

NASA GEOS Composition Forecast System, GEOS-CF



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Introduction

GEOS is an Earth System Model designed to advance the use of satellite data products. Since it is a modular system, it can be run as a numerical weather prediction model and coupled to chemistry modules.

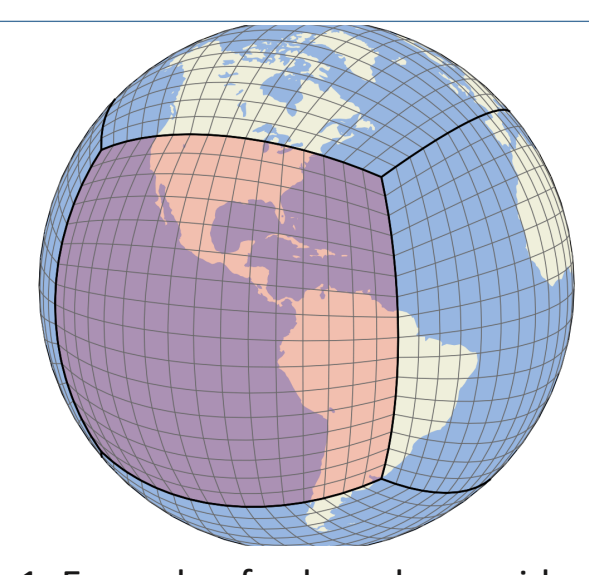


Fig 1: Example of cube sphere grid used in GEOS (Bindle et al., 2021 GMD)

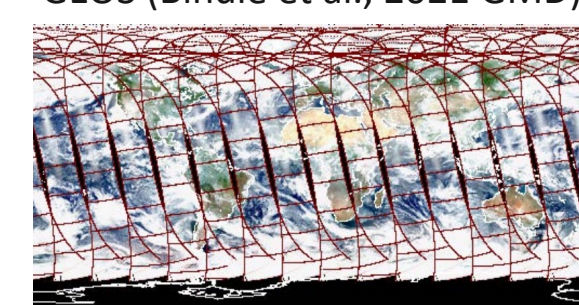


Fig 2: MODIS imagery stitched together to show global coverage (https://modis.gsfc.nasa.gov/)

GEOS-CF

For version 1 of GEOS-CF, the GEOS AGCM is coupled to the GEOS-Chem (v 12) chemistry module with full tropospheric and stratospheric chemistry.

GEOS-CF version 2 development

GEOS-CF v1 was frozen in 2018. Several updates are coming to GEOS-CF version 2, including but not limited to: GEOS AGCM (v10.23.0, release late 2022), new near-real time GEOS for Instrument Teams (GEOS-IT) for meteorological replay segment (see Fig 3b), upgrading to GEOS-Chem v14.0, latest CEDS anthropogenic emissions at 0.1° global resolution up through 2019, data assimilation of Ozone, NO₂, and SO₂ using NASA Aura-based instruments (MLS and OMI).

Results of the comparison of GEOS-CF v1 with a coarser development run for GEOS-CF v2 below

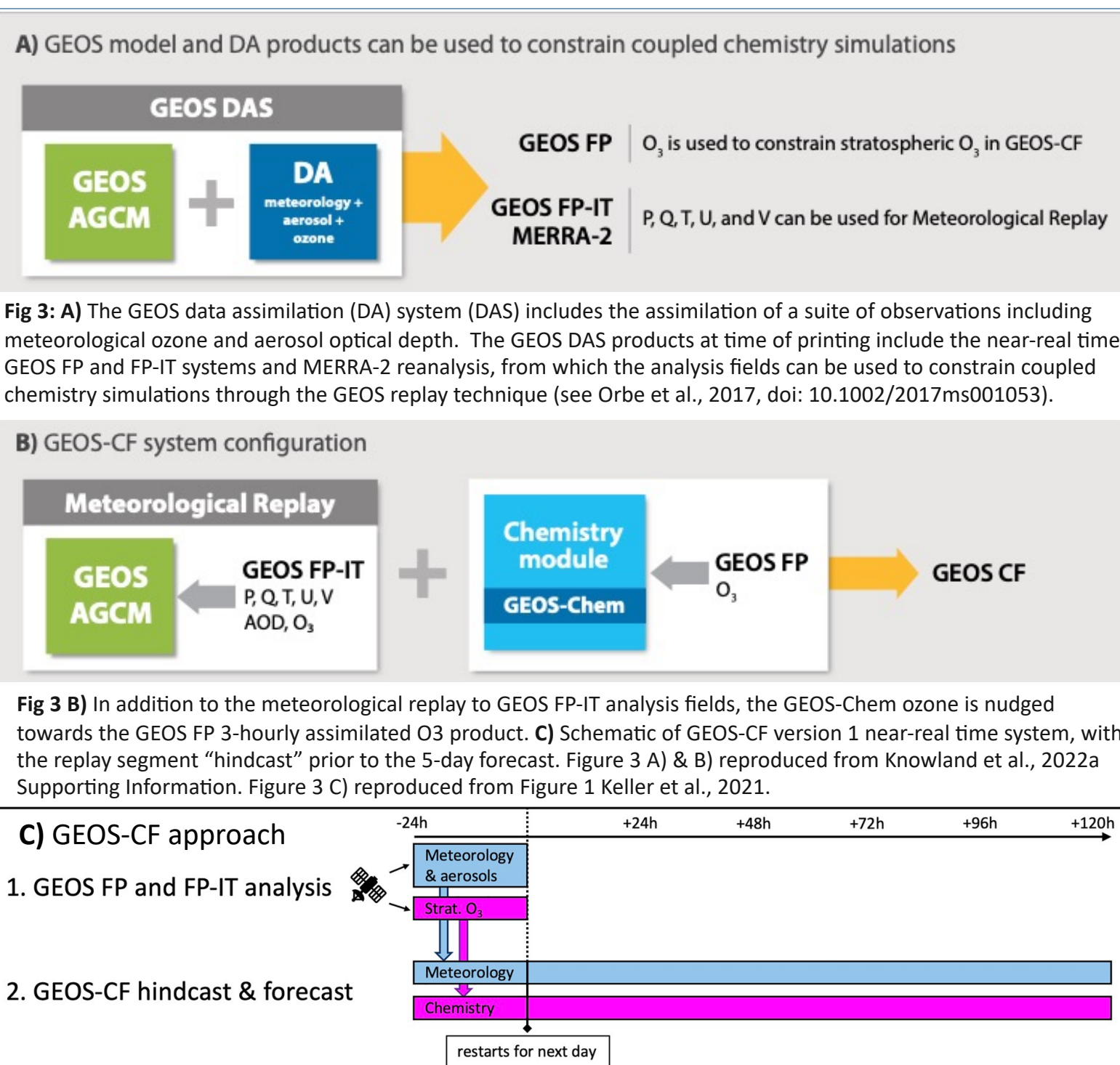


Fig 3 A) The GEOS data assimilation (DA) system (DAS) includes the assimilation of a suite of observations including meteorological ozone and aerosol optical depth. The GEOS DAS products at time of printing include the near-real time GEOS FP and FP-IT systems and MERRA-2 reanalysis, from which the analysis fields can be used to constrain coupled chemistry simulations through the GEOS replay technique (see Orbe et al., 2017, doi: 10.1002/2017ms001053).

Fig 3 B) In addition to the meteorological replay to GEOS FP-IT analysis fields, the GEOS-Chem ozone is nudged towards the GEOS FP 3-hourly assimilated O₃ product. C) Schematic of GEOS-CF version 1 near-real time system, with the replay segment "hindcast" prior to the 5-day forecast. Figure 3 A) & B) reproduced from Knowland et al., 2022a Supporting Information. Figure 3 C) reproduced from Figure 3 Keller et al., 2021.

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GEOS-CF v1 system set-up

- One 5-day forecast per day
- Initialized at 12z
 - 1-day meteorological replay ("hindcast")
 - 5-day forecast
 - c360 (0.25°, ~25x25 km²)
 - 72 layers (surface to 0.01hPa)
 - 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 (for details on available GEOS-CF output, see Knowland et al. 2022b)
 - Available since
 - 1 January 2018 (replay; stratospheric output since 2020)
 - 1 January 2019 (forecast)

Knowland et al., 2022b. "File Specification for GEOS-CF Products." GMAO Office Note No. 17 (Version 1.3), available from http://gmao.gsfc.nasa.gov/pubs/office_notes

- Emissions:
- HTAP v2.2 (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

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>

Knowland, K. E., Keller, C. A., et al. (2022a). NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0: Stratospheric Composition. *JAMES* <https://doi.org/10.1029/2021MS002852>

GEOS-CF v1 Validation

GEOS-CF v1 has been evaluated for both tropospheric and stratospheric composition and forecast skill (Keller et al., 2021; Knowland et al., 2022a). A few examples below:

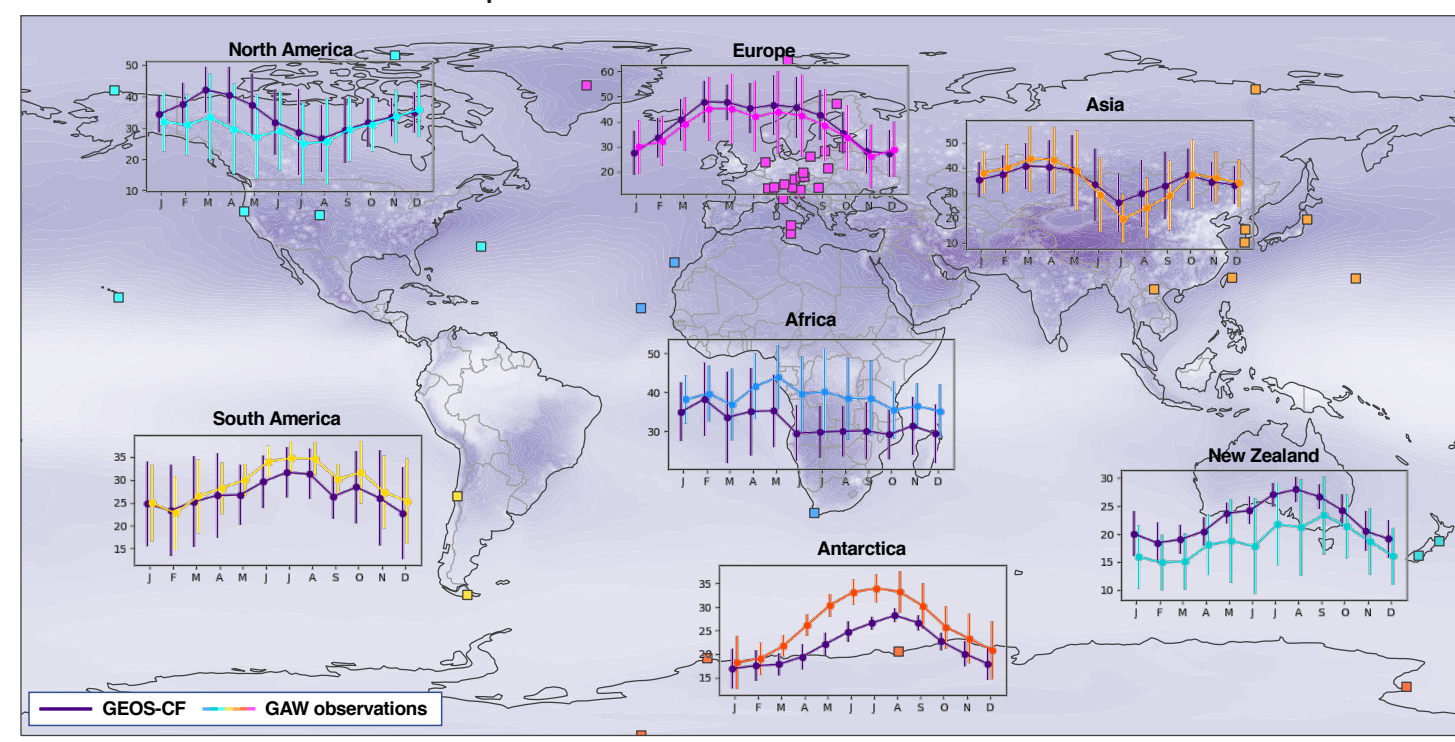
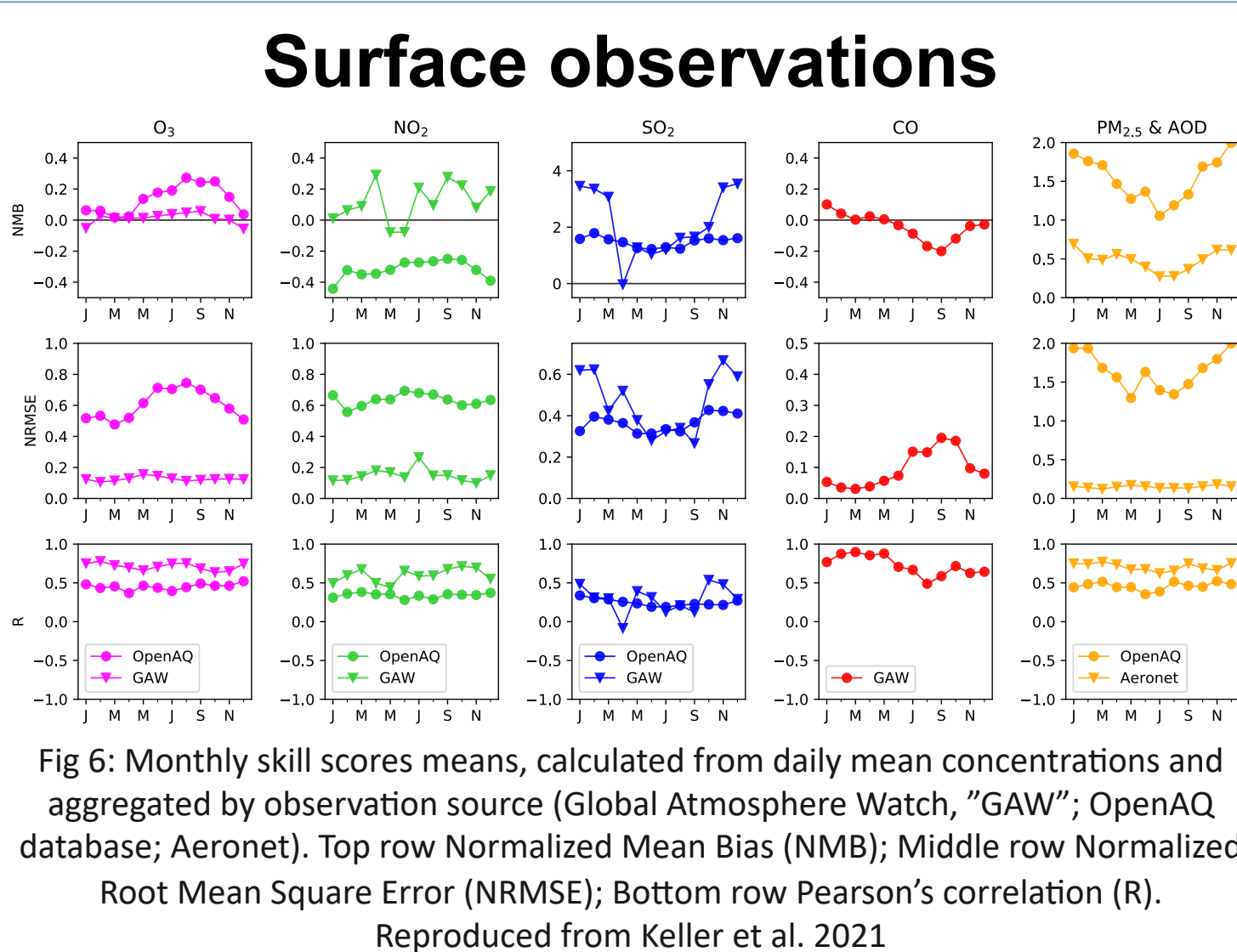
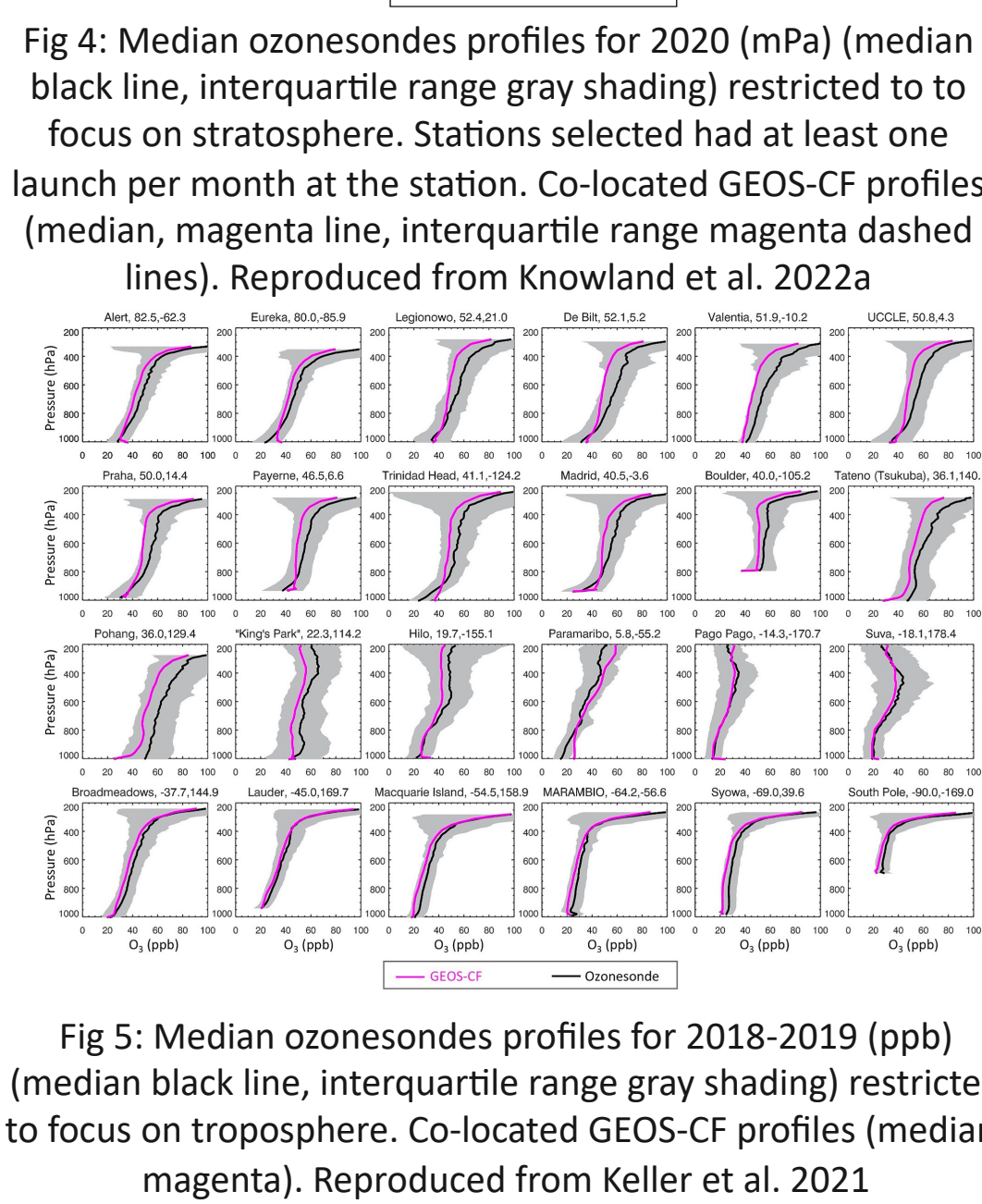
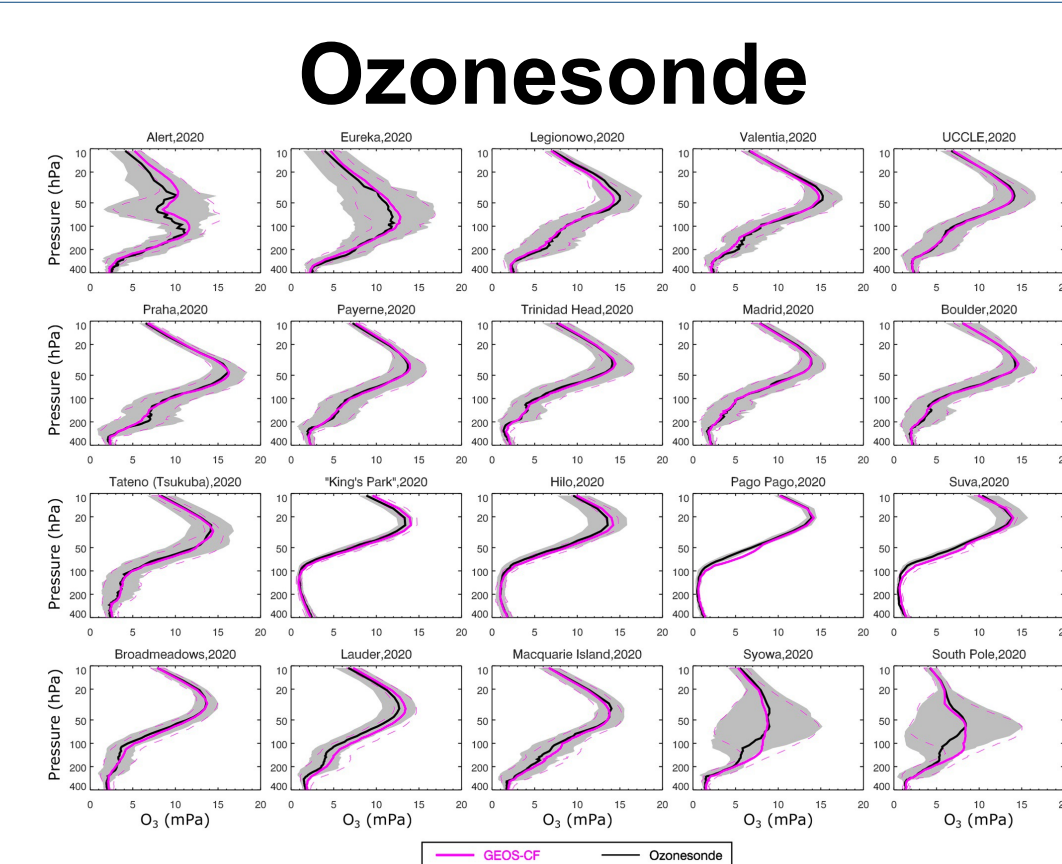


Fig 7: Map shows average surface ozone concentrations for GEOS-CF. Overlayed are the monthly time series of surface ozone from GEOS-CF (purple) and the GAW sites (aggregated by region and colored accordingly). GEOS-CF captures much of the seasonal cycle and variability by region. Figure produced by C. Keller, see https://gmao.gsfc.nasa.gov/research/science_snapshots/2021/CF_O3_GAW.php. Reproduced from Keller et al. 2021

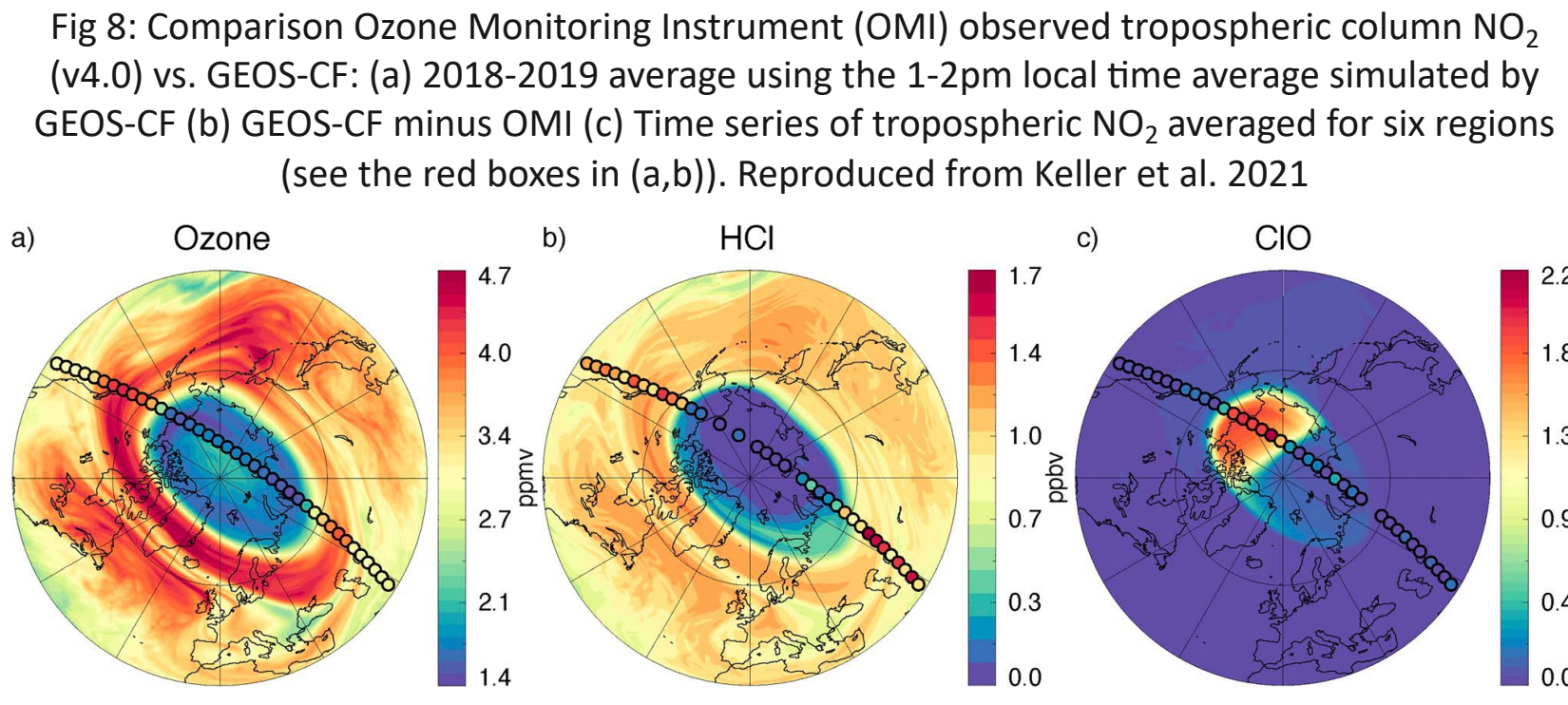
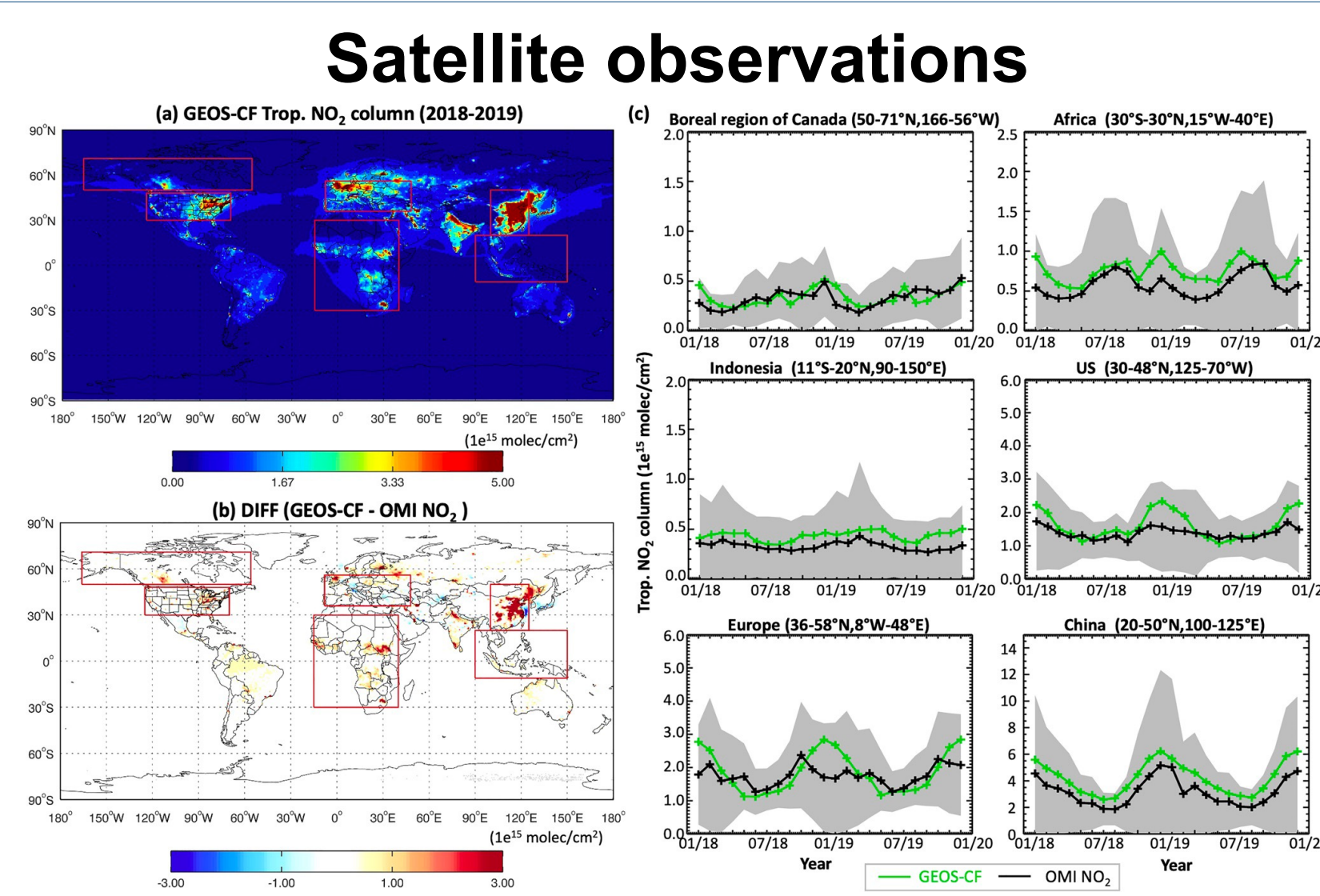


Fig 9: Feb 29, 2020 at 22:00 UTC GEOS-CF (map) and a single over-pass of the Microwave Limb Sounder (MLS) (colored circles, measurements from 21:43 UTC to 22:14 UTC) at 45 hPa for a) Ozone, b) Hydrogen Chloride, c) Chlorine Monoxide. When concentrations are far from climatological, as occurred over the Arctic in late winter/spring of 2020, it is critical to have stratospheric chemistry to capture polar vortex chemistry in O₃ forecasts. Reproduced from Knowland et al. 2022a

Results of GEOS-CF v2 development

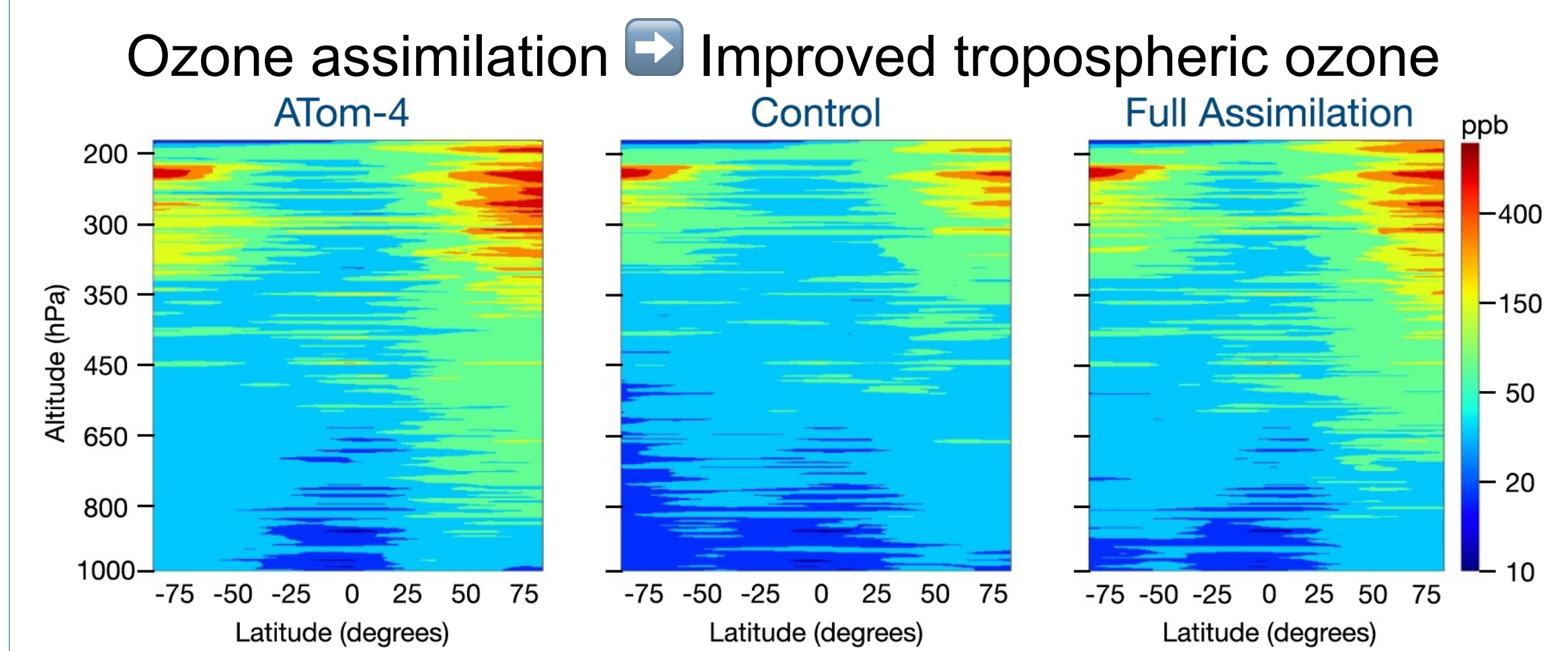


Fig. 10: Ozone assimilation of MLS v4.2 profiles, Total Column Ozone from OMI, and 9.6-micron radiances drastically improves the representation of ozone in the remote atmosphere according to this comparison to ATom-4 measurements and a version of the GEOS-CF v2 system used in testing. Figure reproduced from Makoto M Kelp et al 2023 *Environ. Res. Lett.* 18 094036 DOI 10.1088/1748-9326/acf0b7

New Meteorology Improved summertime (JJA) surface O₃

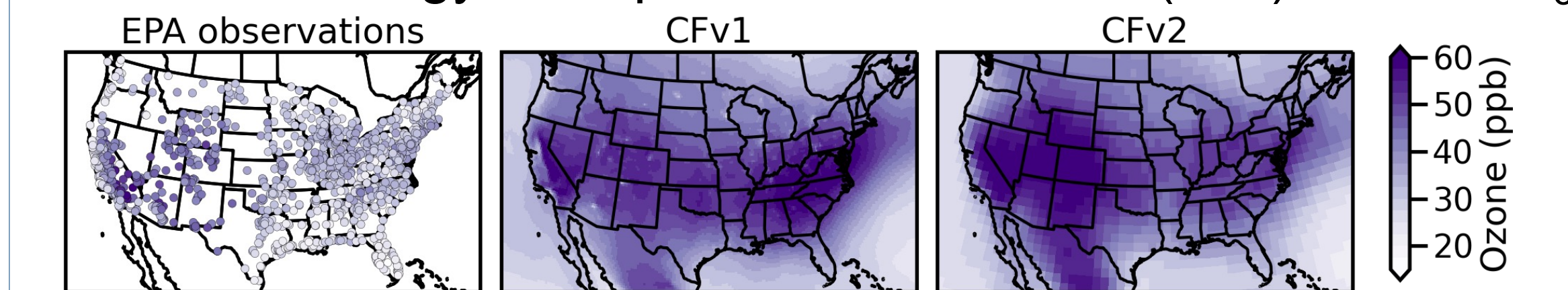


Fig. 11: JJA 2019 average surface ozone. GEOS-CF v1 was known to have a summertime high bias in surface O₃ in SE USA related to a bias in the 2-m Temperature driving the biogenic emissions (middle vs left panels; see also Keller et al. 2021). As demonstrated here for JJA 2019 averages, in a test version of the GEOS-CF v2 at 1° global resolution (right panel), there is a reduction in the O₃ in this region as the driving meteorology no longer has the high bias in temperature. The coarse resolution test (with O₃ assimilated) is biased high compared to EPA observations (left panel) and will be investigated further in future testing. Figures provided by Viral Shah.

GEOS-CF v1 uses HTAP v2.2 which is now >10 years behind Using latest CEDS with current estimates Improved PM_{2.5}

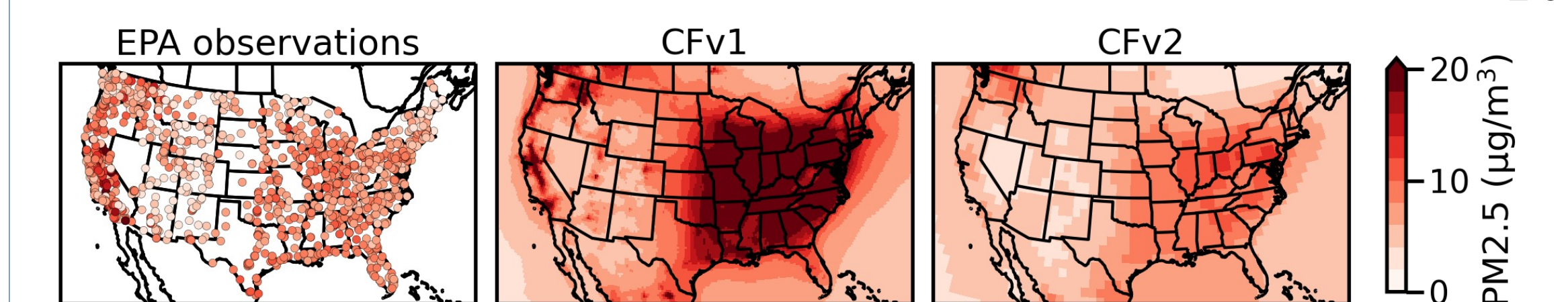


Fig. 12: Annual average PM_{2.5} for 2019. Keller et al. 2021 identified three main reasons for the high bias in aerosols, including PM_{2.5}, in GEOS-CF v1. Those are excessive sulphate aerosols (linked to the anthropogenic emission inventory used), underestimation of aerosol wet scavenging (linked to the version of GEOS-Chem used), and overestimated biomass burning emissions outside of high-intensity wildfire episodes (linked to the enhancement factors used for QFED which were determined for GOCART aerosol module and not GEOS-Chem). All three factors were addressed for GEOS-CF v2 and likely lead to the improvements seen in PM_{2.5} over CONUS, however the lower PM_{2.5} values seen in cities in western USA are not captured in the GEOS-CF v2 test simulation, likely because of the coarse 1° global resolution. This will be watched for in the higher resolution GEOS-CF v2 simulation. Figures provided by Viral Shah.

Applications

GEOS-CF is ingested into several platforms, including CDC tracker, WRI Resource Watch, and Google Earth Engine thanks to the NASA-Google Partnership and supports NASA campaigns, TEMPO and TOLNet .

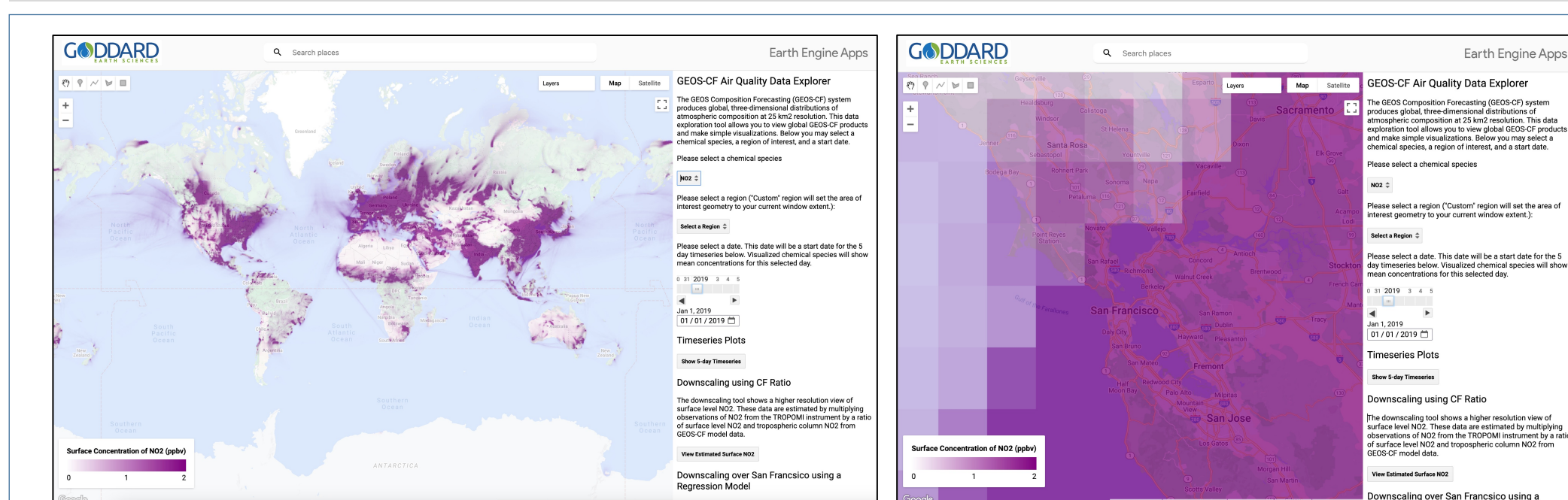


Fig 14: GEOS-CF replay and forecasts files are available in Google Earth Engine (GEE). The GEOS-CF Air Quality Data Explorer was created using publicly available GEE tools and datasets. <https://callumwayman.users.earthengine.app/view/geoscfexplorer>

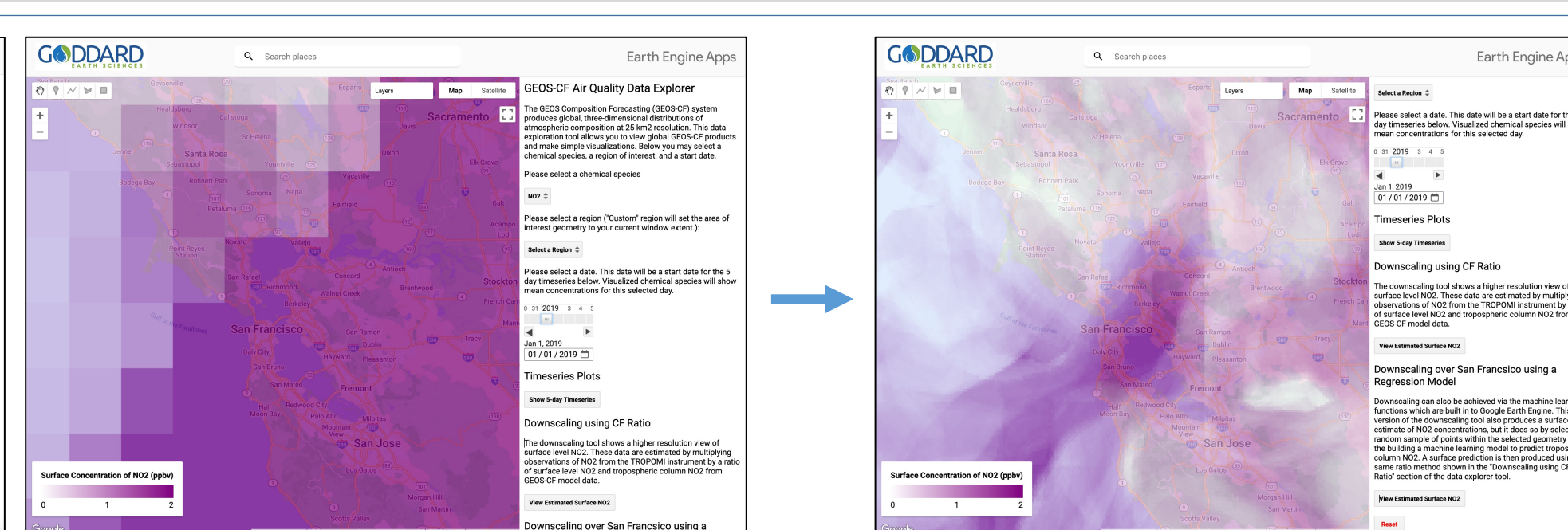


Fig 15: Using ratio techniques (as described in Figure 11 caption) and a machine learning regression algorithm within the GEE code editor, an example application has been developed to fuse GEOS-CF surface level NO₂ data (left figure) with TROPOMI column NO₂ observations. The open accessible tool can be used to generate high-resolution (1 km²) surface NO₂ maps on demand and in near real-time (right figure). <https://callumwayman.users.earthengine.app/view/geoscfexplorer>

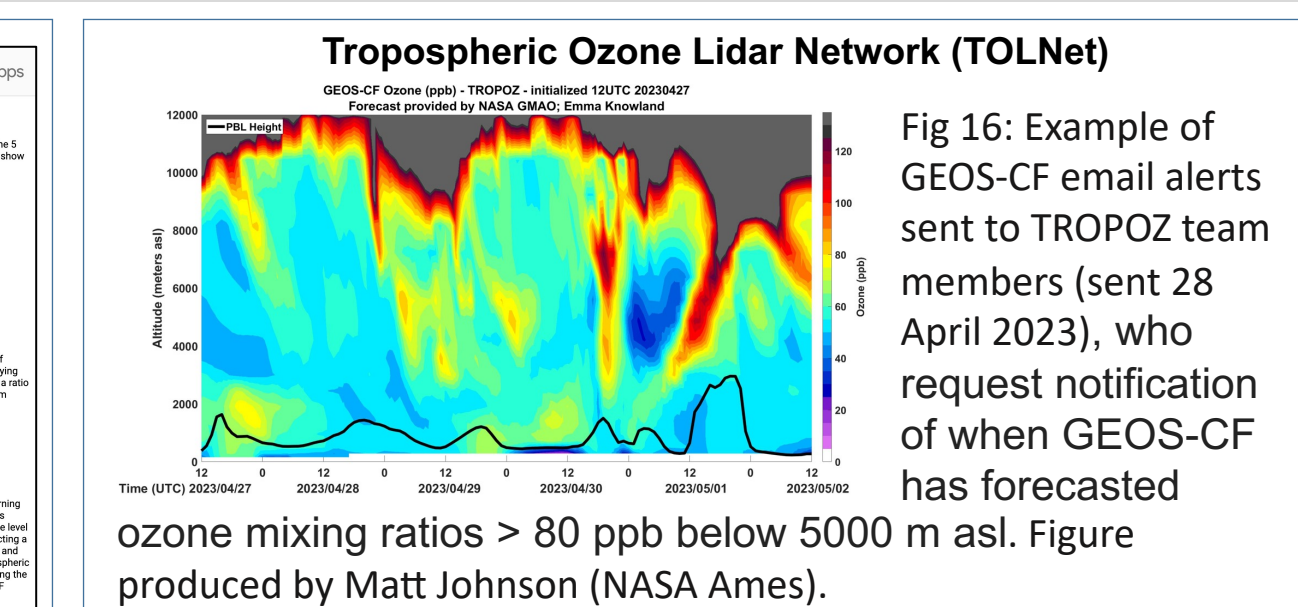


Fig 16: Example of GEOS-CF email alerts sent to TROPQZ team members (sent 28 April 2023), who request notification of when GEOS-CF has forecasted ozone mixing ratios > 80 ppb below 5000 m asl. Figure produced by Matt Johnson (NASA Ames).

