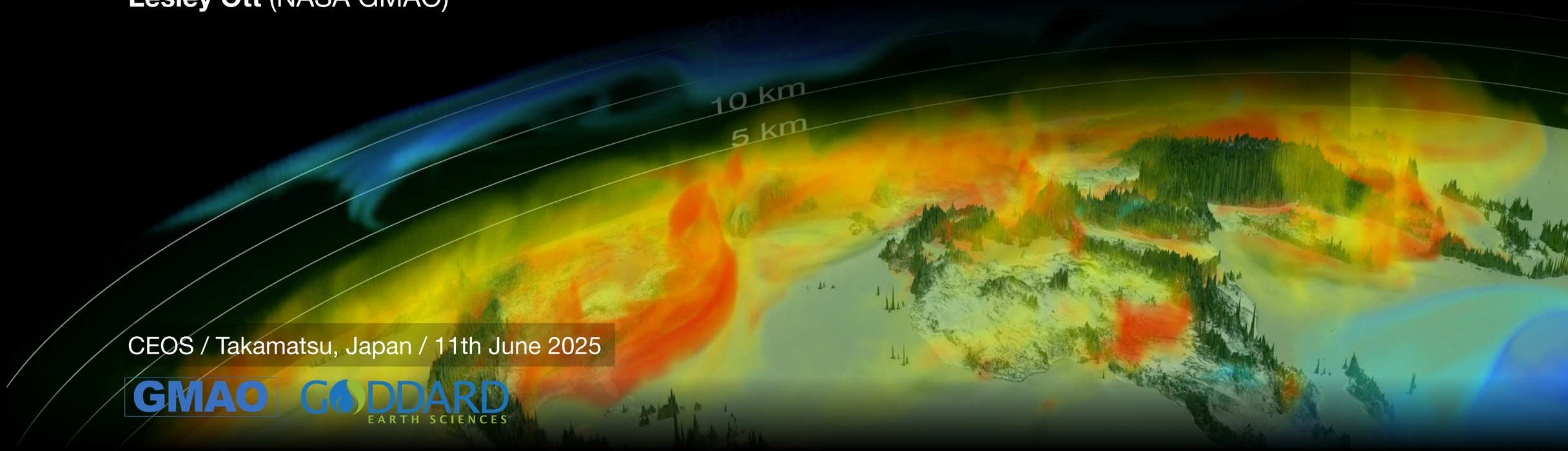
National Aeronautics and
Space Administration

Constituent data assimilation plans of the GMAO at NASA Goddard

Brad Weir (Morgan State & NASA GMAO) <brad.weir@nasa.gov>
Responsible for controversial views, mistakes, and bad ideas
Lesley Ott (NASA GMAO)



CEOS / Takamatsu, Japan / 11th June 2025

GMAO GODDARD EARTH SCIENCES

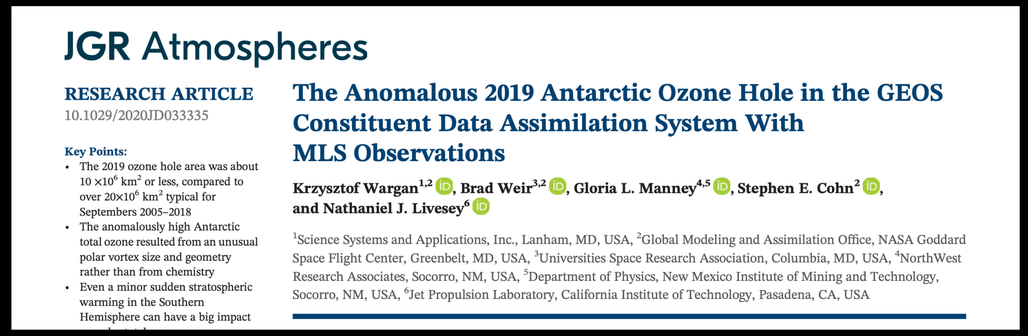
GEOS Constituent Reanalysis (CR)

- NASA's first "all-atmosphere" chemical reanalysis
- Roughly: Retrospective GEOS CF w/ constituent assimilation (CoDAS)

- Meteorology: GEOS GCM replayed to reanalysis (GEOS IT)
- Resolution: 25km horiz., 72 eta levels to 0.01 hPa
- Chemistry: GEOS-Chem

CoDAS (Constituent Data Assimilation System)

- Generalization of legacy O_3 state estimation from NWP systems
- Tracer agnostic: Assimilates any point sample (MLS) or averaging kernel obs (TROPOMI/OCO) of any trace gas
- Available to the public as part of GEOS ADAS: https://github.com/GEOS-ESM/GEOSadas
- Whatever Ens/Var/Hybrid combo you like
- Backbone of several existing and upcoming products



JGR Atmospheres

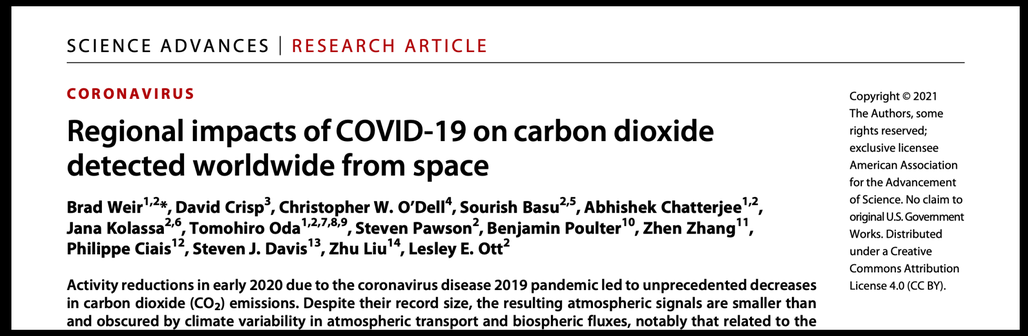
RESEARCH ARTICLE
10.1029/2020JD033335

Key Points:
- The 2019 ozone hole area was about 10 ×10^6 km^2 or less, compared to over 20×10^6 km^2 typical for Septembers 2005–2018
- The anomalously high Antarctic total ozone resulted from an unusual polar vortex size and geometry rather than from chemistry
- Even a minor sudden stratospheric warming in the Southern Hemisphere can have a big impact

The Anomalous 2019 Antarctic Ozone Hole in the GEOS Constituent Data Assimilation System With MLS Observations

Krzysztof Wargan[1,2], Brad Weir[3,2], Gloria L. Manney[4,5], Stephen E. Cohn[2], and Nathaniel J. Livesey[6]

[1]Science Systems and Applications, Inc., Lanham, MD, USA, [2]Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, MD, USA, [3]Universities Space Research Association, Columbia, MD, USA, [4]NorthWest Research Associates, Socorro, NM, USA, [5]Department of Physics, New Mexico Institute of Mining and Technology, Socorro, NM, USA, [6]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA



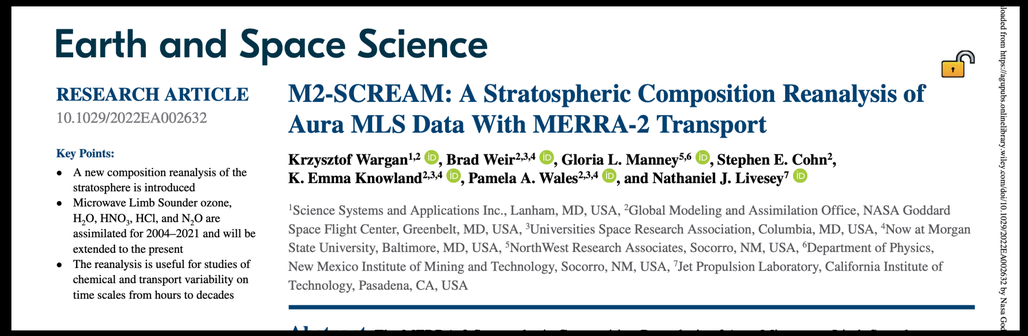
SCIENCE ADVANCES | RESEARCH ARTICLE

CORONAVIRUS

Regional impacts of COVID-19 on carbon dioxide detected worldwide from space

Brad Weir[1,2]*, David Crisp[3], Christopher W. O'Dell[4], Sourish Basu[2,5], Abhishek Chatterjee[1,2], Jana Kolassa[2,6], Tomohiro Oda[1,2,7,8,9], Steven Pawson[2], Benjamin Poulter[10], Zhen Zhang[11], Philippe Ciais[12], Steven J. Davis[13], Zhu Liu[14], Lesley E. Ott[2]

Activity reductions in early 2020 due to the coronavirus disease 2019 pandemic led to unprecedented decreases in carbon dioxide (CO_2) emissions. Despite their record size, the resulting atmospheric signals are smaller than and obscured by climate variability in atmospheric transport and biospheric fluxes, notably that related to the



Earth and Space Science

RESEARCH ARTICLE
10.1029/2022EA002632

Key Points:
- A new composition reanalysis of the stratosphere is introduced
- Microwave Limb Sounder ozone, H_2O, HNO_3, HCl, and N_2O are assimilated for 2004–2021 and will be extended to the present
- The reanalysis is useful for studies of chemical and transport variability on time scales from hours to decades

M2-SCREAM: A Stratospheric Composition Reanalysis of Aura MLS Data With MERRA-2 Transport

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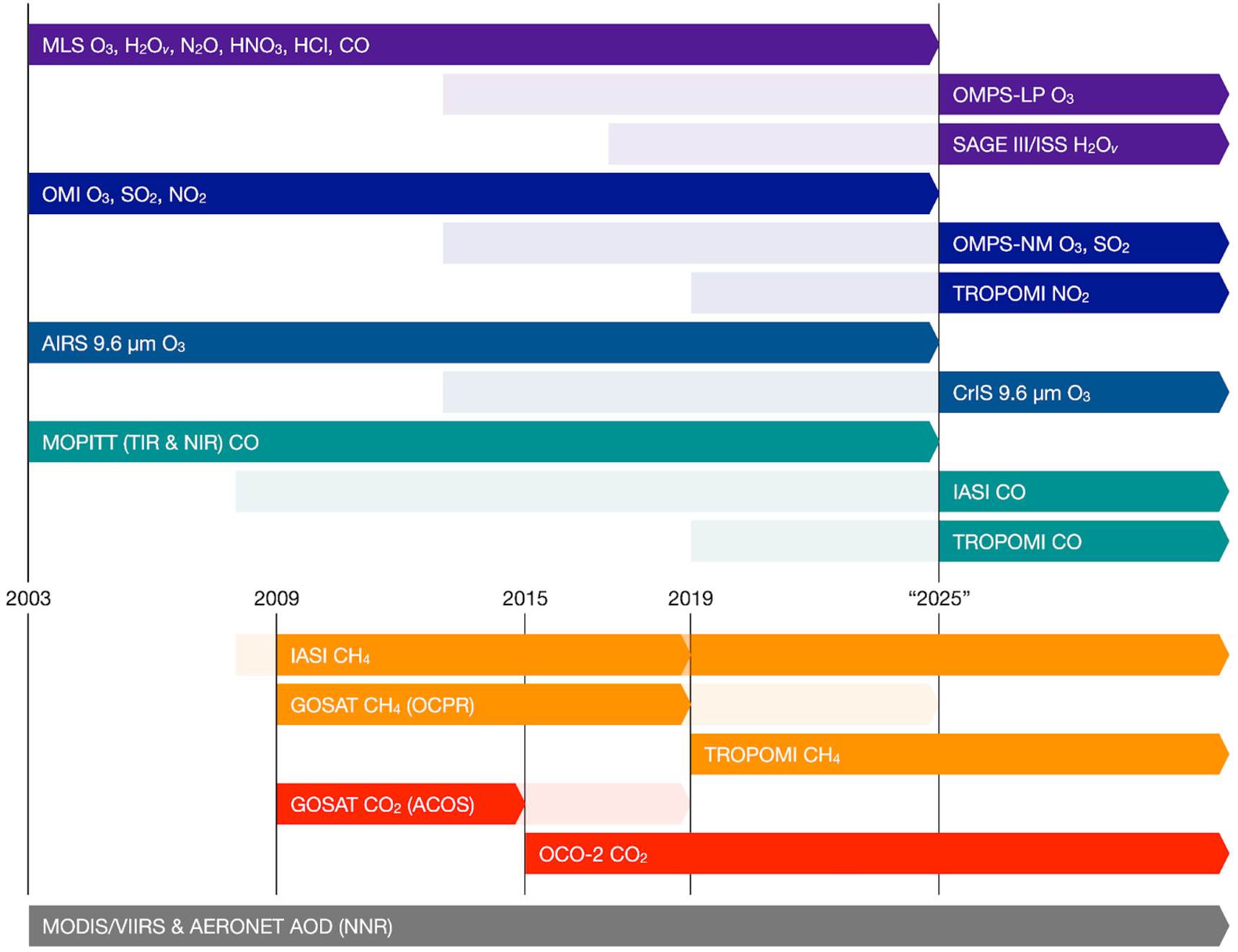
GEOS CR: Heritage

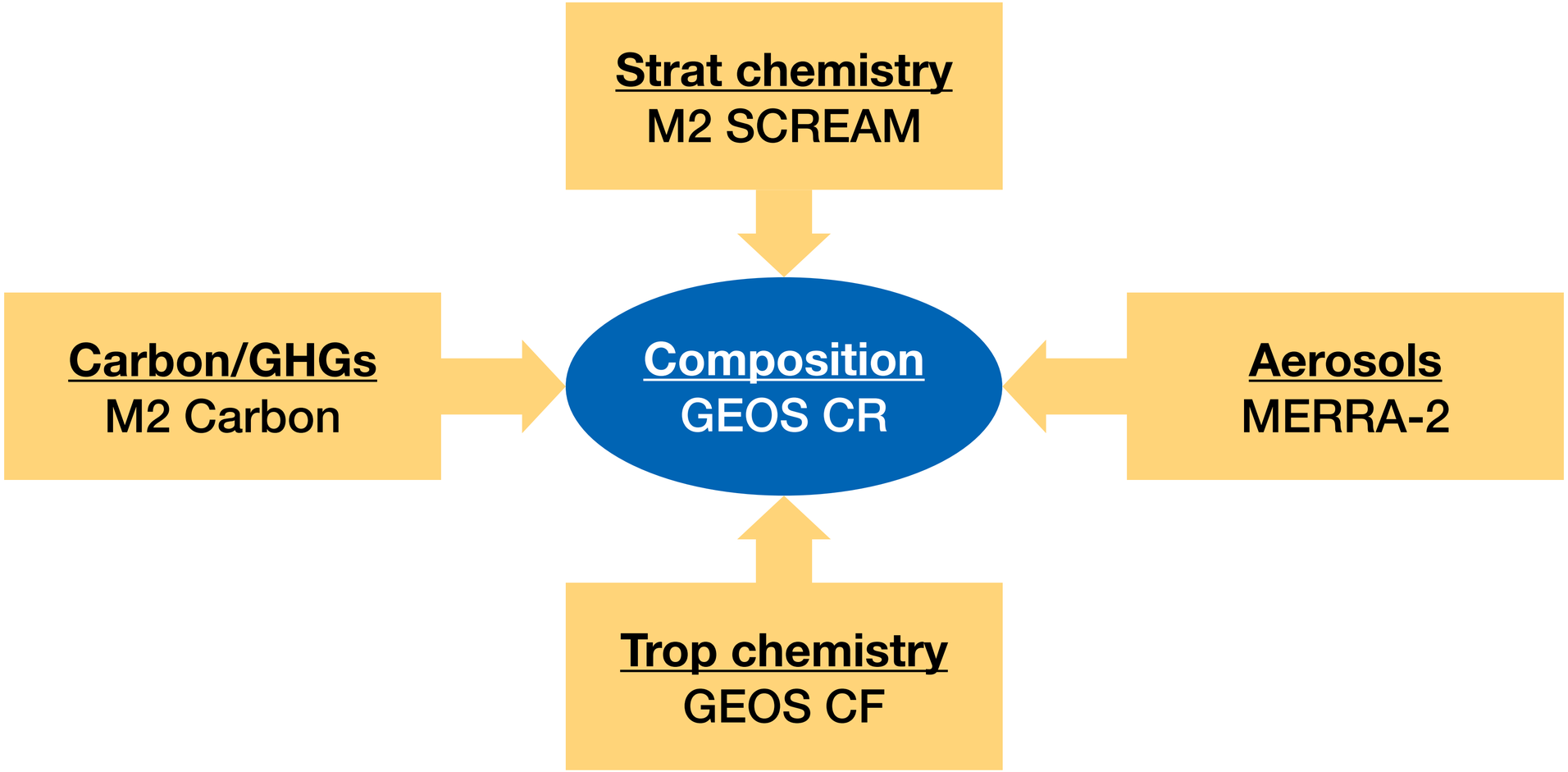
- Previously
  - MERRA-2 met: Strat ozone, **trop** water vapor (H_2O), and aerosols
  - Carbon: CO_2, CH_4, CO
  - M2 SCREAM strat: **Strat** H_2O, N_2O, HNO_3, HCl, CO, CH_3Cl
  - GEOS CF trop: NO_2, SO_2, 9.6 um O_3

- GEOS CR: Everything together in one system



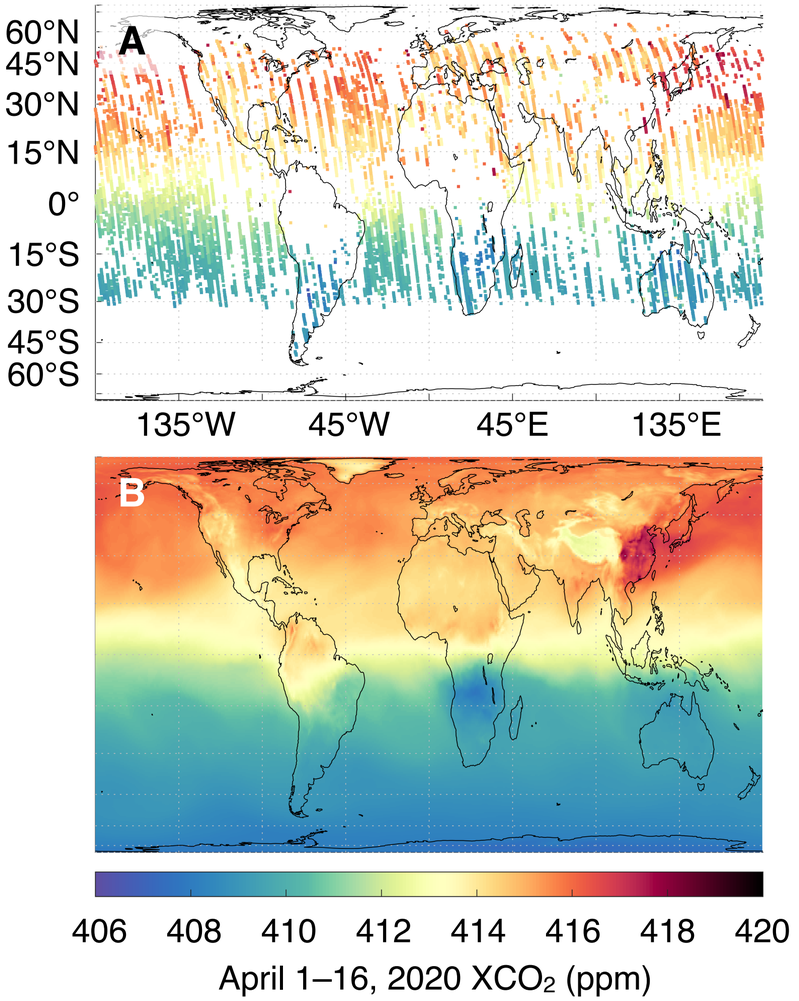
Vertical lines: Notable changes in observing system
Light shading: Overlap used for tuning, evaluation, & bias correction

GEOS CR: Putting it all together



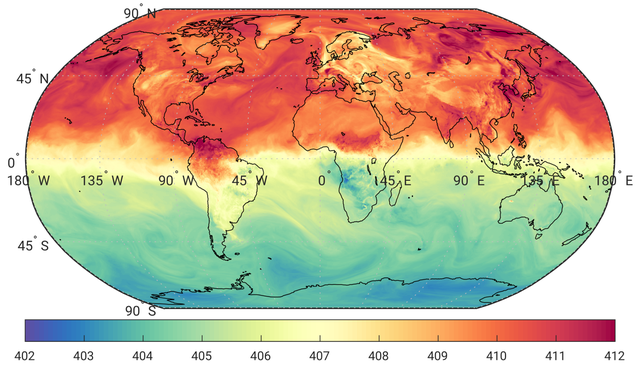
Carbon assimilation

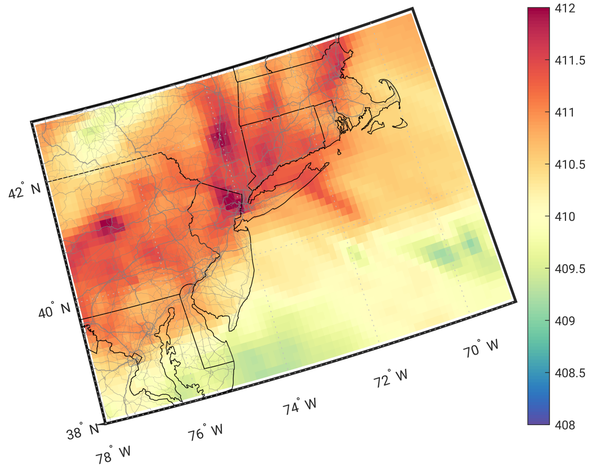
- Assimilate satellite column CO_2, CH_4, and CO obs to produce time-varying, 3D fields (M2CC)
- 50km replay to MERRA-2 met, 12km run in progress
- Observationally-informed flux package (e.g. night lights, NDVI, FRP, surface growth rate)
- CO_2 is OCO-2 L3 product (OCO-2/GEOS) available on GES DISC & visualizations at https://fluid.nccs.nasa.gov/carbon
- Able to estimate fluxes



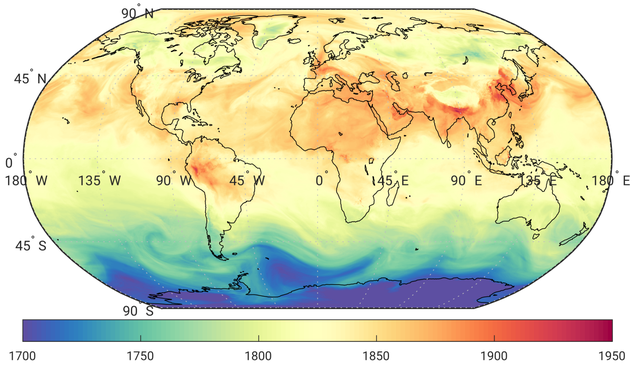
12km carbon DA

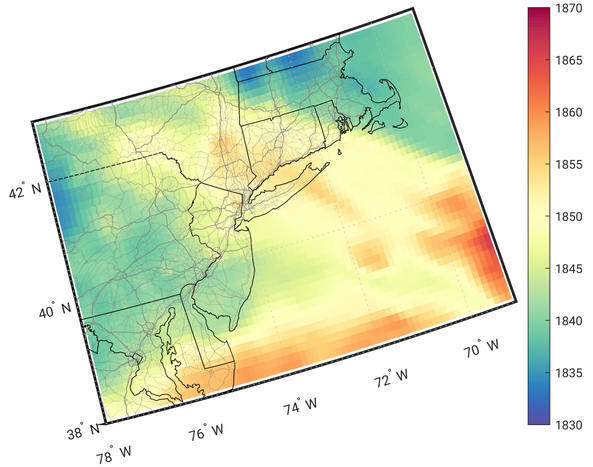
OCO-2 XCO_2 [ppm]



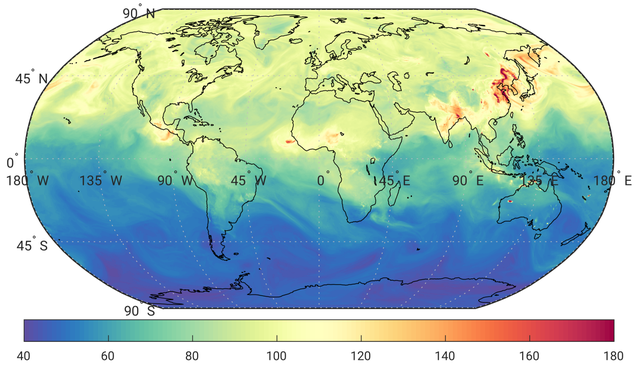


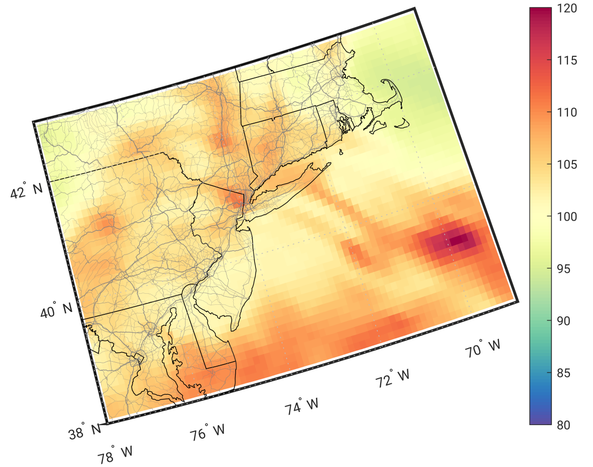
TROPOMI XCH_4 [ppb]





TROPOMI XCO [ppb]

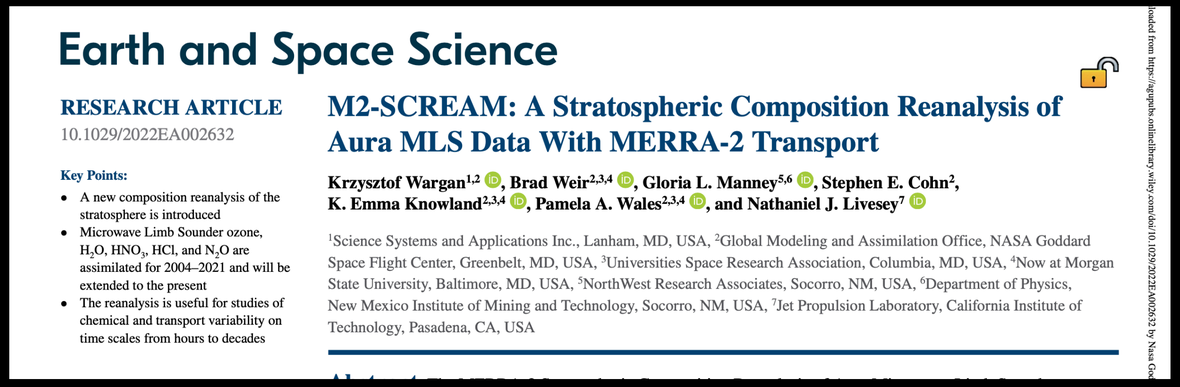




M2 SCREAM

MERRA-2 Stratospheric Composition Reanalysis of Aura MLS

- 50 km replay to MERRA-2 met (except strat H_2O)
- Assimilates O_3, HCl, HNO_3, N_2O, and **strat** H_2O profiles from MLS & OMI column O_3
- Realistic, data-constrained, high-resolution **strat** and **trop** H_2O
- Publicly available: 2004 – now(ish) on GES DISC



Earth and Space Science

RESEARCH ARTICLE
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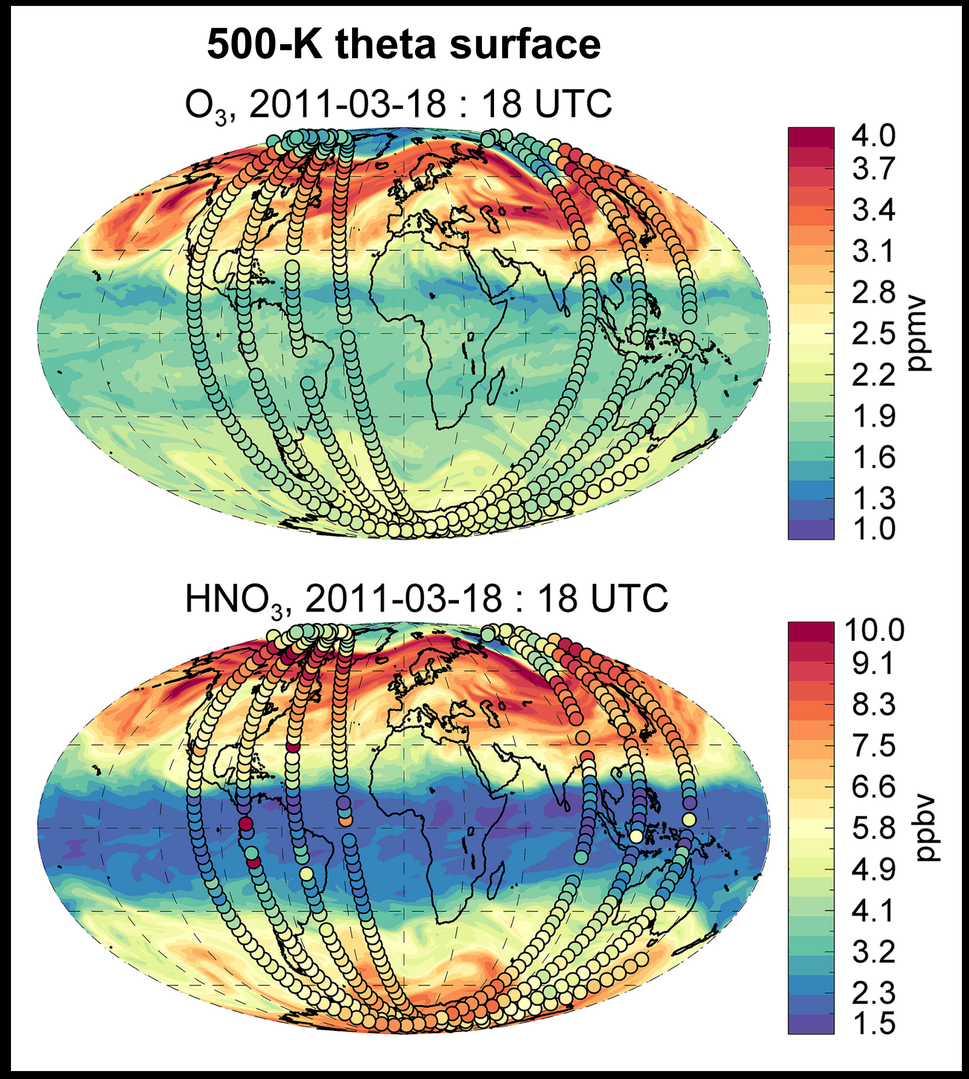

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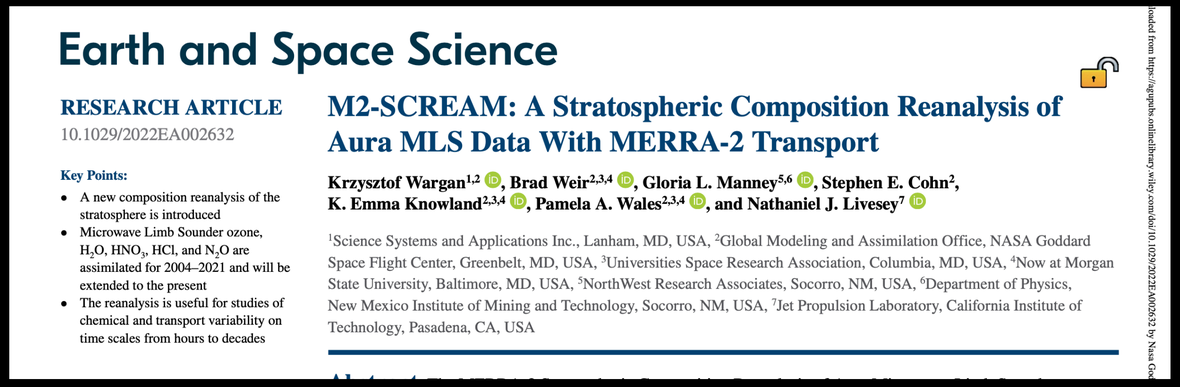

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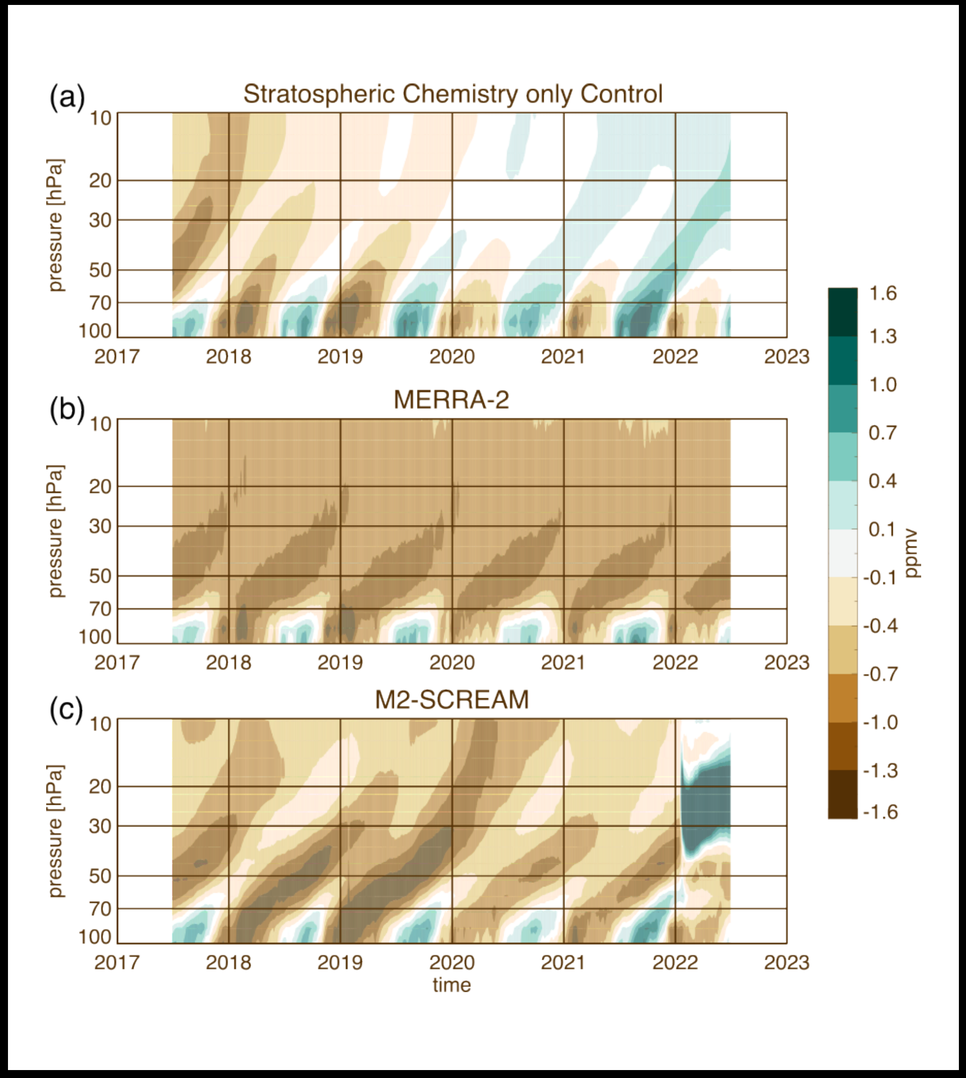
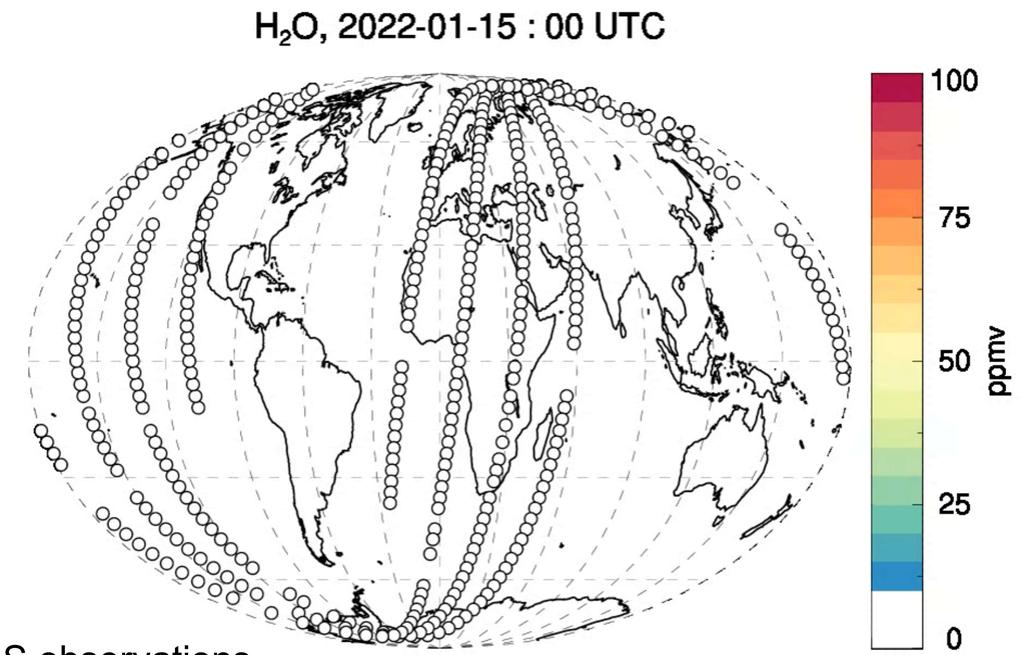


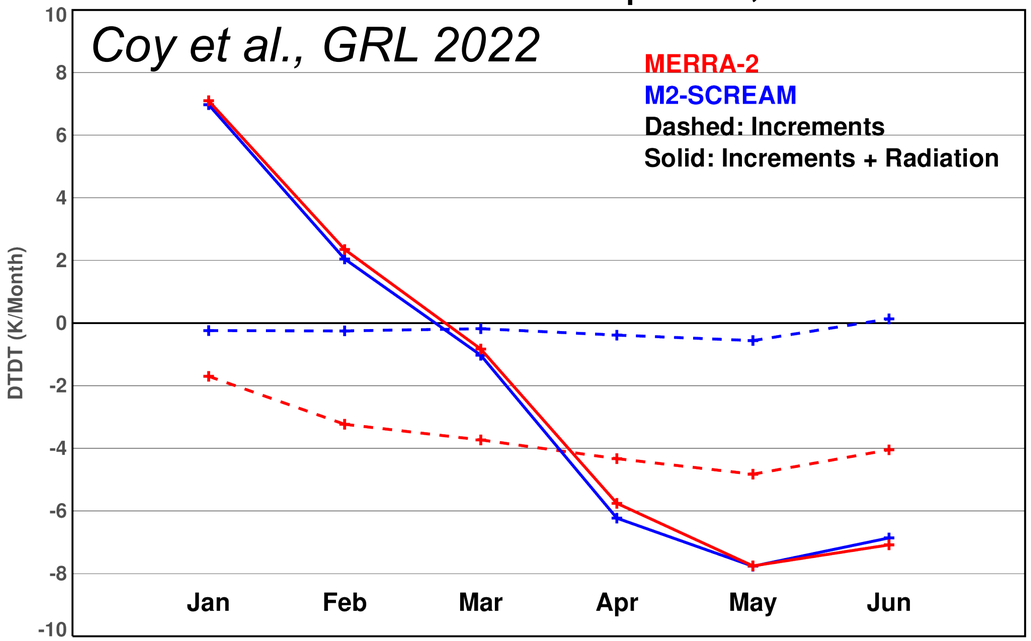
Hunga Tonga–Hunga Ha’apai



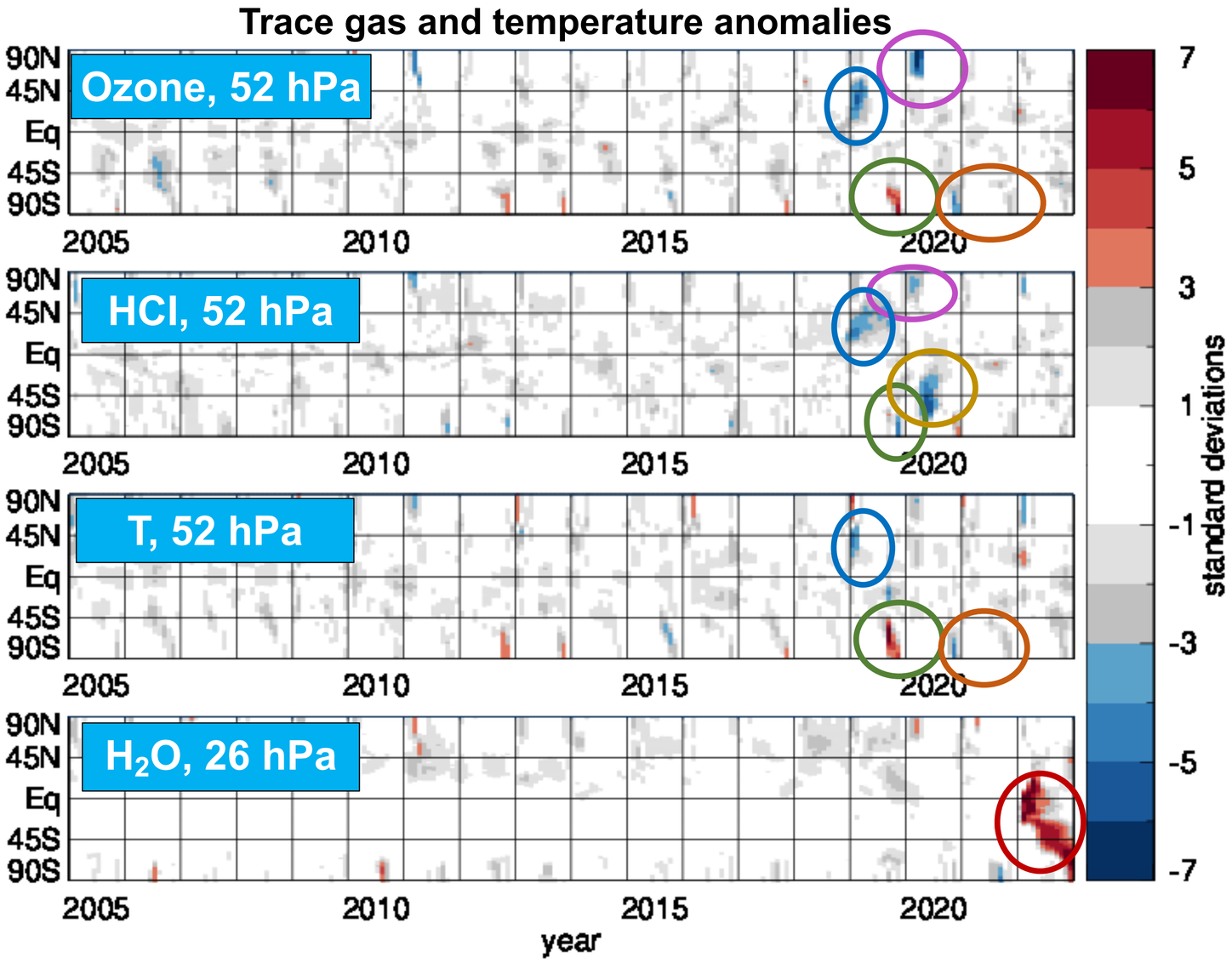
- MLS observations

Water vapor at 650 K potential temperature (~26 km) from M2-SCREAM

Southern hemisphere, 20 hPa



The extra water vapor induces radiative cooling and dynamical perturbations consistent w/ M2 analysis tendency



Early 2019: Dynamically-driven anomaly

Late 2019: Rare sudden stratospheric warming over Antarctica

2020: Exceptionally strong Arctic polar vortex

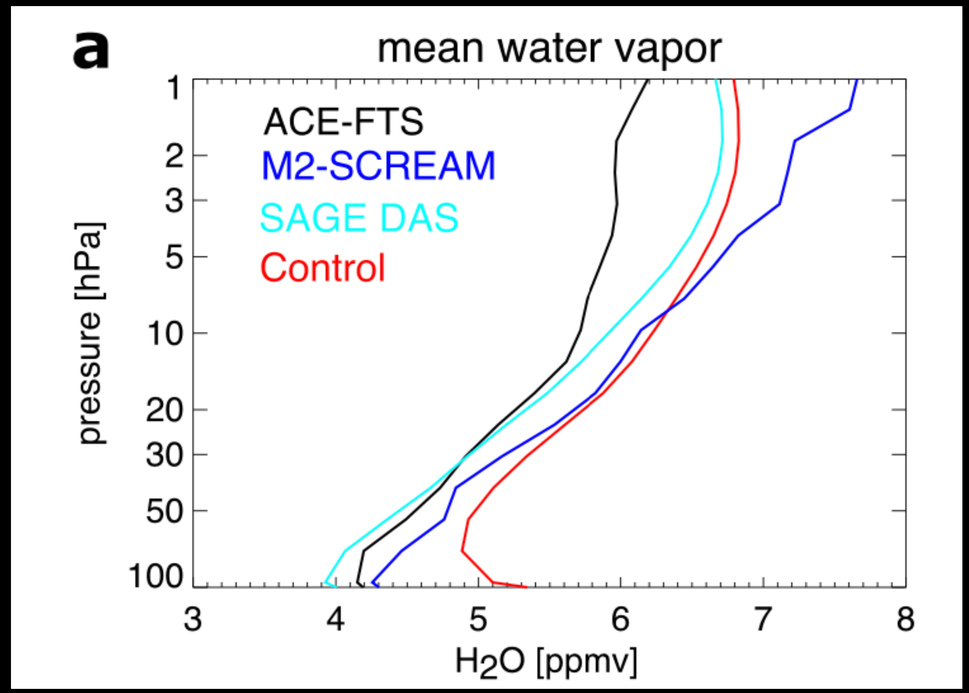
2020: Australian New Year's wildfires

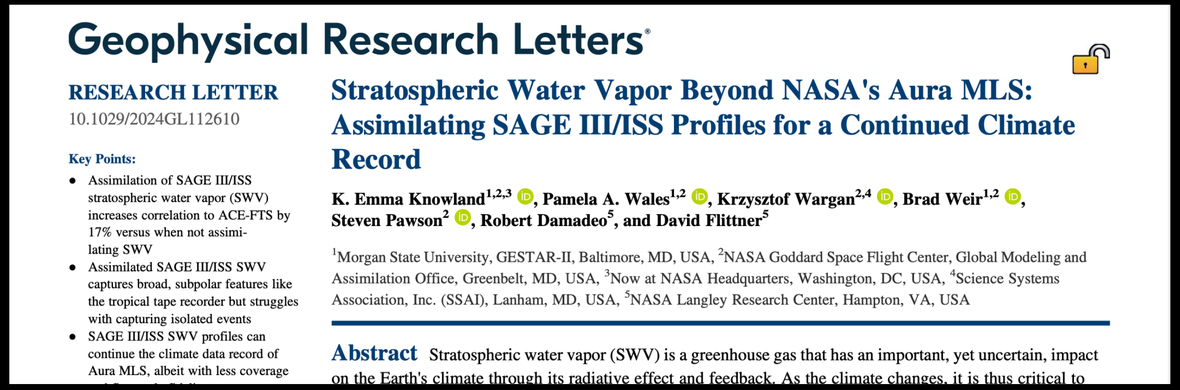
2020 and 2021: Long-lasting Antarctic polar vortices

2022: Hunga Tonga eruption

MLS continuity

- Possible to continue strat H2Ov record from MLS w/ SAGE III/ISS data
- Other constituents … not so much





Geophysical Research Letters

RESEARCH LETTER
10.1029/2024GL112610

Key Points:

- Assimilation of SAGE III/ISS stratospheric water vapor (SWV) increases correlation to ACE-FTS by 17% versus when not assimilating SWV
- Assimilated SAGE III/ISS SWV captures broad, subpolar features like the tropical tape recorder but struggles with capturing isolated events
- SAGE III/ISS SWV profiles can continue the climate data record of Aura MLS, albeit with less coverage

Stratospheric Water Vapor Beyond NASA's Aura MLS: Assimilating SAGE III/ISS Profiles for a Continued Climate Record

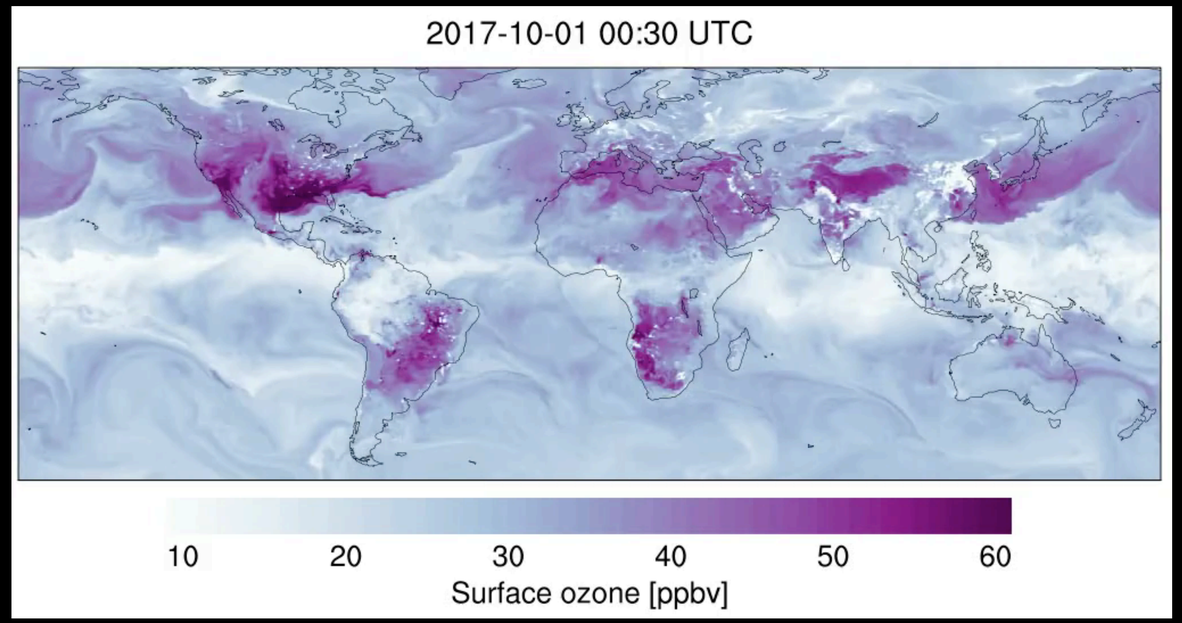
K. Emma Knowland[1,2,3], Pamela A. Wales[1,2], Krzysztof Wargan[2,4], Brad Weir[1,2], Steven Pawson[2], Robert Damadeo[5], and David Flittner[5]

[1]Morgan State University, GESTAR-II, Baltimore, MD, USA, [2]NASA Goddard Space Flight Center, Global Modeling and Assimilation Office, Greenbelt, MD, USA, [3]Now at NASA Headquarters, Washington, DC, USA, [4]Science Systems Association, Inc. (SSAI), Lanham, MD, USA, [5]NASA Langley Research Center, Hampton, VA, USA

Abstract Stratospheric water vapor (SWV) is a greenhouse gas that has an important, yet uncertain, impact on the Earth's climate through its radiative effect and feedback. As the climate changes, it is thus critical to

GEOS CF

- GEOS-Chem chemistry: 250 gas-phase species, 725 reactions
- 25km replay to GEOS IT met
- Coupling w/ aerosol chemistry
- https://fluid.nccs.nasa.gov/cf



Atmos. Chem. Phys., 21, 3555–3592, 2021
https://doi.org/10.5194/acp-21-3555-2021

Atmospheric Chemistry and Physics
Open Access
EGU

Global impact of COVID-19 restrictions on the surface concentrations of nitrogen dioxide and ozone

Christoph A. Keller[1,2], Mathew J. Evans[3,4], K. Emma Knowland[1,2], Christa A. Hasenkopf[5], Sruti Modekurty[5], Robert A. Lucchesi[1,6], Tomohiro Oda[1,2], Bruno B. Franca[7], Felipe C. Mandarino[7], M. Valeria Díaz Suárez[8], Robert G. Ryan[9], Luke H. Fakes[3,4], and Steven Pawson[1]

JAMES | Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2020MS002413

Key Points:
- GEOS-CF is a new modeling system that produces global forecasts of atmospheric composition at 25 km^2 horizontal resolution
- GEOS-CF model output is freely available and offers a new tool for academic researchers, air quality managers, and the public

Correspondence to:

Description of the NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0

Christoph A. Keller[1,2], K. Emma Knowland[1,2], Bryan N. Duncan[1], Junhua Liu[1,2], Daniel C. Anderson[1,2], Sampa Das[1,2], Robert A. Lucchesi[1,3], Elizabeth W. Lundgren[4], Julie M. Nicely[1,5], Eric Nielsen[1,3], Lesley E. Ott[1], Emily Saunders[1,3], Sarah A. Strode[1,2], Pamela A. Wales[1,2], Daniel J. Jacob[4], and Steven Pawson[1]

[1]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [2]Universities Space Research Association, Columbia, MD, USA, [3]Science Systems and Applications, Inc., Lanham, MD, USA, [4]School of Engineering and Applied Sciences, Harvard University, Cambridge, MA, USA, [5]Earth System Science Interdisciplinary Center, University of Maryland, College Park, Lanham, MD, USA

JAMES | Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2021MS002852

Key Points:
- Demonstrate the GEOS-CF system is capable of supporting NASA science missions and applications which observe stratospheric composition
- The GEOS-CF model produces realistic stratospheric ozone forecasts, a new capability during anomalous polar vortex conditions
- Spatial patterns of the GEOS-CF simulated concentrations of stratospheric composition agree well

NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0: Stratospheric Composition

K. E. Knowland[1,2,3], C. A. Keller[1,2,3], P. A. Wales[1,2,3], K. Wargan[2,4], L. Coy[2,4], M. S. Johnson[5], J. Liu[1,3,6], R. A. Lucchesi[2,4], S. D. Eastham[7,8], E. Fleming[4,6], Q. Liang[6], T. Leblanc[9], N. J. Livesey[10], K. A. Walker[11], L. E. Ott[2], and S. Pawson[2]

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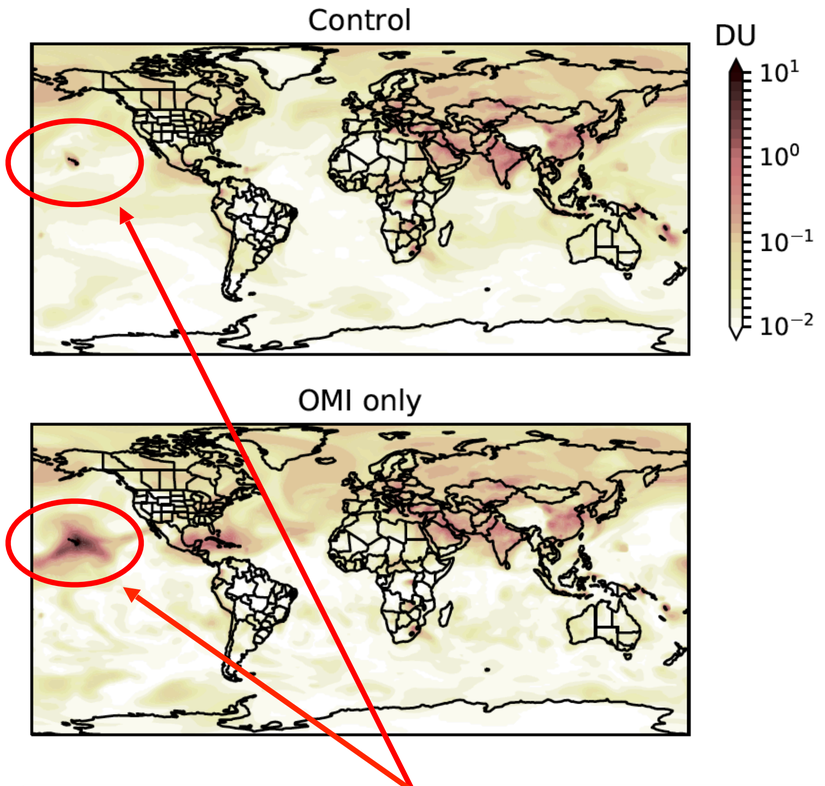
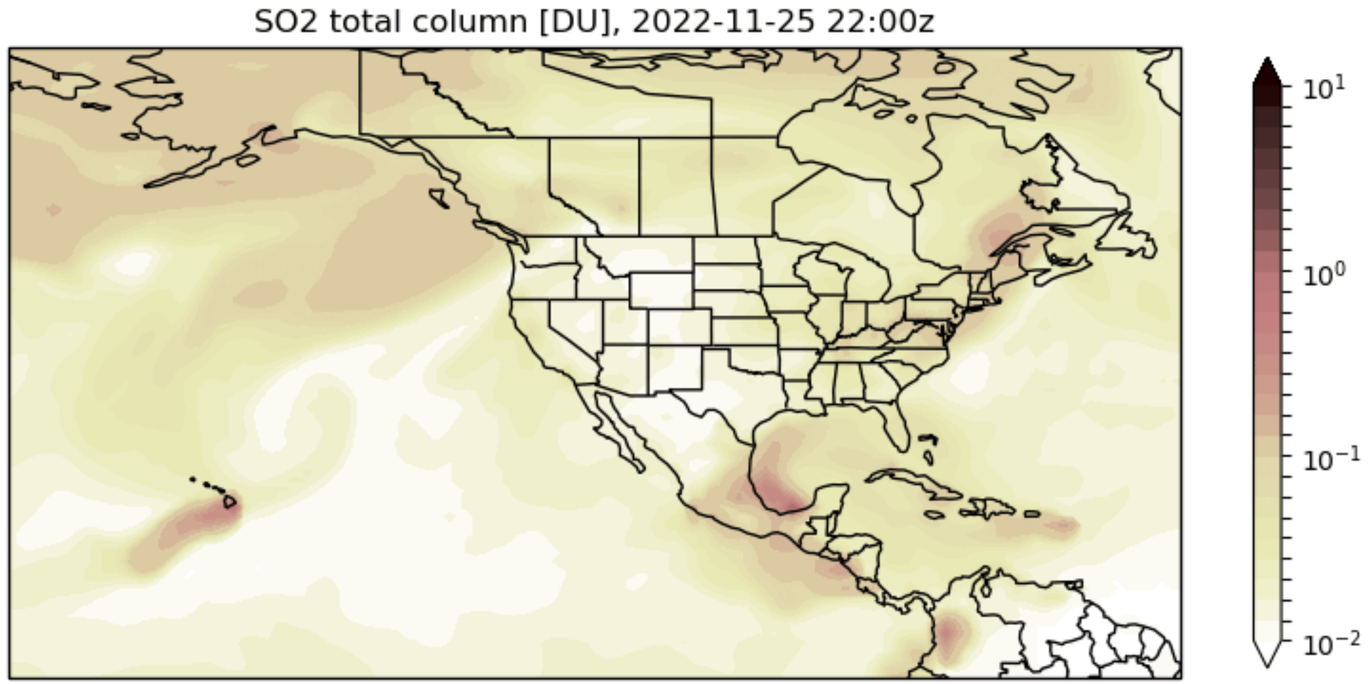
SO_2 assimilation: Mauna Loa eruption

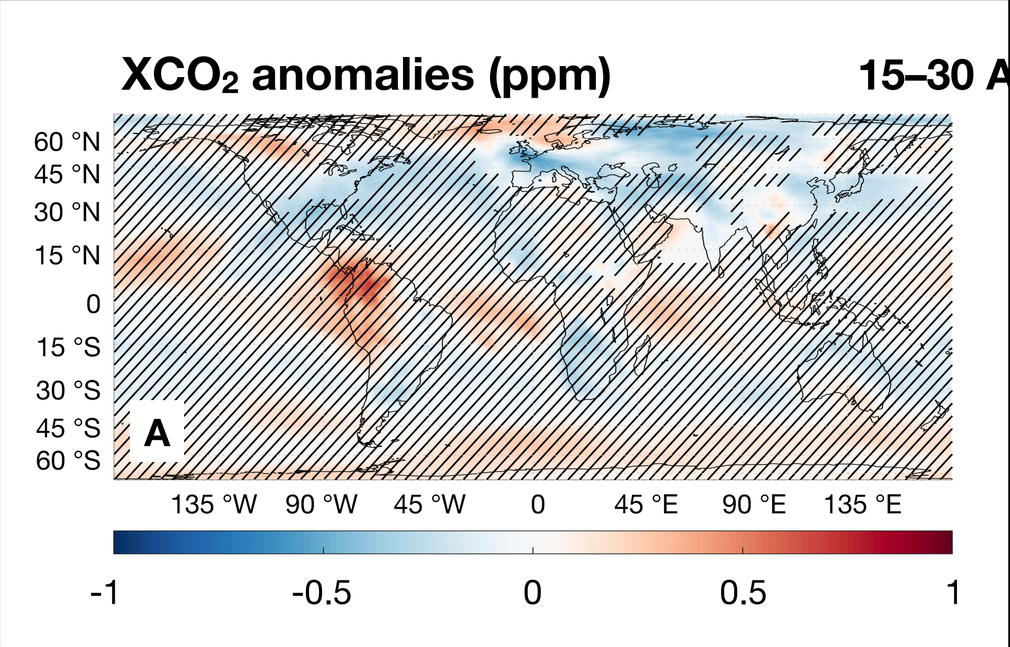
SO_2 total column, 6 Dec 2022

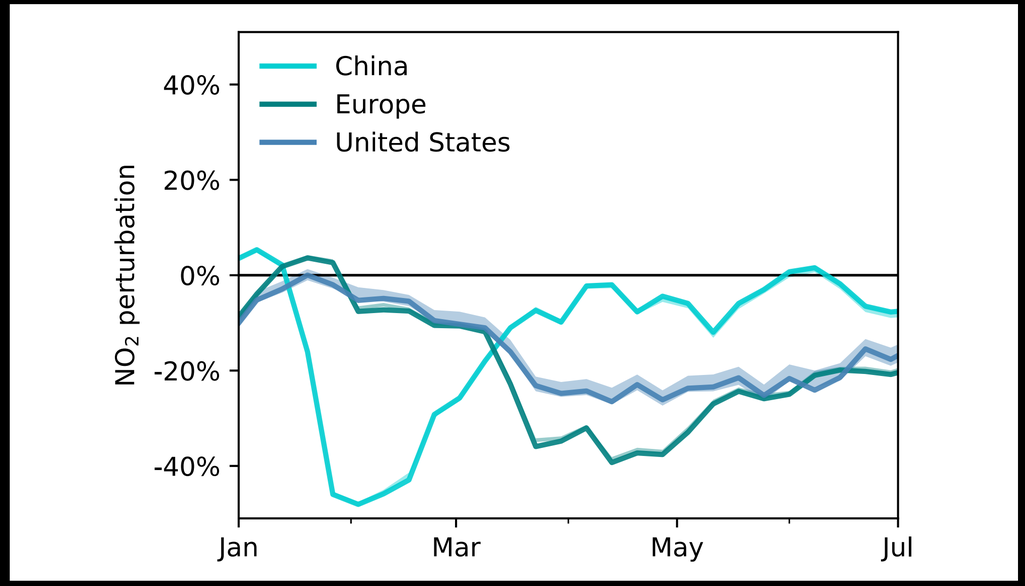


Mauna Loa eruption not simulated (top), yet still captured by assimilation (bottom)



COVID-19 CO_2, NO_2, and O_3





SCIENCE ADVANCES | RESEARCH ARTICLE

CORONAVIRUS

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from C Keller

Tomorrow's Enterprise

- State estimation systems transitioning to Joint Effort for Data assimilation Integration (JEDI)
- Joint effort of GMAO, NOAA EMC & PSL, NCAR, Navy, Air Force, and UK Met Office managed through JCSDA
- Will be the basis of future coupled ocean-atmosphere (and more) analyses, e.g., MERRA-3
- Interoperable "all-DAS" system

Conclusions

- GMAO maintains state-of-the-art Earth System modeling and data assimilation systems
- Code (GitHub), products (GES DISC), etc. publicly available and documented in literature
- Increased coupling, resolution, fidelity of constituent analyses
- GEOS CR production starting soon
- Further inter-center interoperability, coordination, and collaboration w/ JEDI