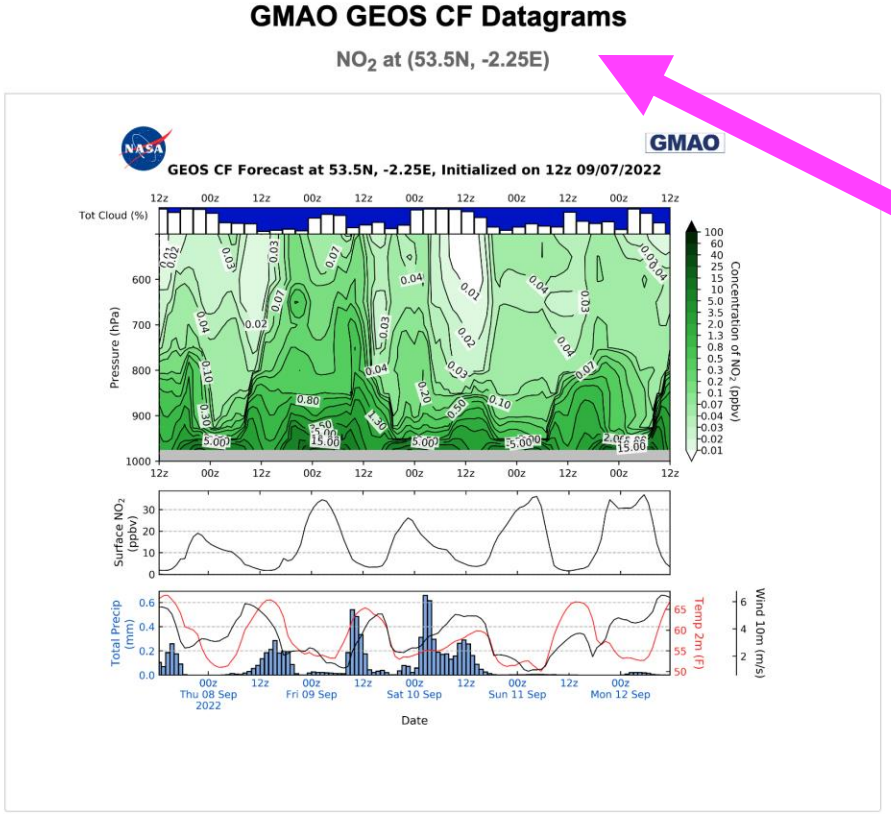
GEOS-CF output is available online in near real-time

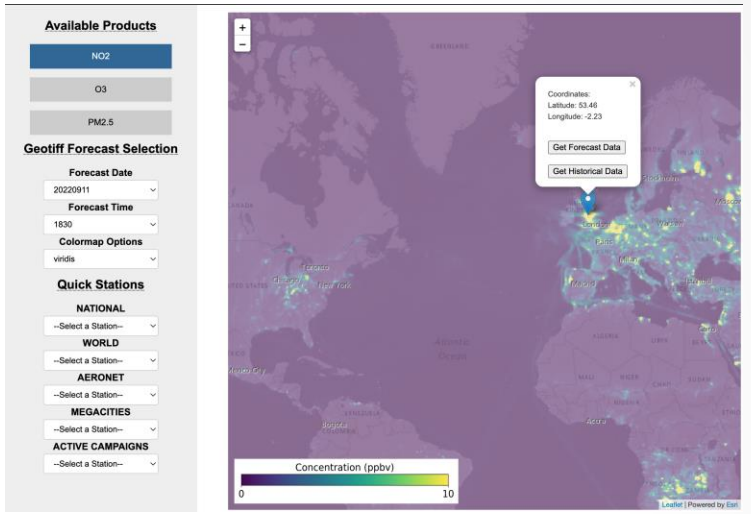
On-demand Forecast Imagery with cf_map tool

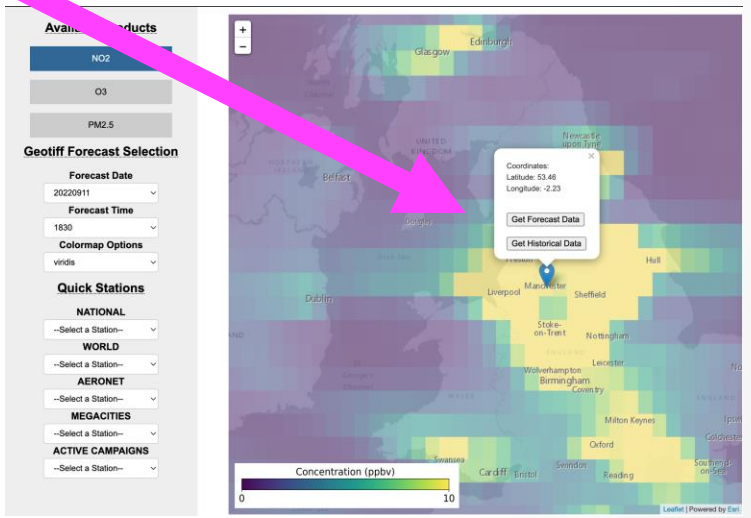
https://fluid.nccs.nasa.gov/cf_map/



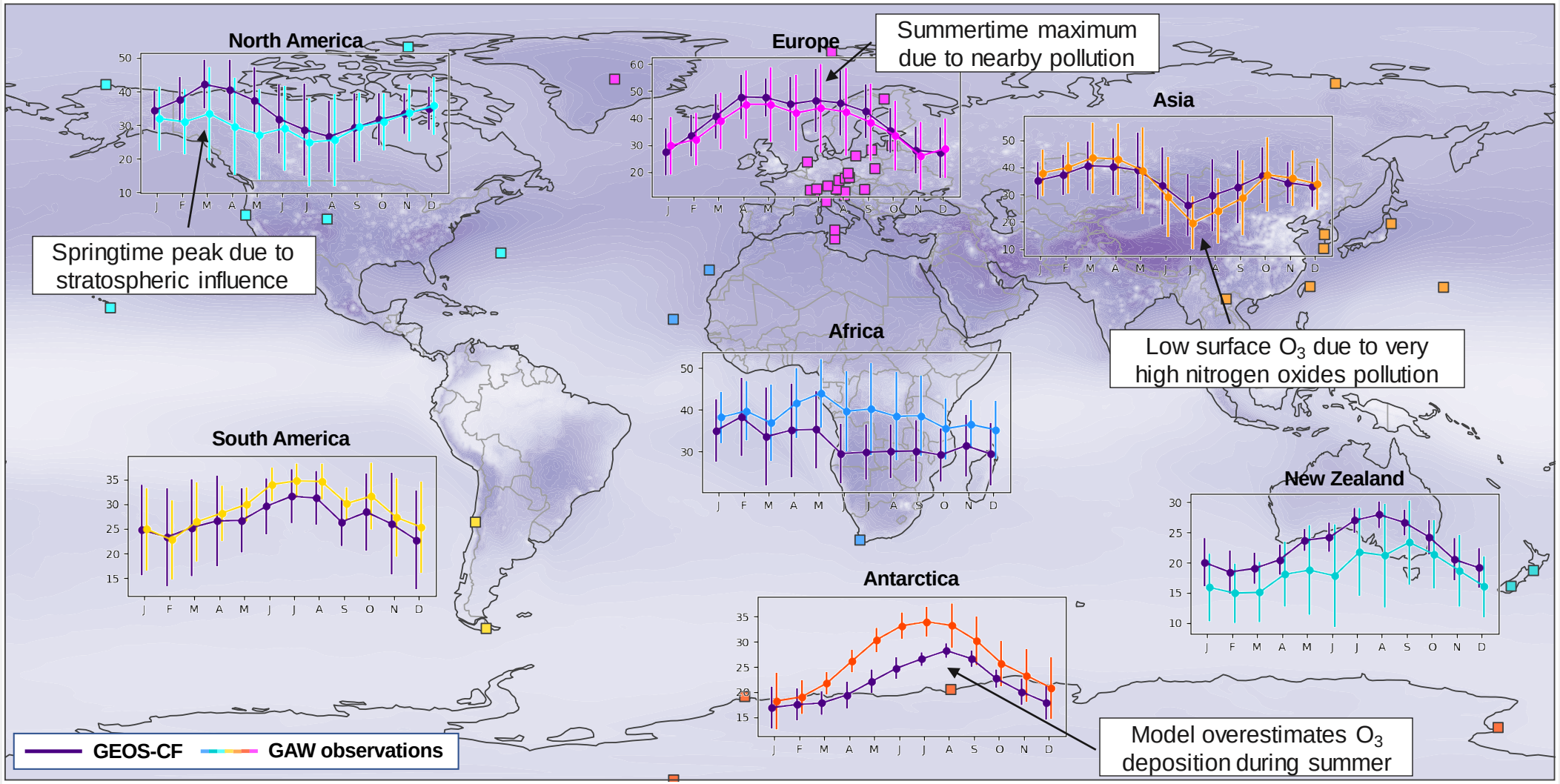
Manchester







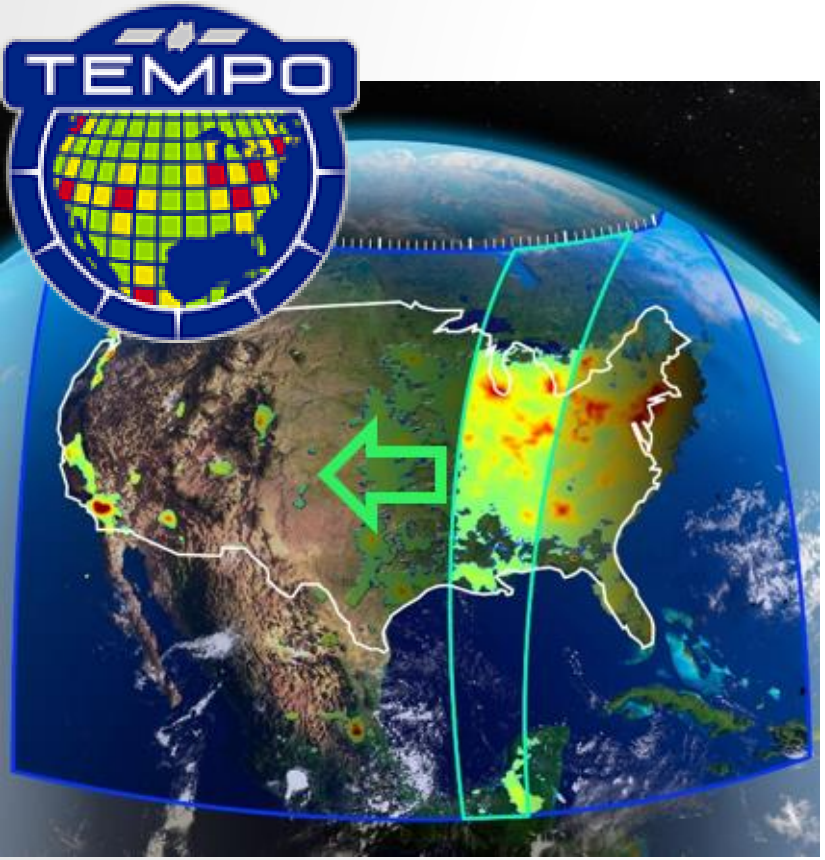
GEOS-CF surface ozone compares well against background observations from the Global Atmospheric Watch (GAW) network



https://gmao.gsfc.nasa.gov/research/science_snapshots/2021/CF_O3_GAW.php

Support a broad range of NASA applications

GEOS - CF

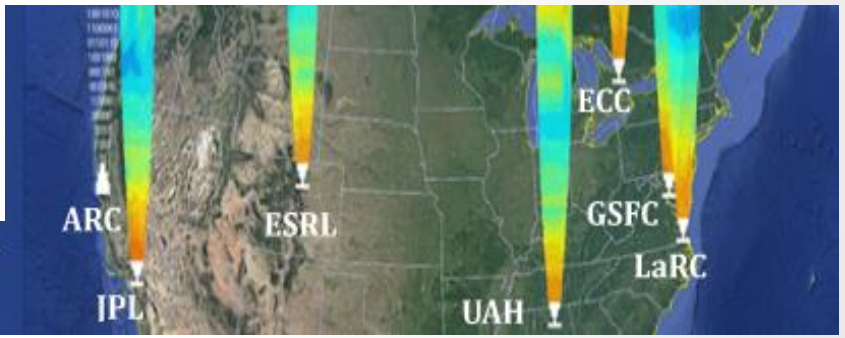


Realistic atmospheric composition in the troposphere **and** stratosphere in GEOS-CF is essential to support a broad range of NASA applications measuring trace gases and aerosols, including:

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

TOLNET

Tropospheric Ozone LIDAR Network



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 µg m-3) enhancements.

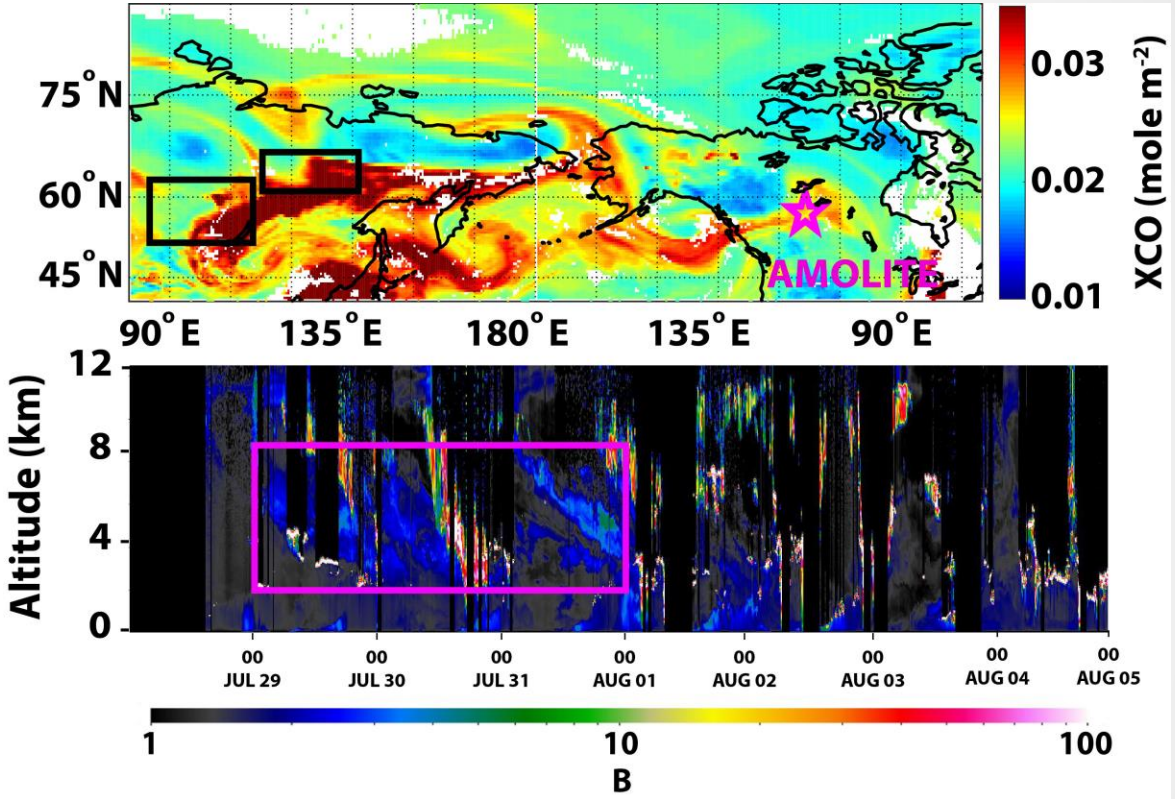


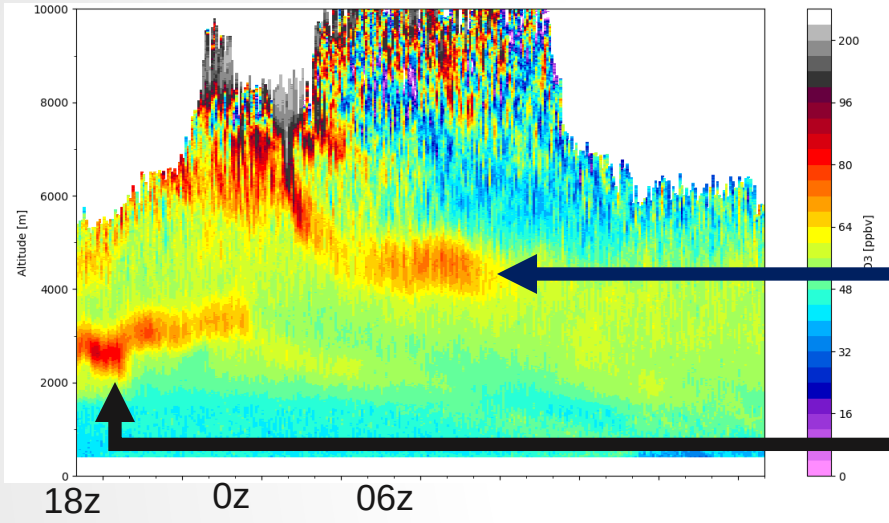
Figure 1. **GEOS-CF** XCO (mole m^{-2}) on July 29, 2019 (top) and AMOLITE aerosol backscatter ratio (B) between July 28 and August 5, 2019 (bottom). The magenta star and box highlight the location of AMOLITE and the large aerosol lamina observed by the system, respectively.

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

GEOS - CF

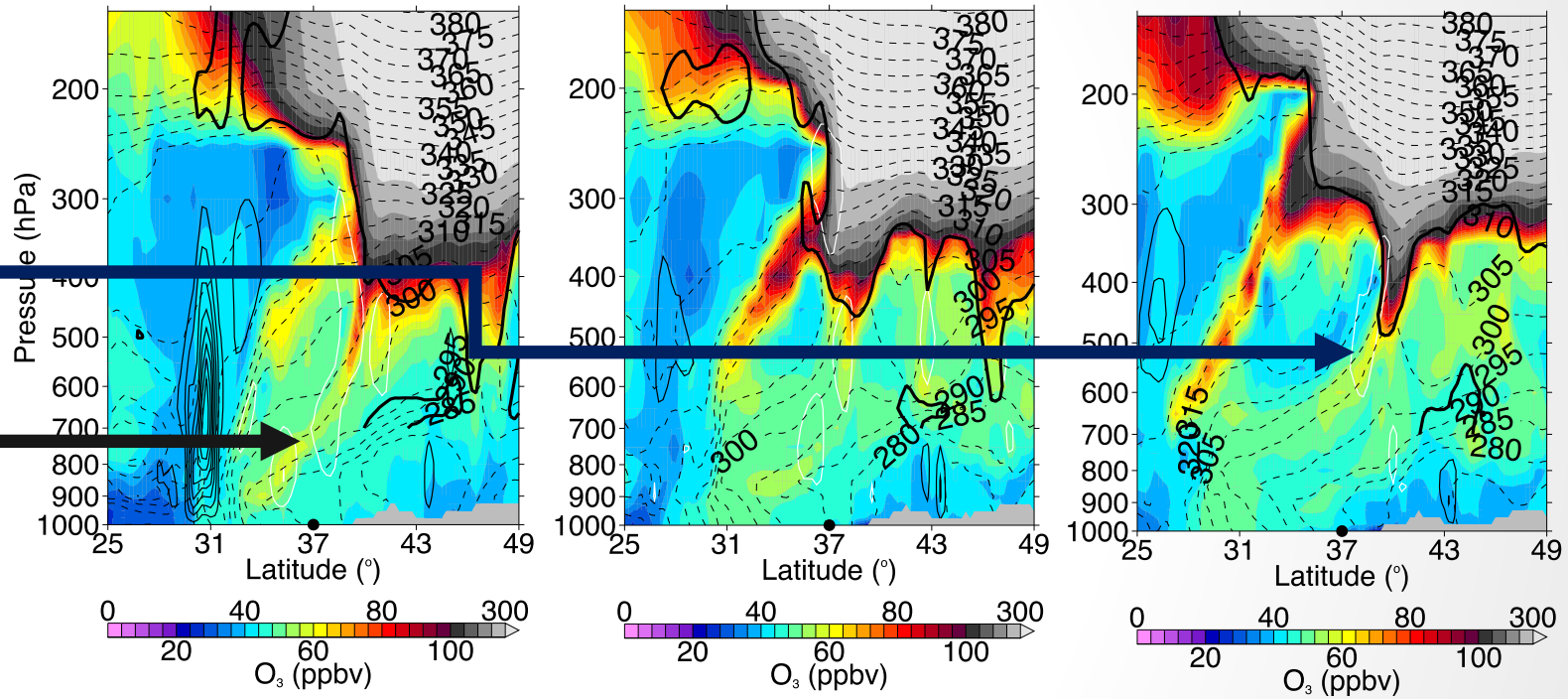
NASA LaRC Feb 13-14, 2019



Feb 13, 2019 18z

Feb 14, 2019 00z

Feb 14, 2019 06z

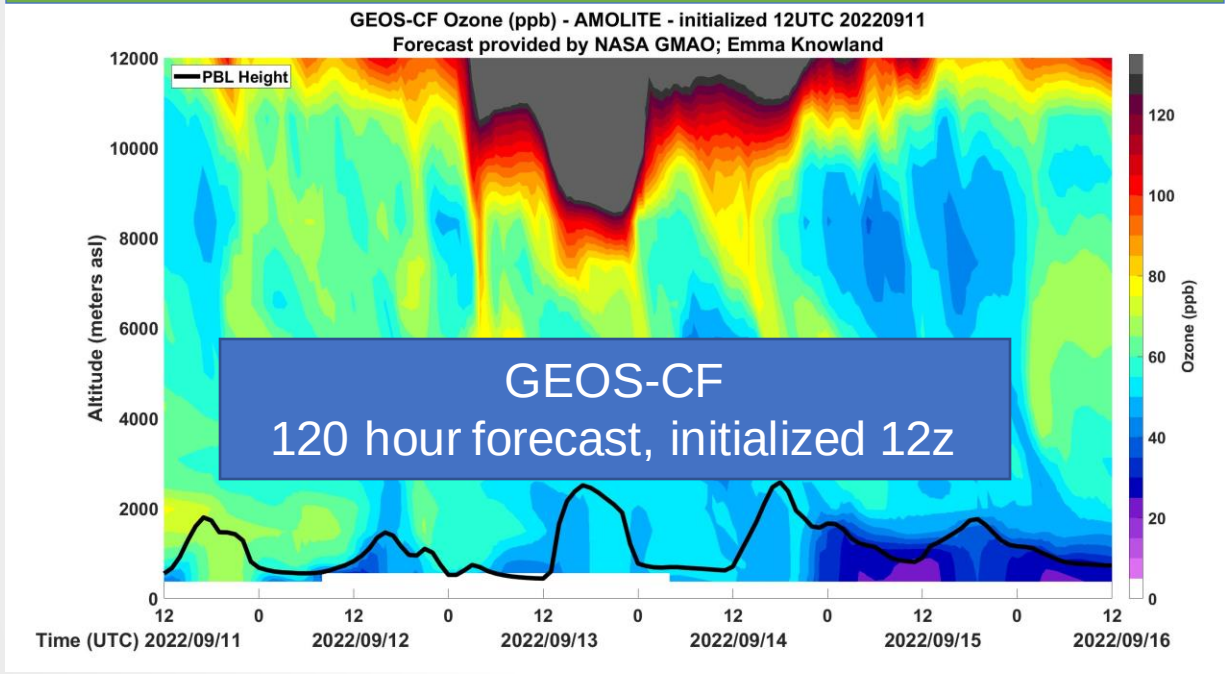


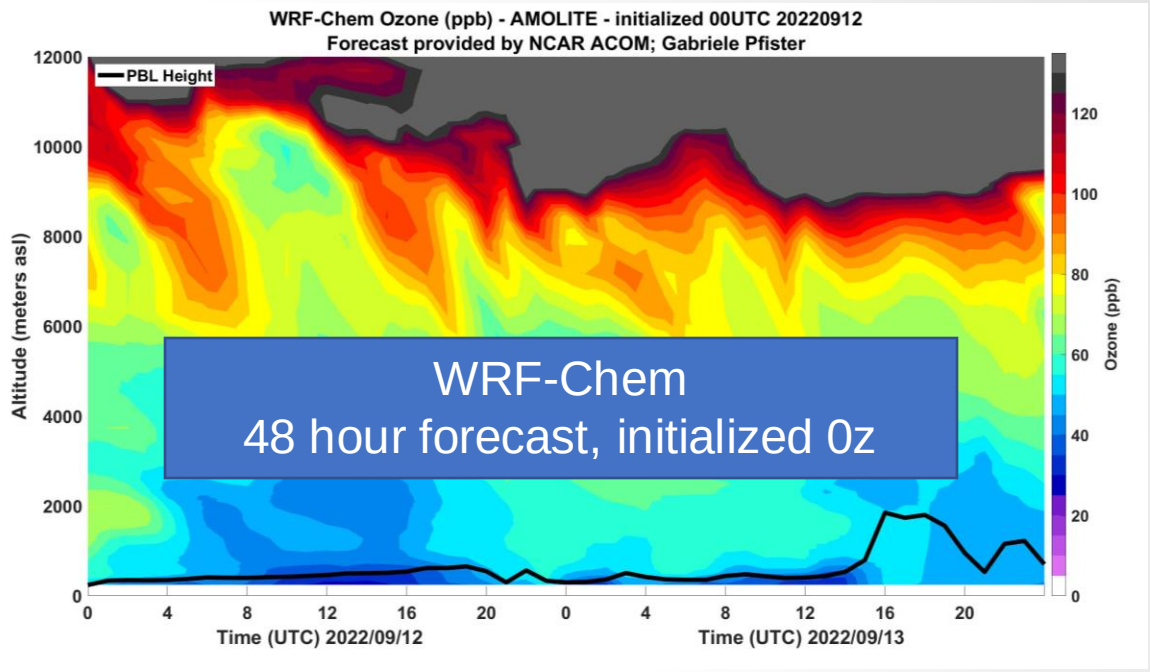
High ozone observed in the troposphere on February 13th and 14th of 2019 at LaRC have stratospheric origin, as indicated by the GEOS-CF curtain plots

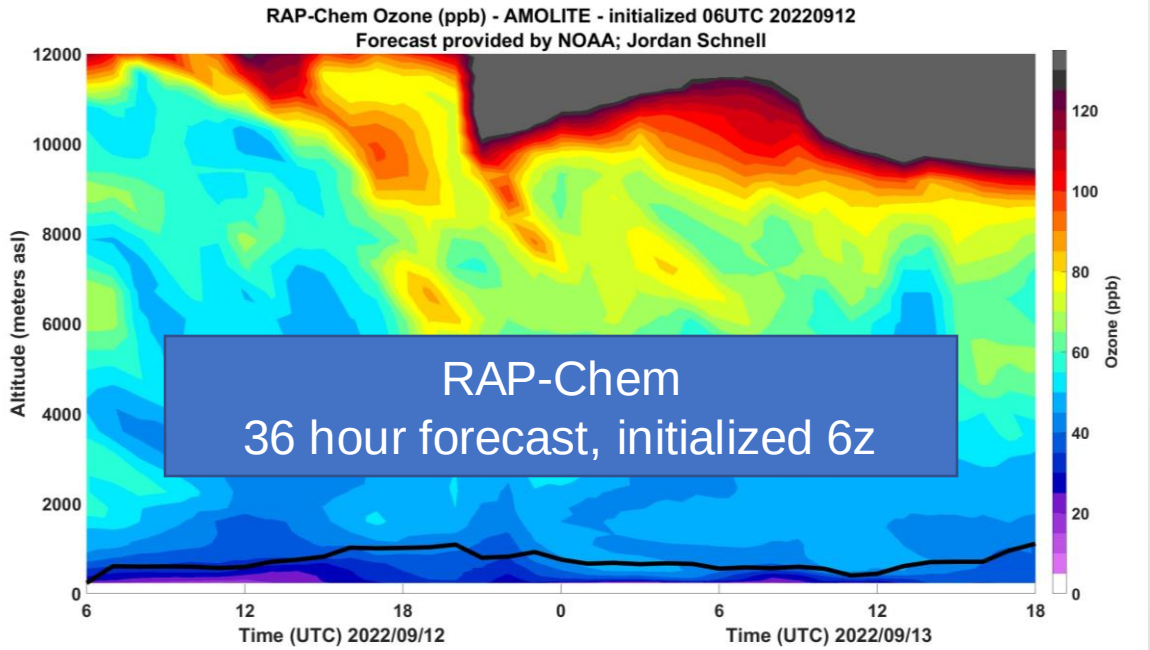
Gronoff, G., Berkoff, T., Knowland, K. E., et al. "Case study of stratospheric Intrusion above Hampton, Virginia: lidar-observation and modeling analysis." Atmos. Environ., 2021, DOI: 10.1016/j.atmosenv.2021.118498

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

GEOS - CF



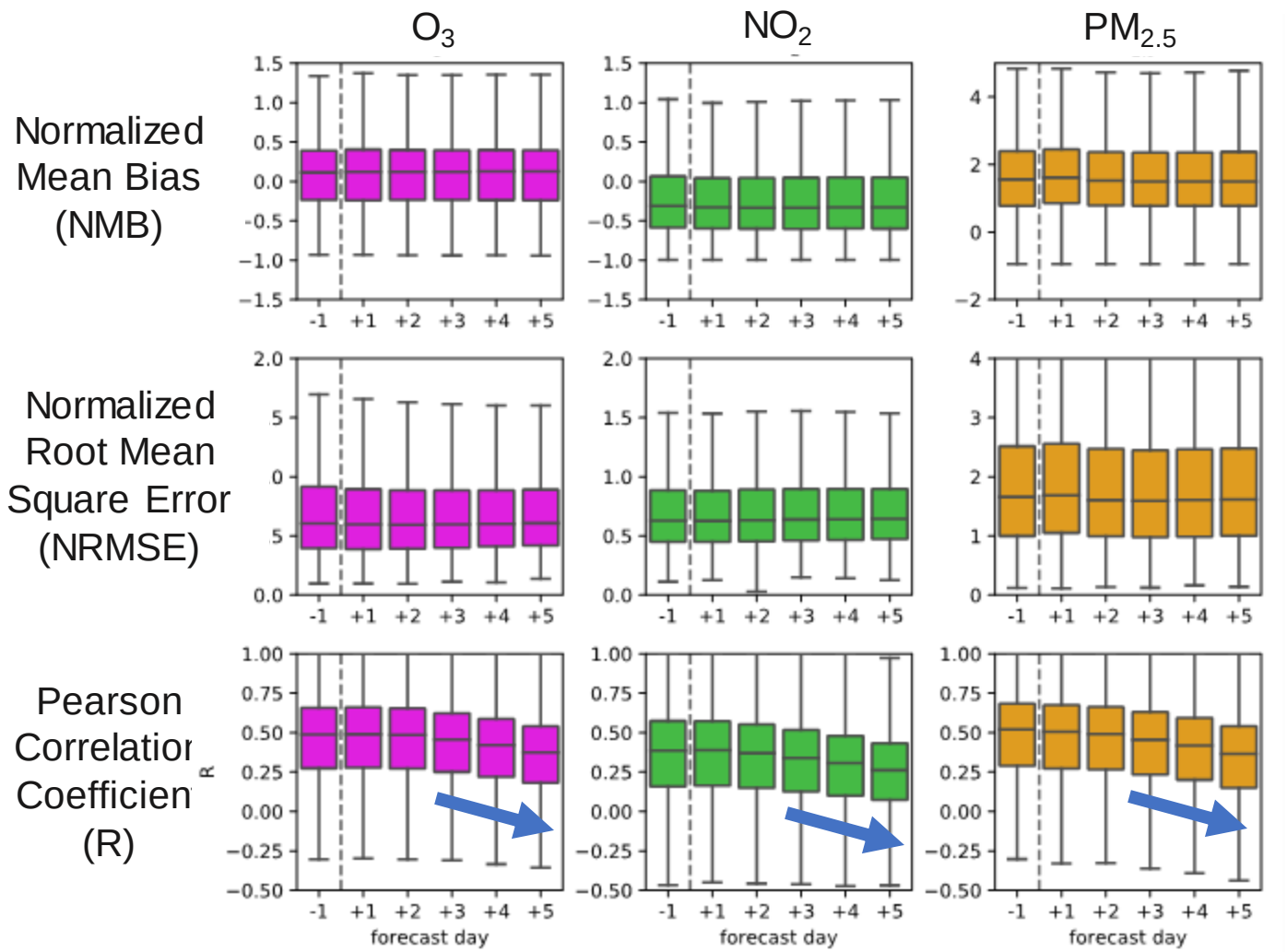




Tailored email alert system using three forecast models provides operators with confidence/uncertainty in predicted features

Figures courtesy of Matt Johnson

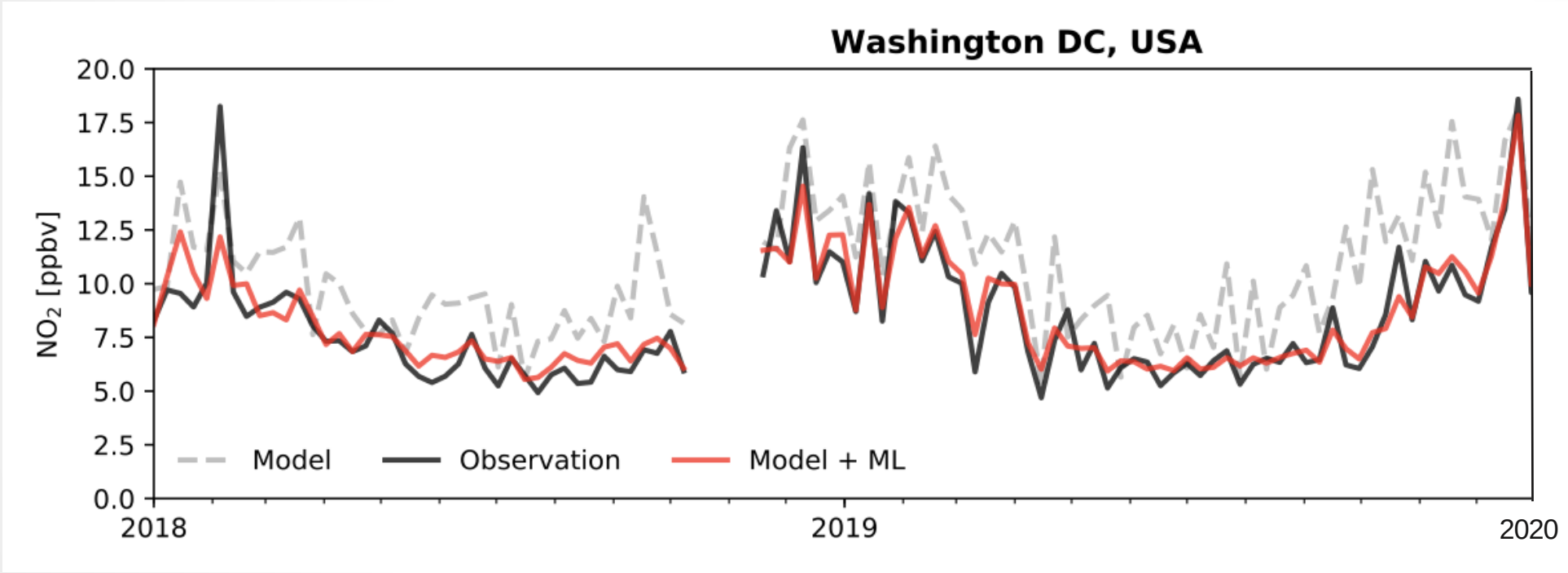
GEOS CF Forecast skill (GAW and OpenAQ)

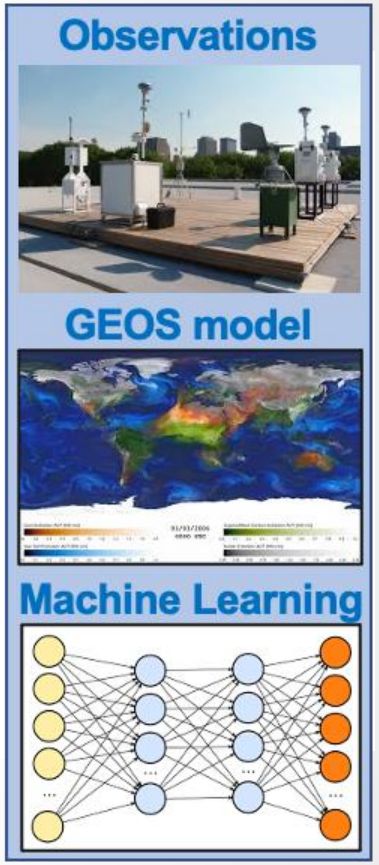


- Little variation in the skill scores out to 5 days
- Correlation tends to decrease after day 2 and this is likely due to changes in the meteorological forecast and biomass burning emissions.

Keller et al., 2021 JAMES

Machine learning can be used to produce bias-corrected (localized) prediction

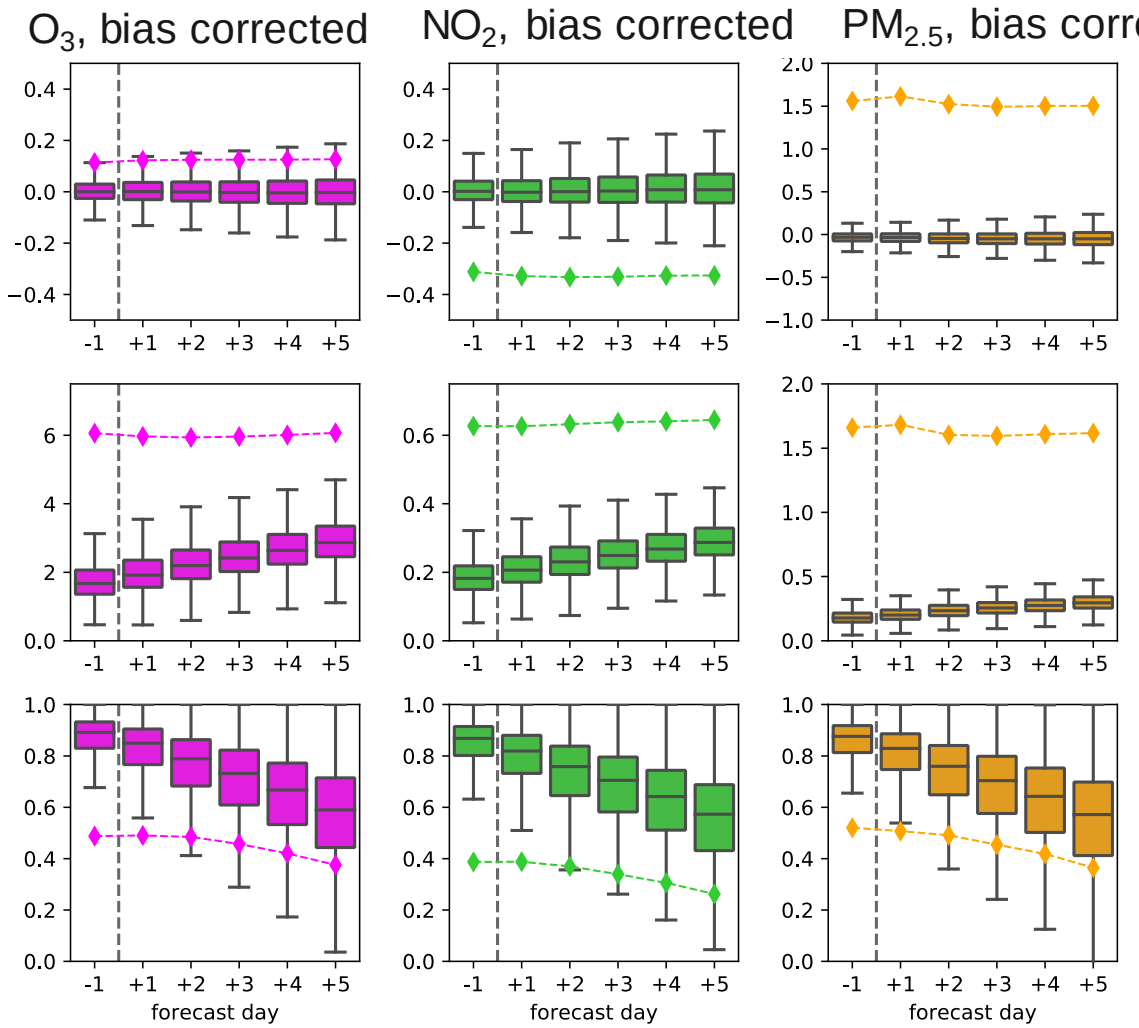




This method is limited to locations with surface observations

Keller et al., 2021 ACP

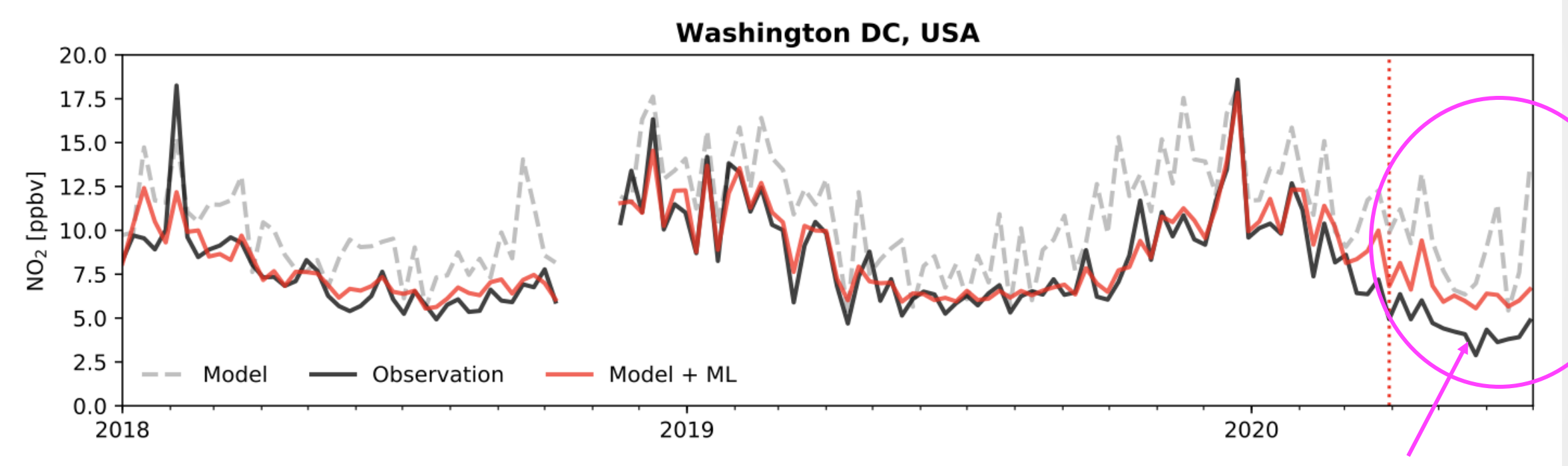
GEOS CF Forecast skill of bias-corrected predictions



- ✓ 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

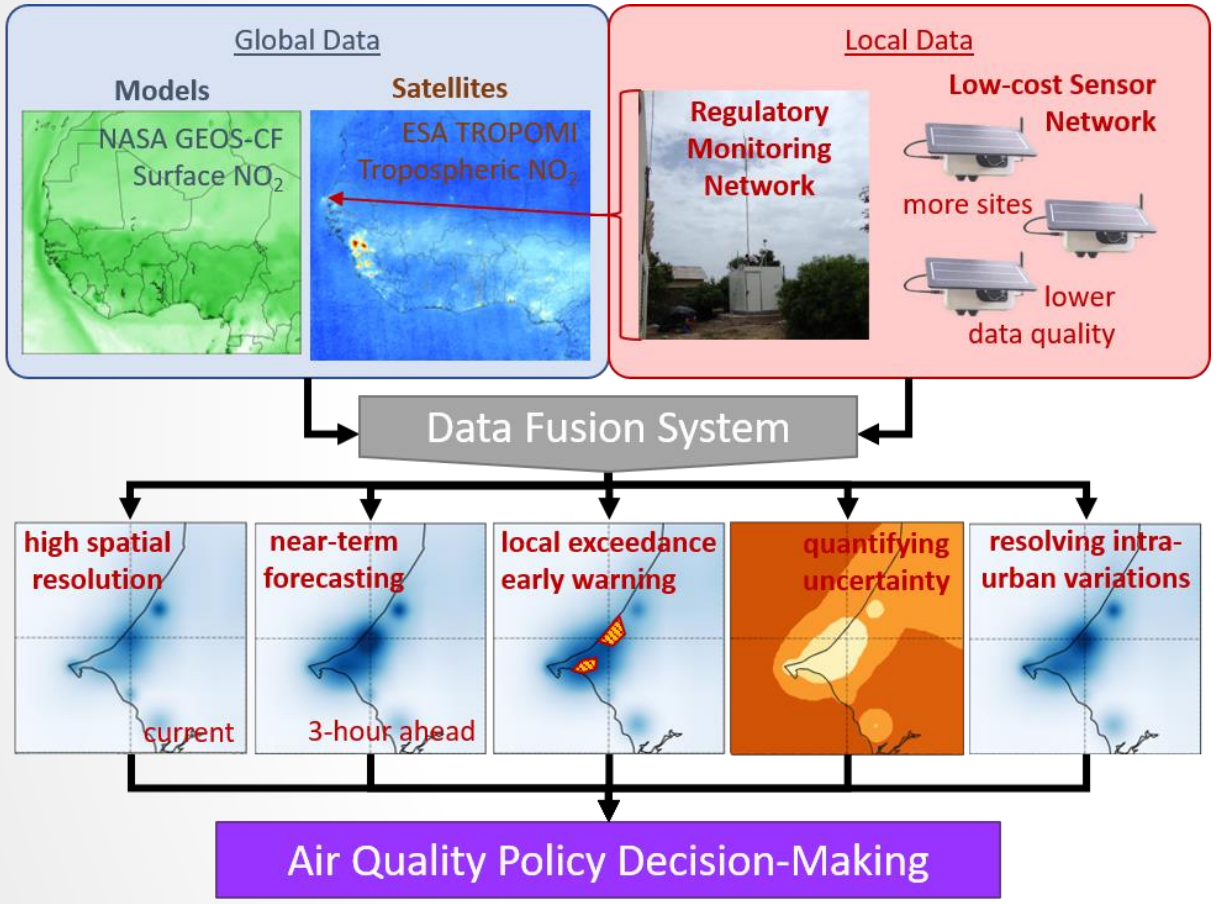
Novel application of the GEOS-CF ML algorithm



Impact of COVID-19 restrictions

Keller et al., 2021 ACP

Ongoing & Future Work



See Malings et al., 2021 ESS for details on Data Fusion System

NASA Earth Science Applications: Health and Air Quality

Supporting local government public health and air quality decision-making with a sub-city scale air quality forecasting system from data fusion of models, satellite, in situ measurements, and low-cost sensors.

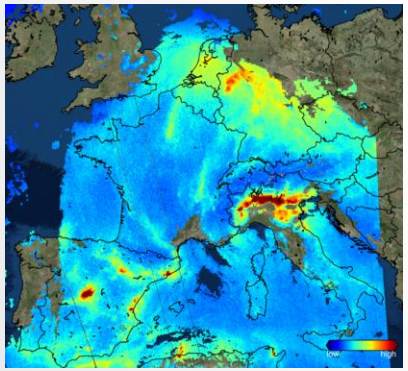
Cities: Dakar, **Senegal**
Rio de Janeiro, **Brazil**
Charleston, Denver, Boulder, Gulfport, Portland, **USA**

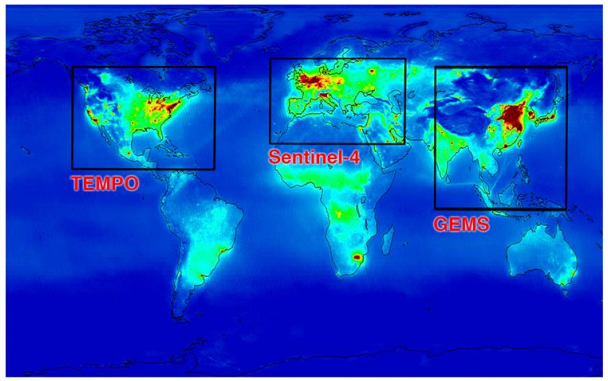
Co-Investigators: Sonoma Technology, Inc.

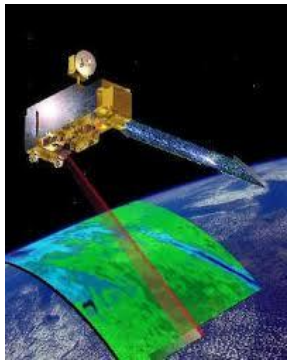
Collaborators: US EPA
UN Environment Programme
Clarity Movement, Co.
Columbia University, WUSTL

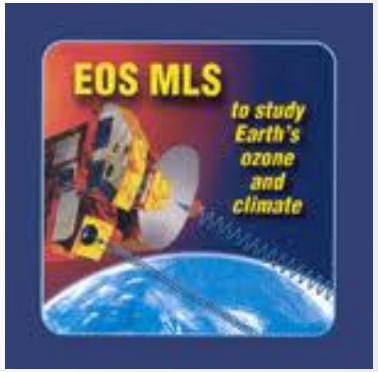
Planned upgrades for GEOS-CF

- Model update to GEOS-Chem v14
  - Improvements to ozone deposition
  - Updates to NO_3 washout ⇢ likely reduce PM2.5 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, SO_2









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, except the AQ collection of surface pollutants (O_3, NO_2, CO, PM2.5, and SO_2) available since January 2019 for research
- Forecast visualizations and data available at: fluid.nccs.nasa.gov/cf and /cf_map
- 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
  - GEOS-CF forecasts to be on Google Earth Engine and AWS

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

Extra slides

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

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

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Non-Refereed

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