

Bridging the SAGE data gap: Toward a climate data product with ozone and water vapor data from NASA SAGE and Aura missions and NASA reanalyses



K. Emma Knowland

USRA/GESTAR

NASA Global Modeling and Assimilation Office (GMAO)

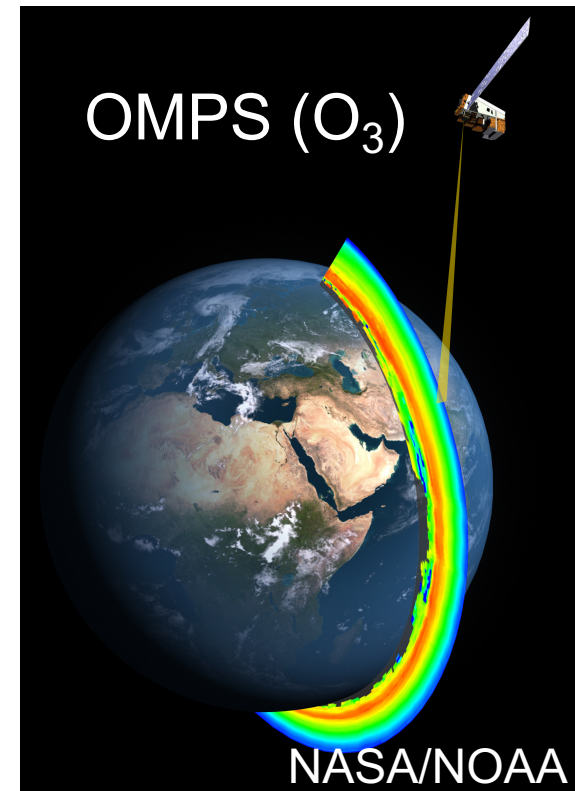
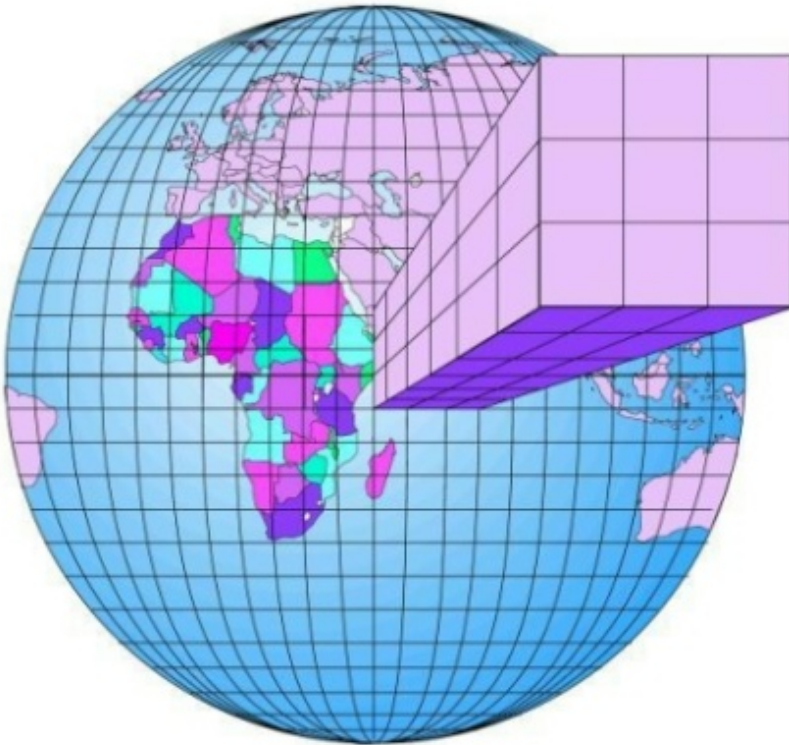
Co-Investigators

Steven Pawson (GMAO), Pam Wales (USRA/GMAO), Kris Wargan (SSAI/GMAO), Brad Weir (USRA/GMAO)



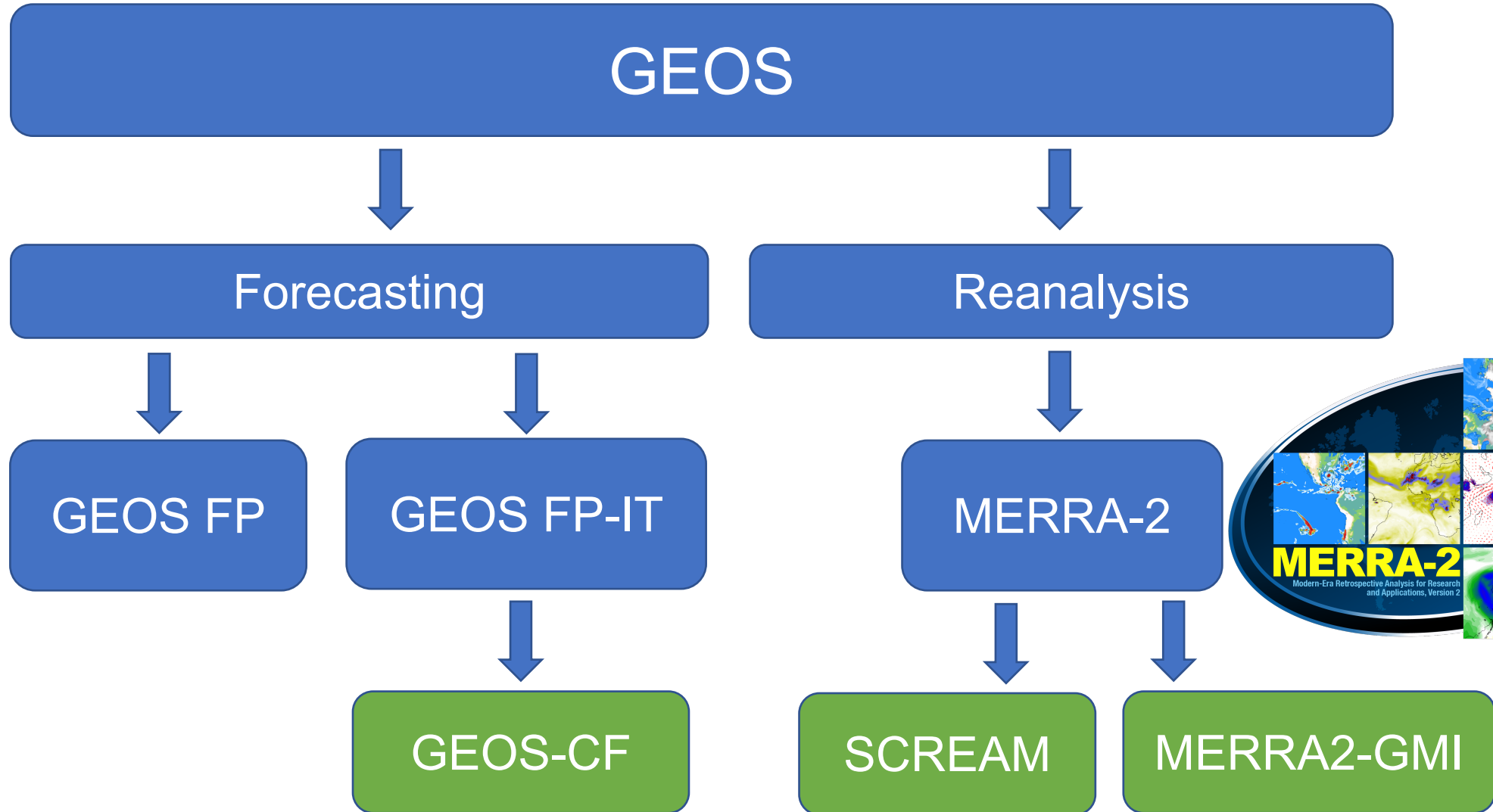
NASA GMAO global meteorology and chemistry products

GEOS



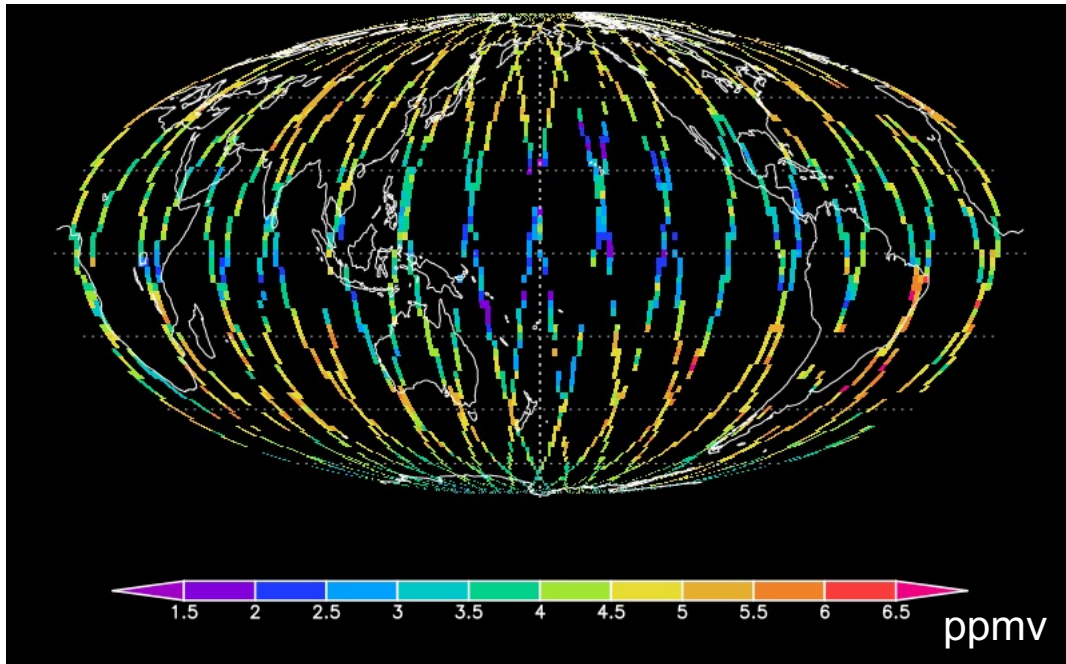
www.nasa.gov

NASA GMAO global meteorology and chemistry products

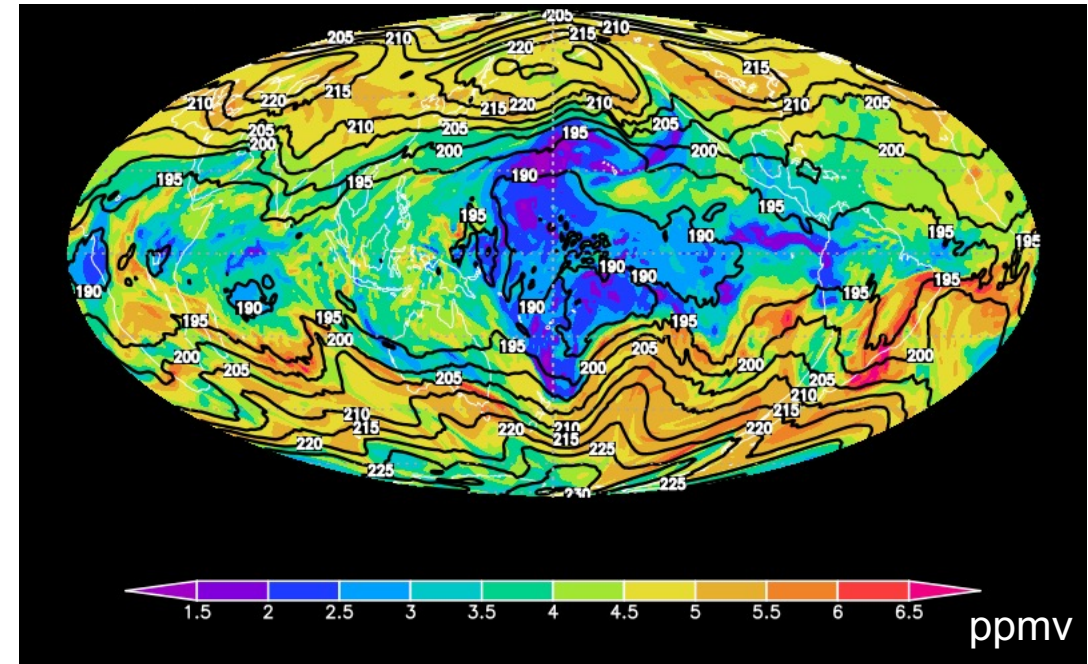


Constituent Data Assimilation

MLS water vapor at 100 hPa, 2 Jan 2016



Assimilated MLS water vapor and MERRA-2 temperature at 100 hPa, 2 Jan 2016



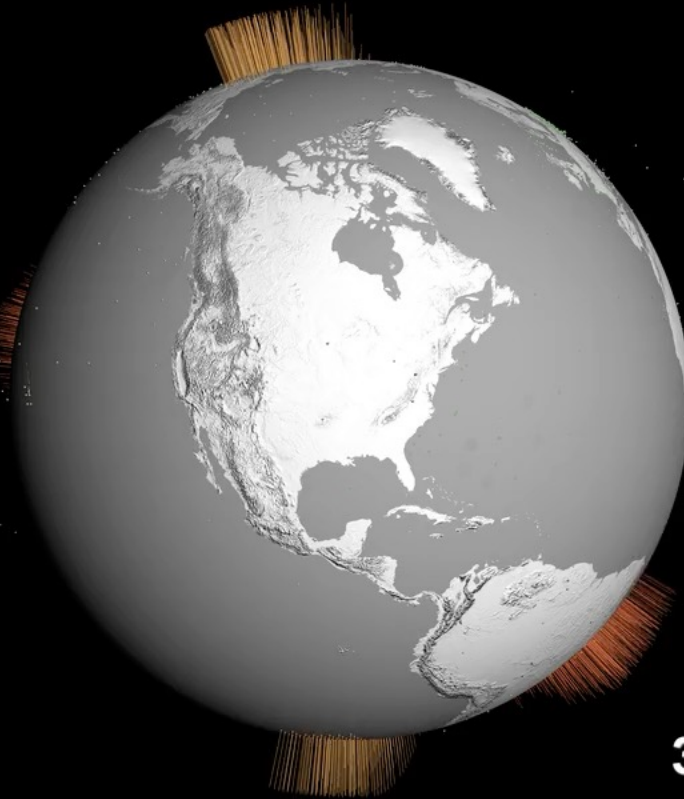
Data assimilation is a Bayesian method of combining and propagating information from observations in space and time using the governing equations and error estimates.

Figures courtesy of Kris Wargan

Changes to the observing system

1980

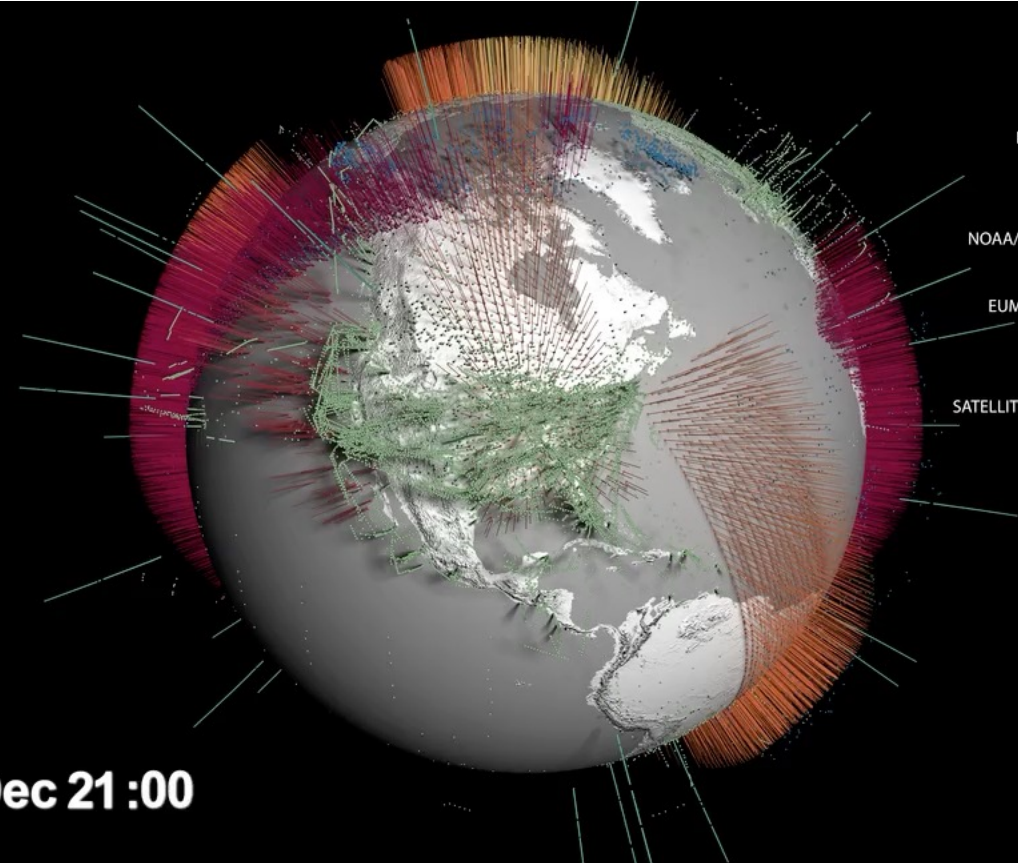
- NOAA POES
- NOAA/NASA TIROS-N
- CONVENTIONAL
- SATELLITE-DERIVED WINDS



31 Dec 21:00

2018

- EUMETSAT METOP
- NOAA GOES
- NOAA POES
- NOAA/NASA SUOMI-NPP
- NASA EOS AQUA
- EUMETSAT METEOSAT
- CONVENTIONAL
- GPS
- SATELLITE-DERIVED WINDS



<https://svs.gsfc.nasa.gov/4654>

NASA's MERRA-2 Reanalysis

- High resolution global data set
 - 50 km horizontal
0.5° latitude x 0.625° longitude
 - 72 levels up to 0.01 hPa
- Available since 1980 to a few weeks behind present
- Product of GEOS data assimilation system
 - Assimilates meteorological observations, aerosols and ozone
 - **For the ozone observing system**
 - **1980-2004: SBUV**
 - **2004-present: Profiles from MLS, Total Column from OMI**
- **Ozone chemistry is simplified production and loss rates**

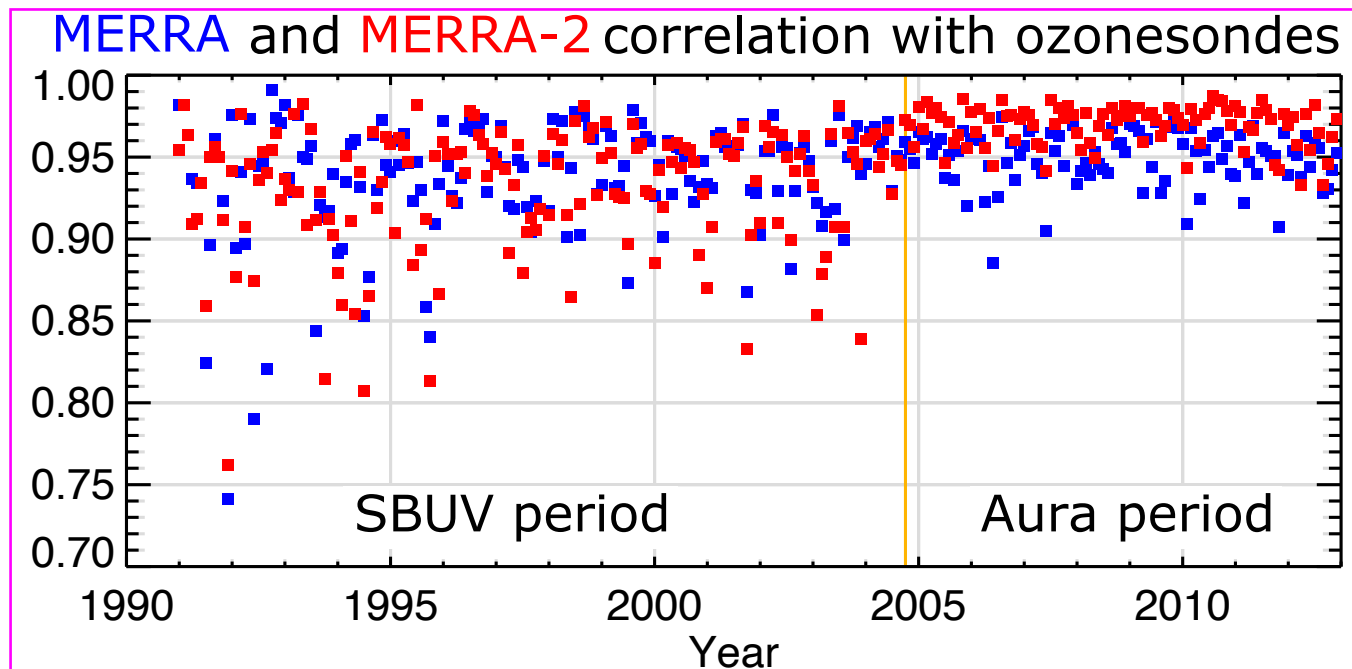
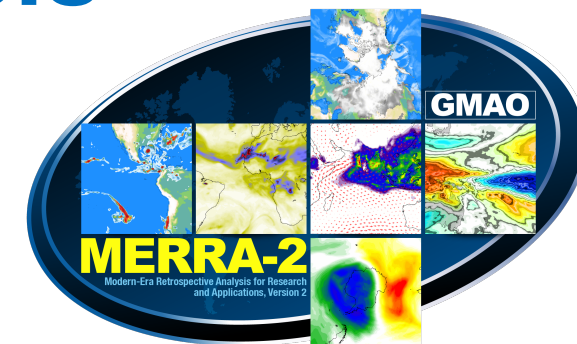
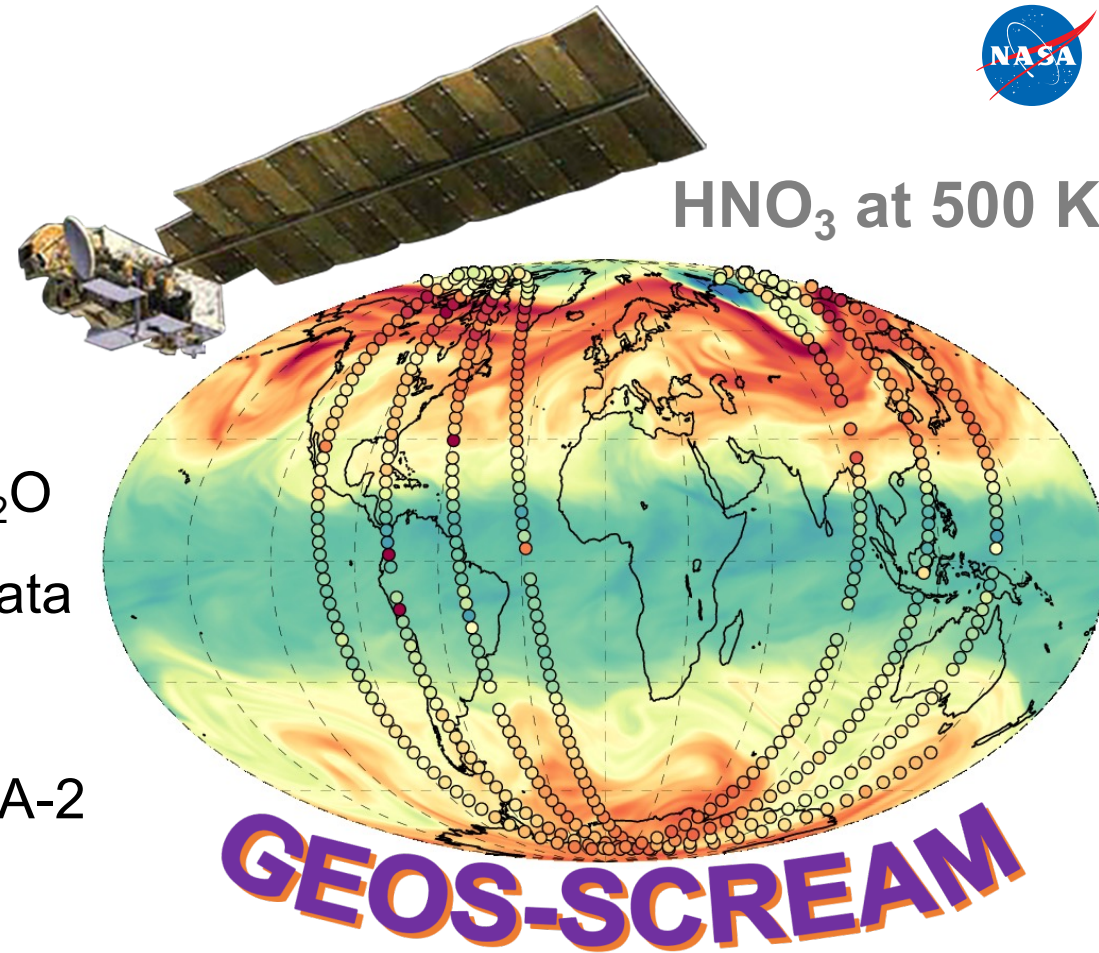


Figure from Wargan et al., 2017

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*

HNO_3 at 500 K

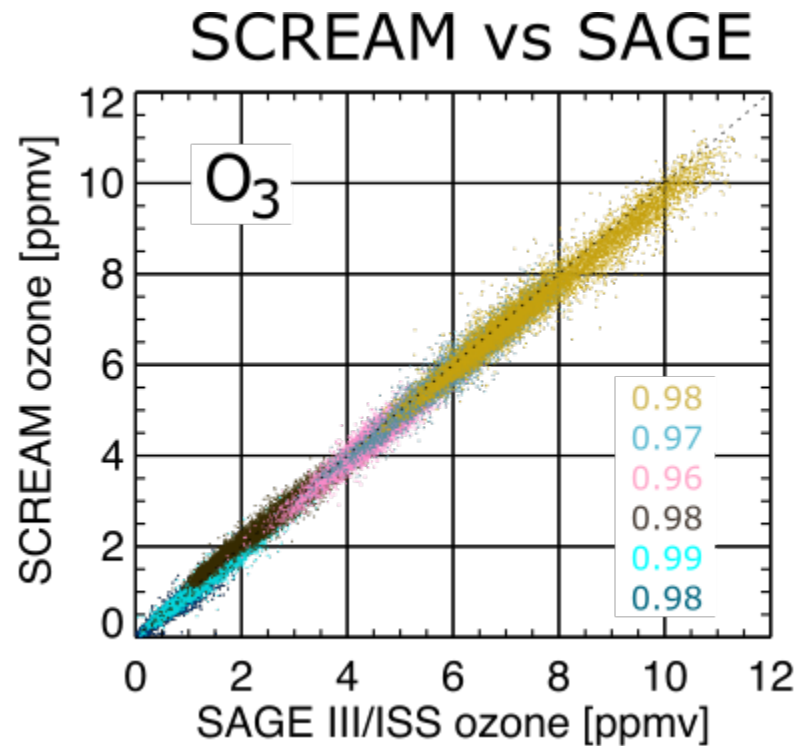
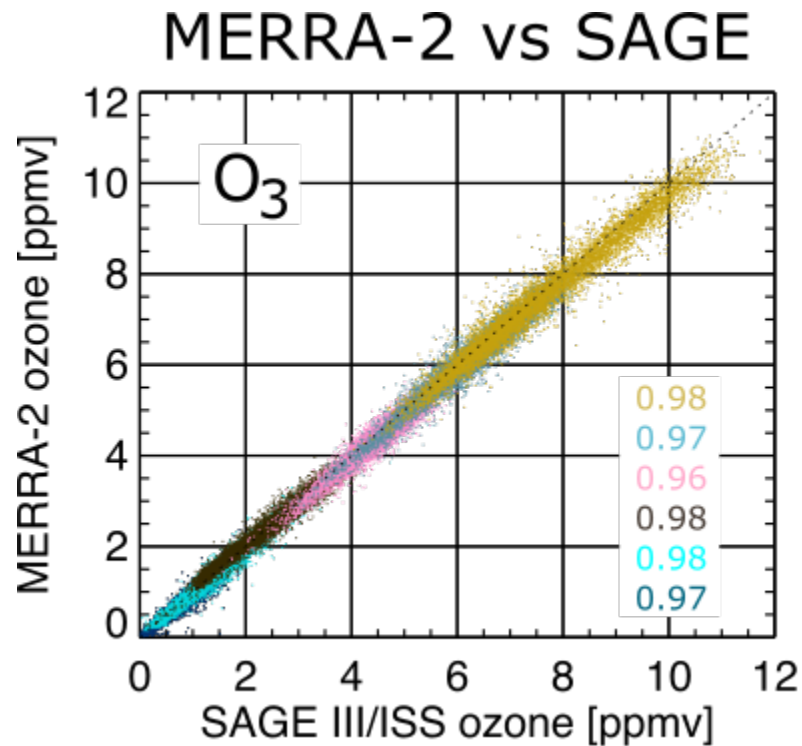


- ❑ Assimilating **MLS v4.2 ozone**, H_2O , HCl , HNO_3 , & N_2O and OMI **total ozone** using the GEOS Constituent Data Assimilation System “CoDAS”
- ❑ Constrained by assimilated meteorology from MERRA-2
- ❑ GEOS “StratChem” stratospheric-only chemistry
- ❑ Period: September 2004 – May 2021+
- ✓ Close agreement with ACE-FTS and GLORIA data and the BRAM2 reanalysis

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>

Motivation

It is essential for trend and climate analysis to have consistent well-constrained data products such as reanalyses



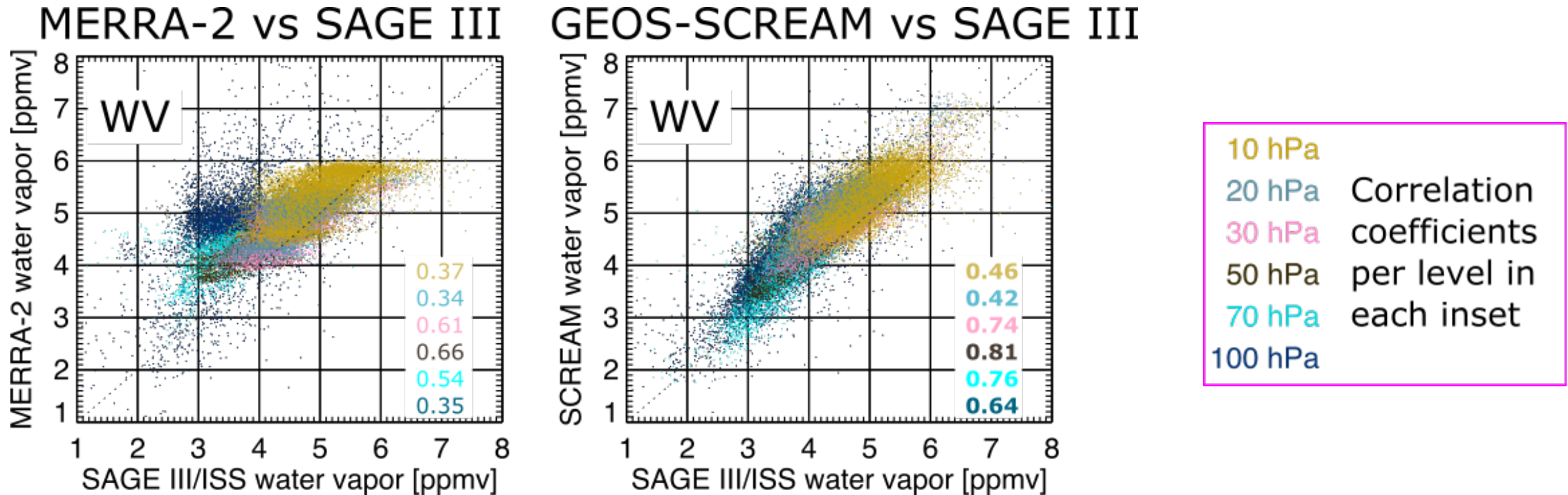
10 hPa
20 hPa
30 hPa
50 hPa
70 hPa
100 hPa

Correlation
coefficients
per level in
each inset

1. Despite differences in the complexity of stratospheric ozone chemistry, the analyzed ozone in both reanalyses have near perfect correlation with co-located 2018 SAGE III/ISS ozone.

Motivation

It is essential for trend and climate analysis to have consistent well-constrained data products such as reanalyses



2. Reanalysis stratospheric water vapor (“WV”) historically poor without an observational constraint.

Bridging the SAGE data gap

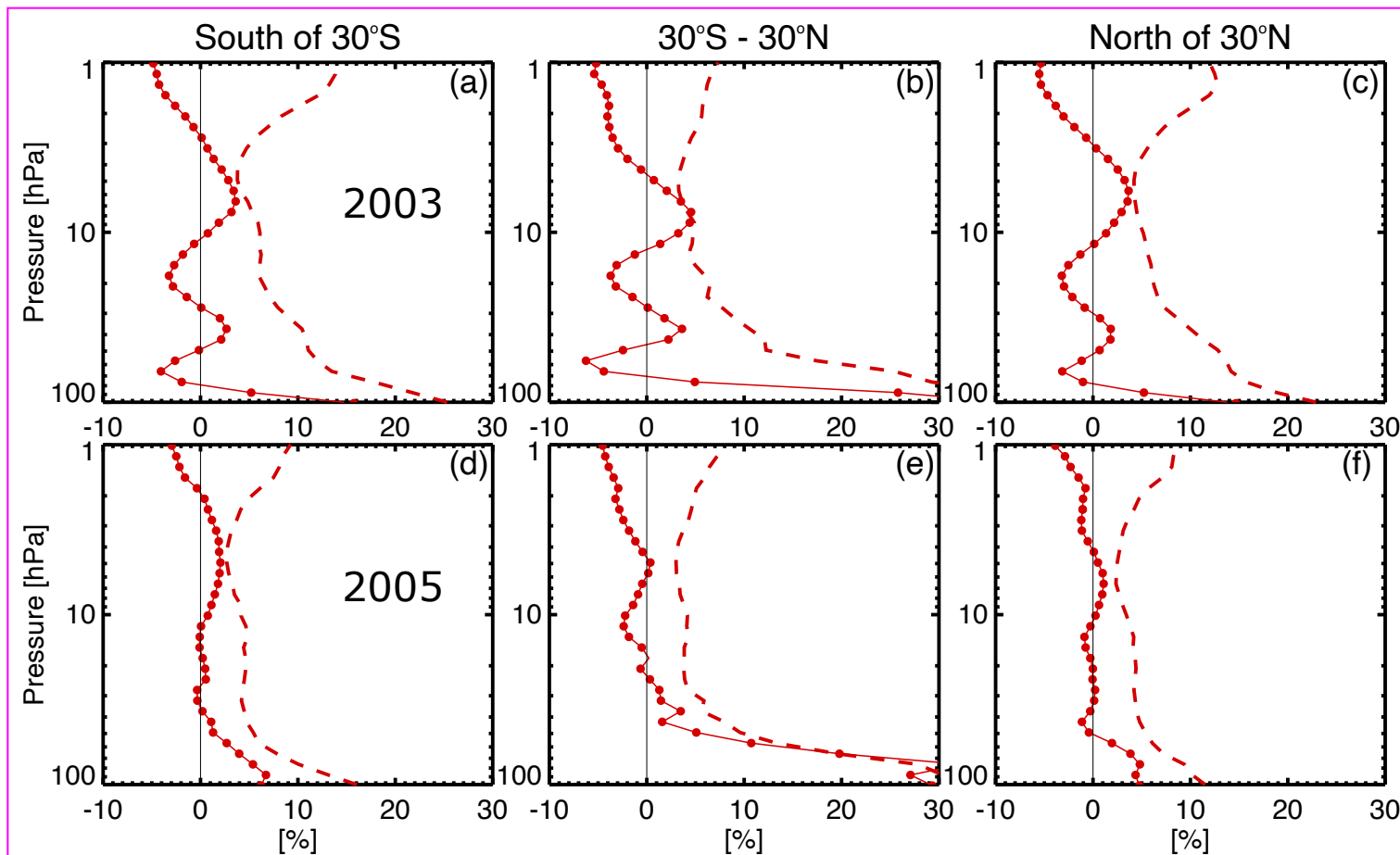
We will use NASA's uniformly-gridded, global GEOS model and DAS products to bridge the gap between the earlier SAGE missions and the SAGE III/ISS products.

- A combination of GEOS model and DAS products constrained by satellite retrievals aboard NASA's Aura satellite, has great potential to characterize O₃ and water vapor (WV) distribution, trends, and variability from the SAGE II mission through SAGE III/ISS observations.
- The assimilation of SAGE WV and O₃ is now possible in the CoDAS framework to carry-on the trend and climate assessments after the Aura mission.

Scientific Objectives

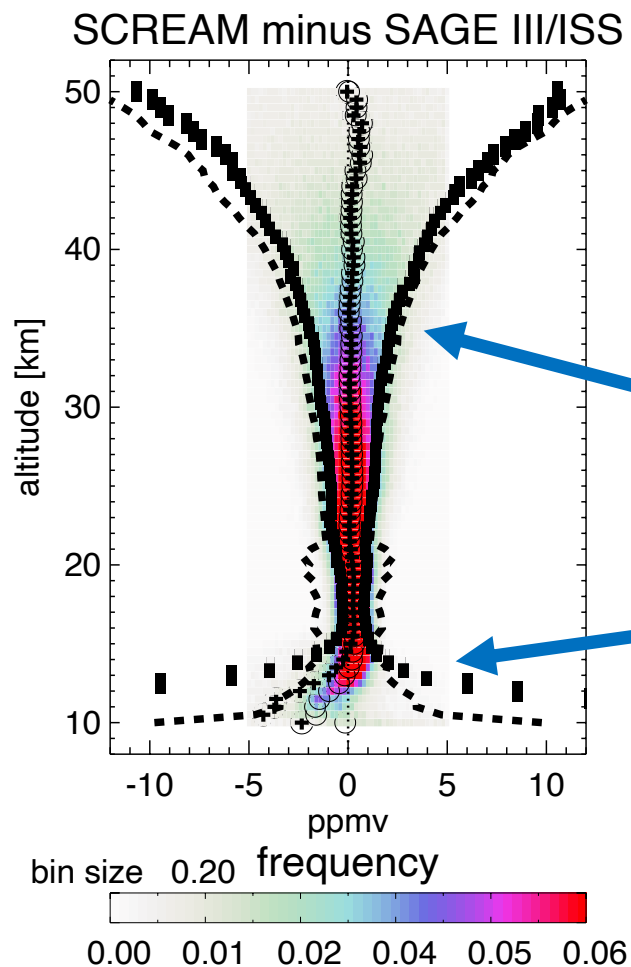
1. Statistical trend analysis of O₃ and WV profiles

- We will conduct a statistical analysis of SAGE III and SAGE II observational data sets with the corresponding analyzed O₃ and WV from MERRA-2 and GEOS-SCREAM.



MERRA-2 O₃ compared to SAGE II O₃ from Wargan et al., 2017: mean difference (closed circles) and standard deviation (dashed lines)

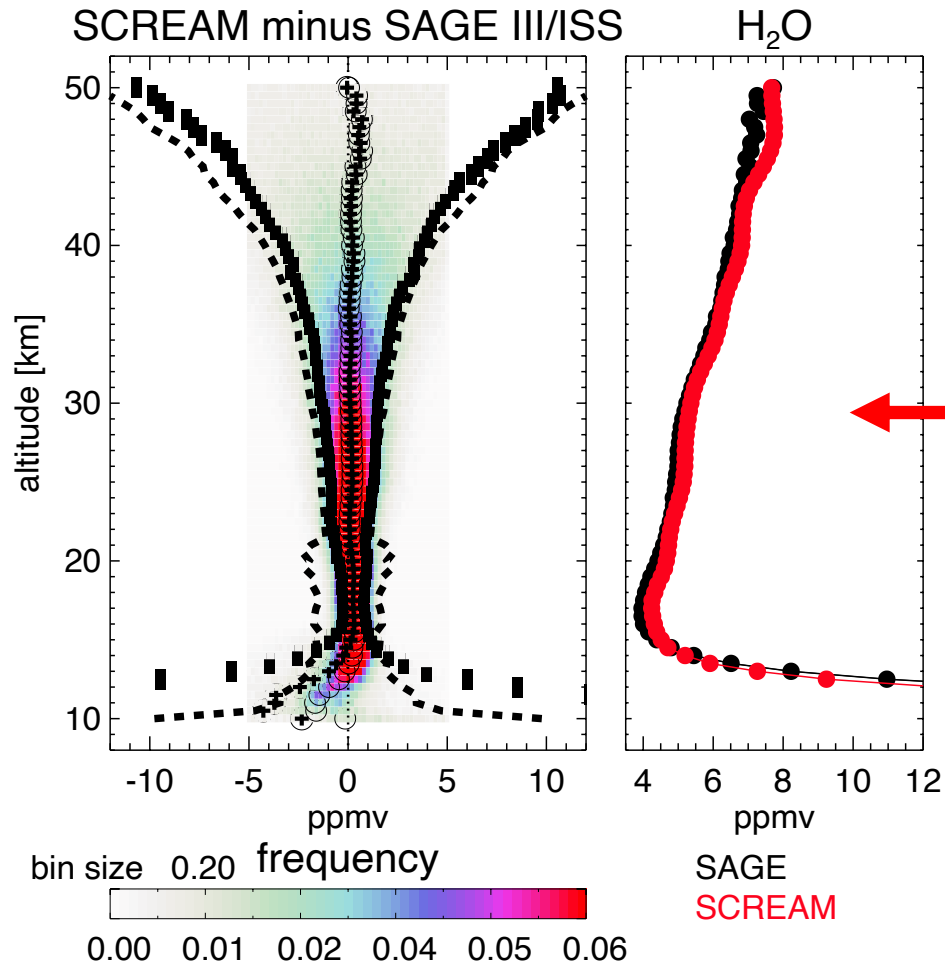
2018 SAGE III/ISS water vapor profiles compared to GEOS-SCREAM



Annual Global Mean stratospheric Water Vapor from the SCREAM reanalysis agrees well with SAGE III/ISS for 2017 through 2020 (*only 2018 shown here).

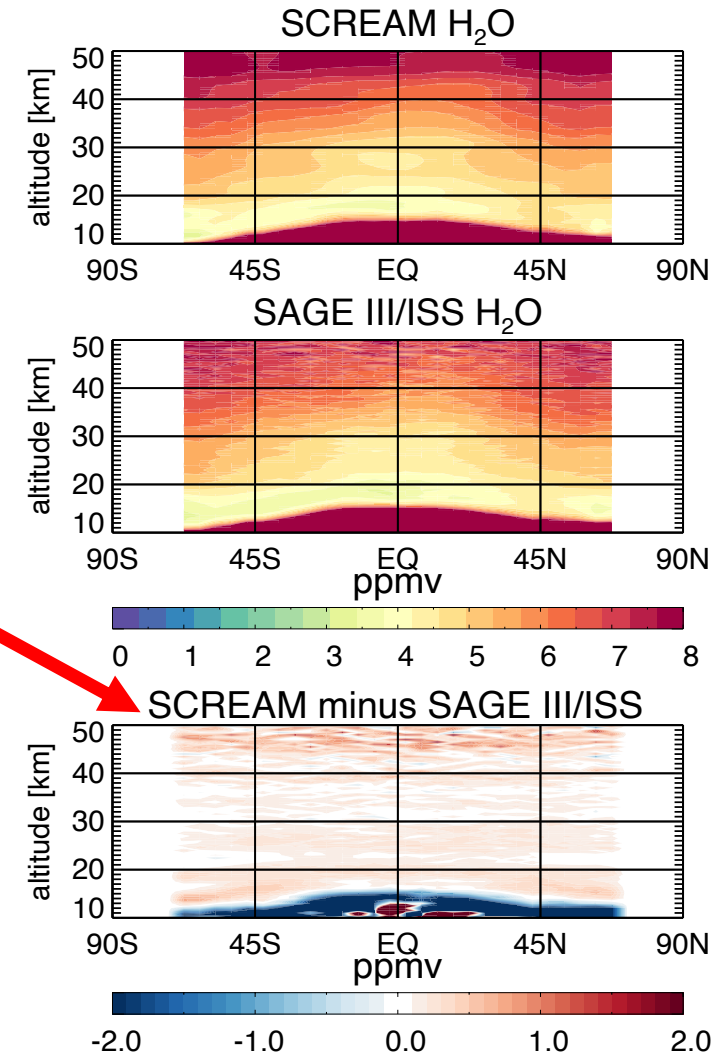
Instrument precision from SAGE III/ISS (dotted lines, left) agree well with the standard deviation (dashed lines, left) of the instrument.

2018 SAGE III/ISS water vapor profiles compared to GEOS-SCREAM

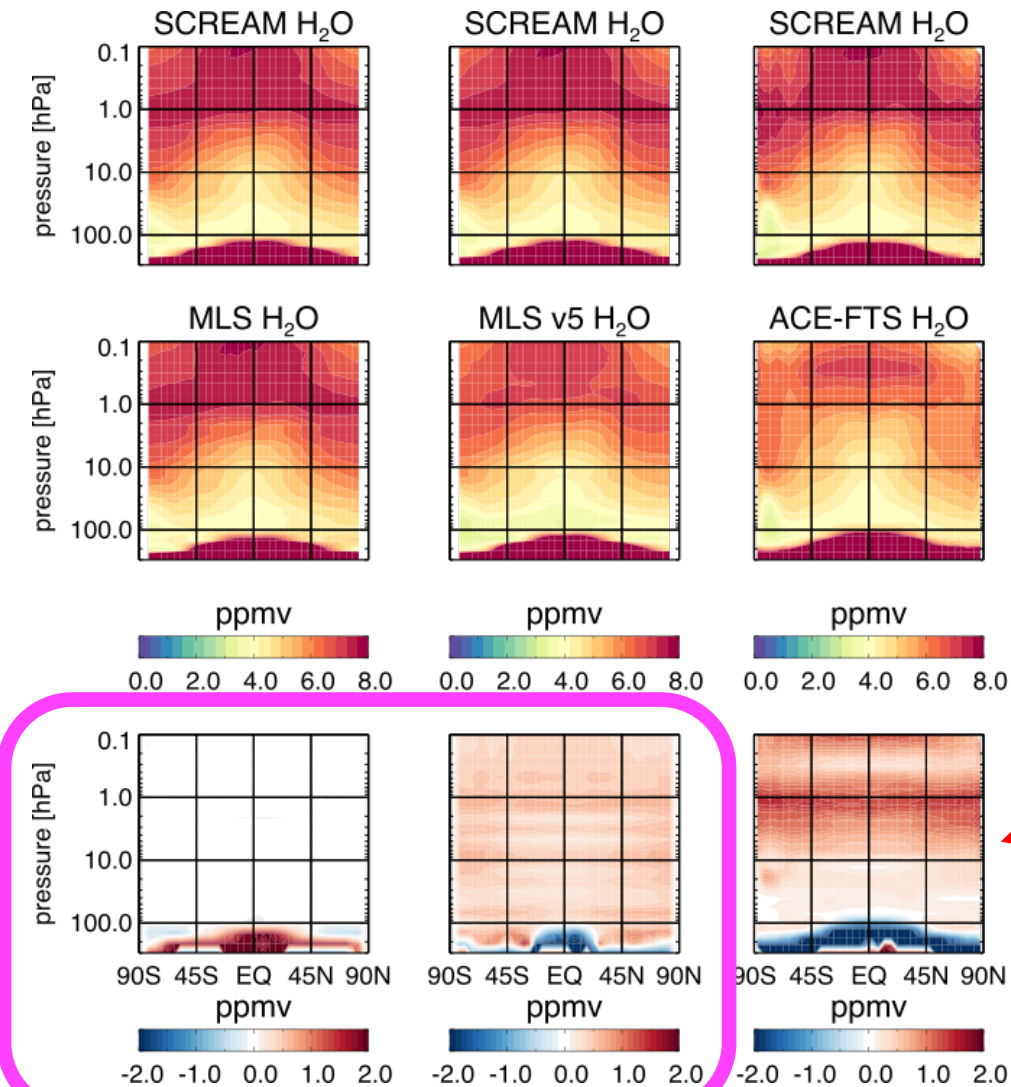


Annual Global Mean stratospheric Water Vapor from the SCREAM reanalysis agrees well with SAGE III/ISS for 2017 through 2020 (*only 2018 shown here).

Positive bias throughout stratosphere in **SCREAM** is seen at **all** latitudes.

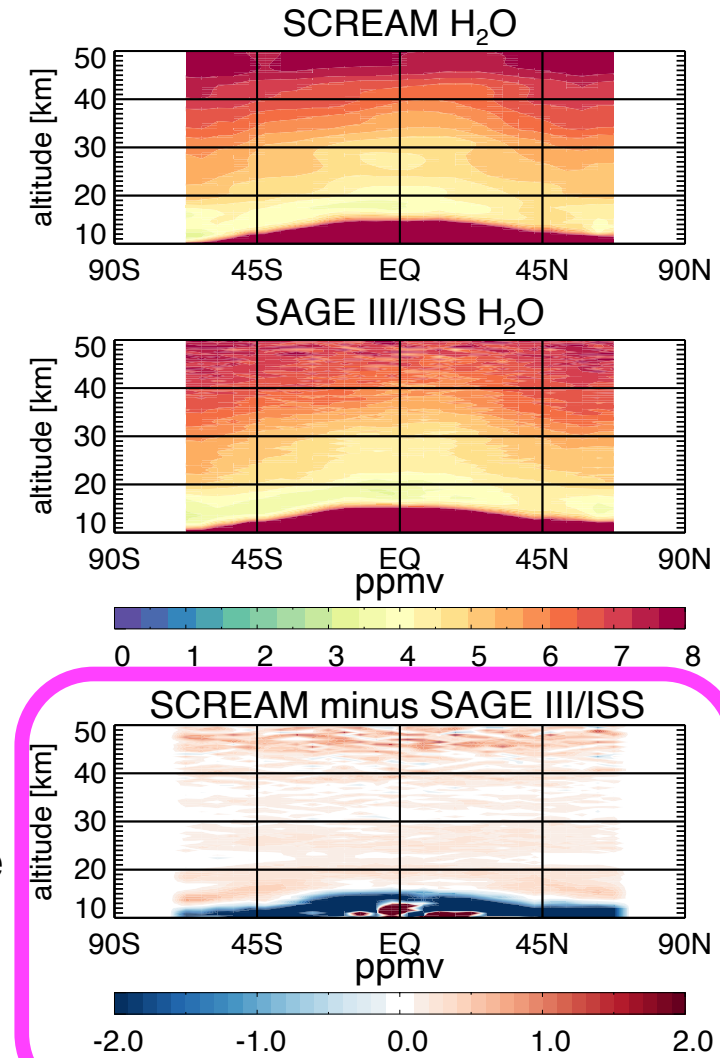


2018 SAGE III/ISS water vapor profiles compared to GEOS-SCREAM

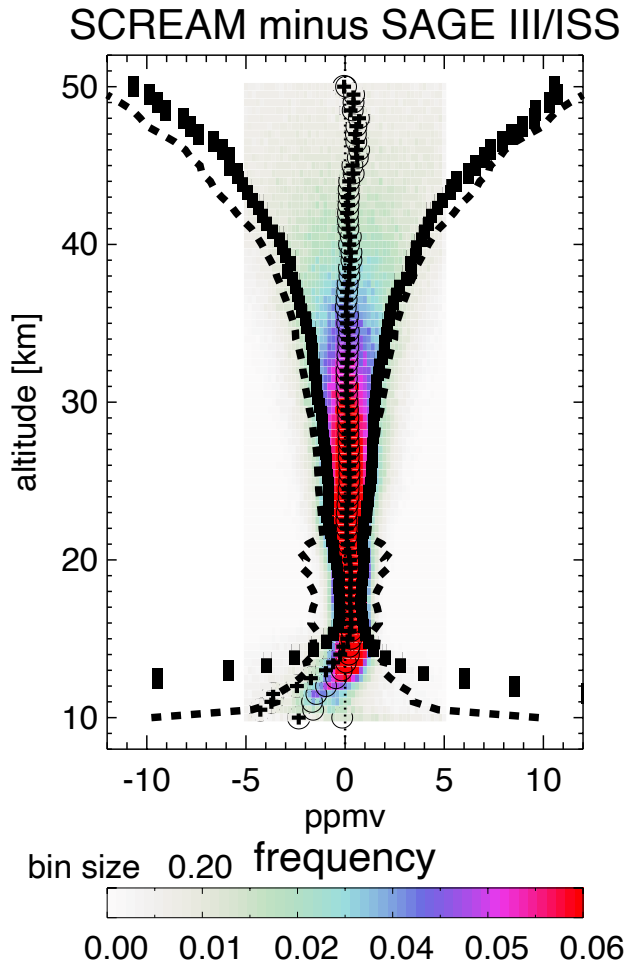


This high bias throughout stratosphere in **SCREAM** is driven by the assimilation of MLS v4.2 (right) instead of the now available MLS v5 (middle), which corrects for the bias during the entire record (2005-2020 plotted on left) (see also Livesey et al 2021 ACP <https://doi.org/10.5194/acp-21-15409-2021>).

SCREAM compared against ACE-FTS indicates the reanalysis is even wetter in the stratosphere than independent observations (2005-2020).

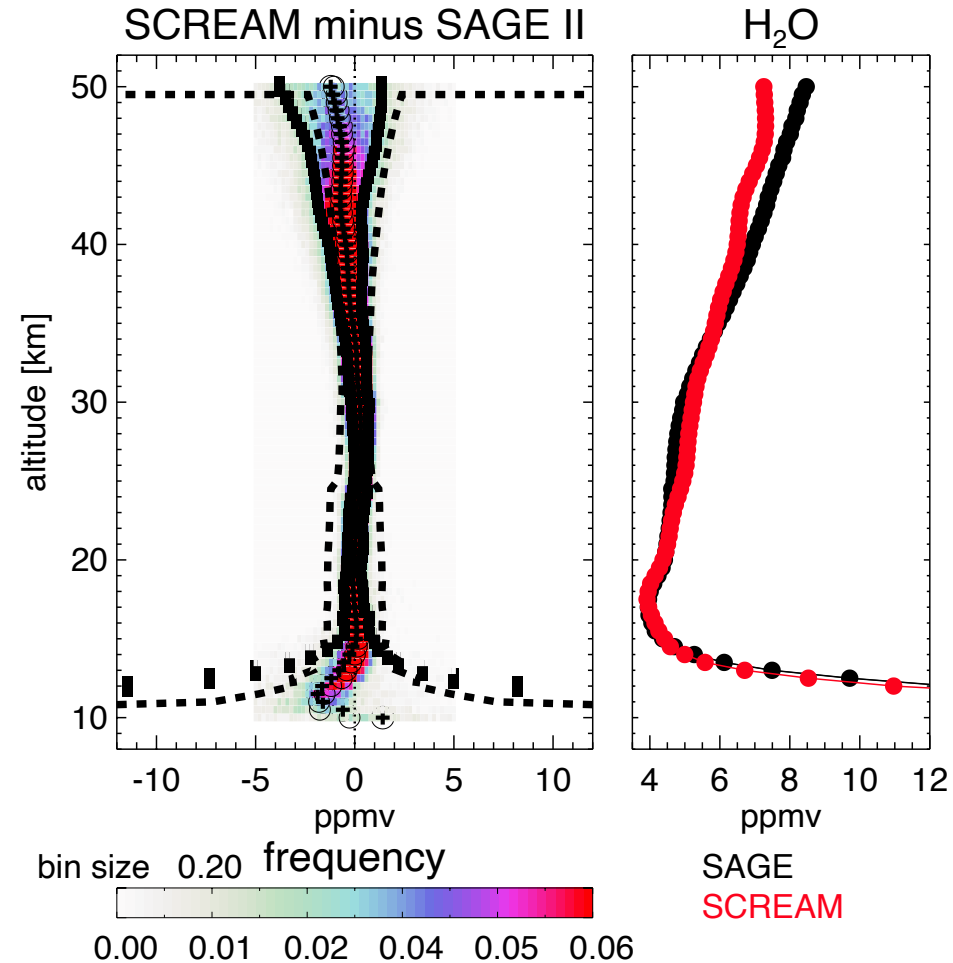


2018 SAGE III/ISS & 2005 SAGE II water vapor profiles compared to GEOS-SCREAM

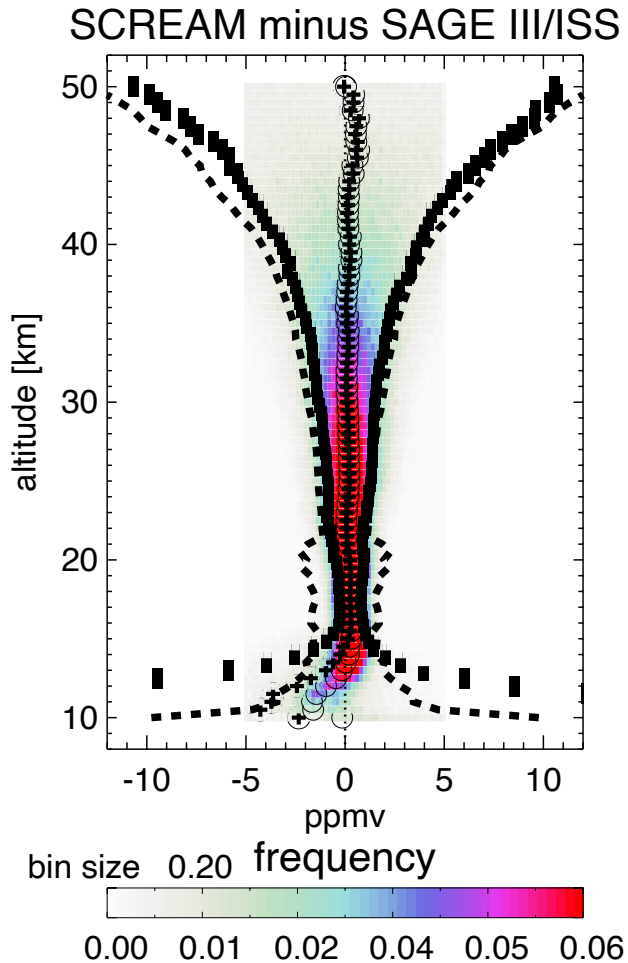


Need to bridge the gap from the earlier SAGE II and SAGE III/Meteor-3M.

In 2005, there is less spread in water vapor between SCREAM and SAGE II, although the GEOS product is bias low at higher altitudes.

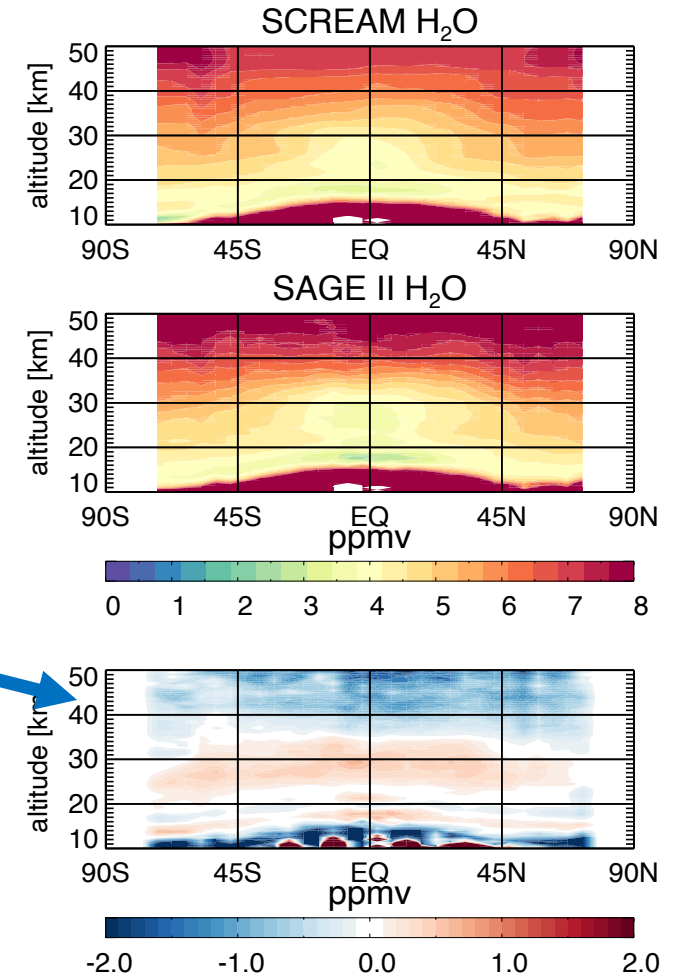


2018 SAGE III/ISS & 2005 SAGE II water vapor profiles compared to GEOS-SCREAM



Need to bridge the gap from the earlier SAGE II and SAGE III/Meteor-3M.

In 2005, there is less spread in water vapor between SCREAM and SAGE II, although the GEOS product is bias low at higher altitudes, throughout the globe.



Scientific Objectives

1. Statistical trend analysis of O₃ and WV profiles

- For such an assessment to be meaningful we will have to consider the few discontinuities in the MERRA-2 observing system. We will evaluate using both the GEOS-SCREAM analyzed O₃, which uses MLS v4.2 throughout, and the M2-GMI simulated O₃ (no O₃ assimilation) to bias correct the MERRA-2 O₃ for the 2015 MLS version update and the 2016 MLS pressure level update, both occurring prior to the SAGE III/ISS period.

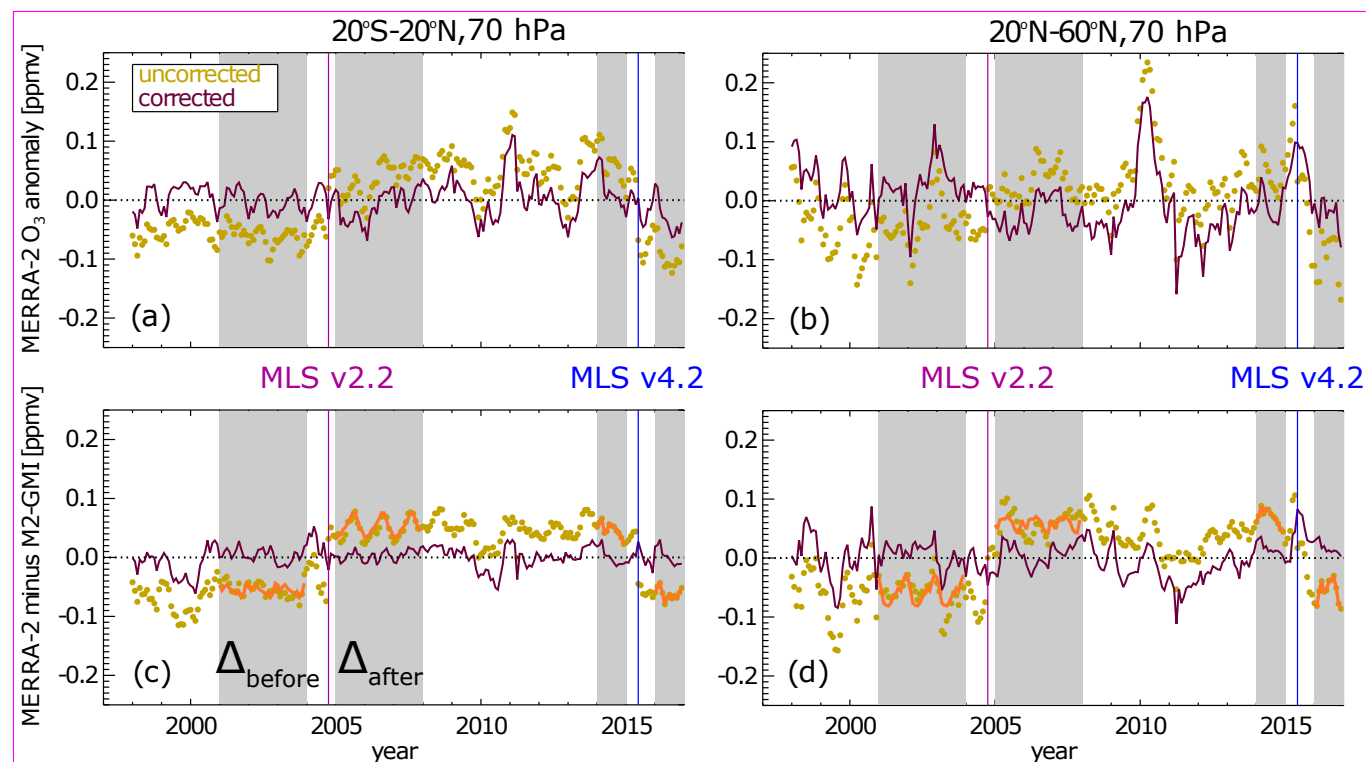
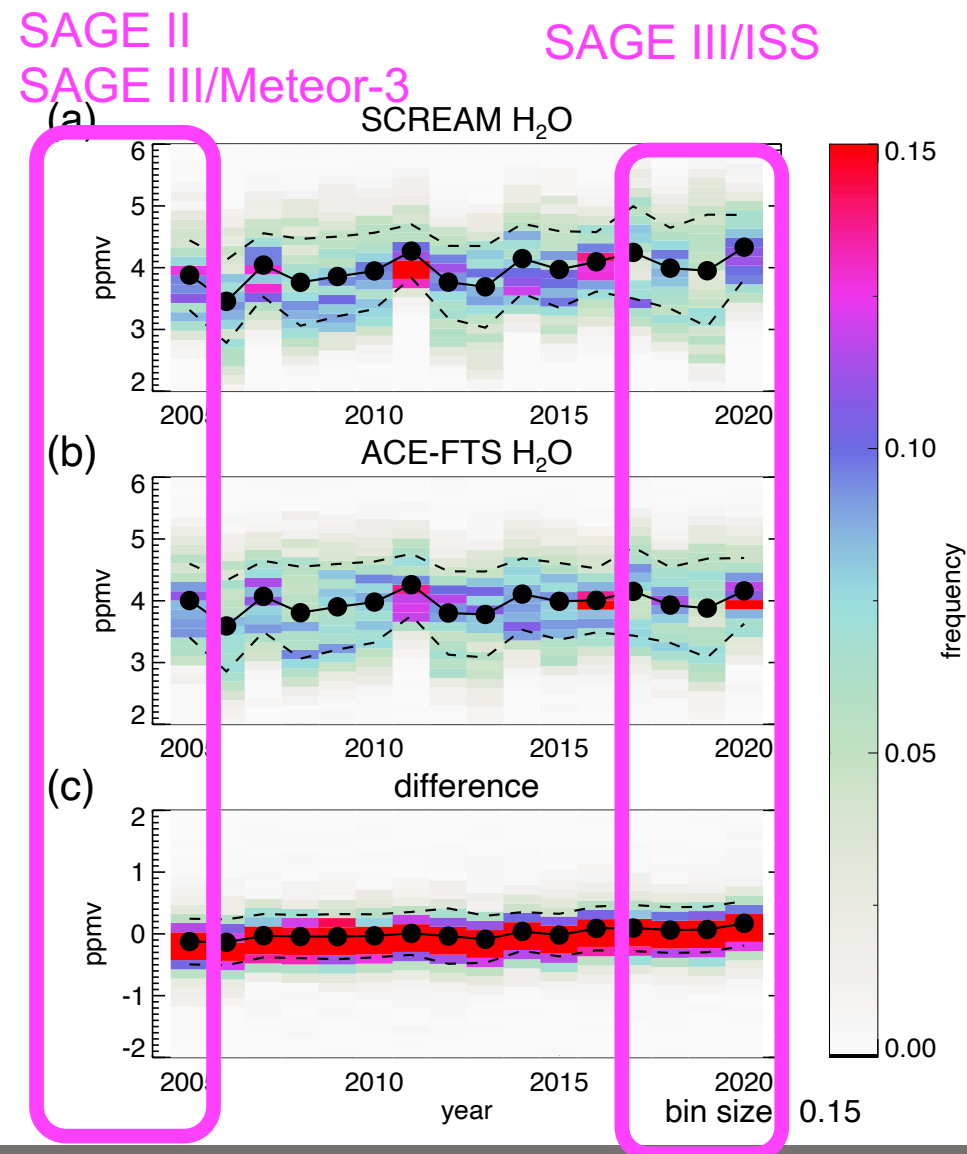


Figure adapted from Wargan et al., 2018

Scientific Objectives

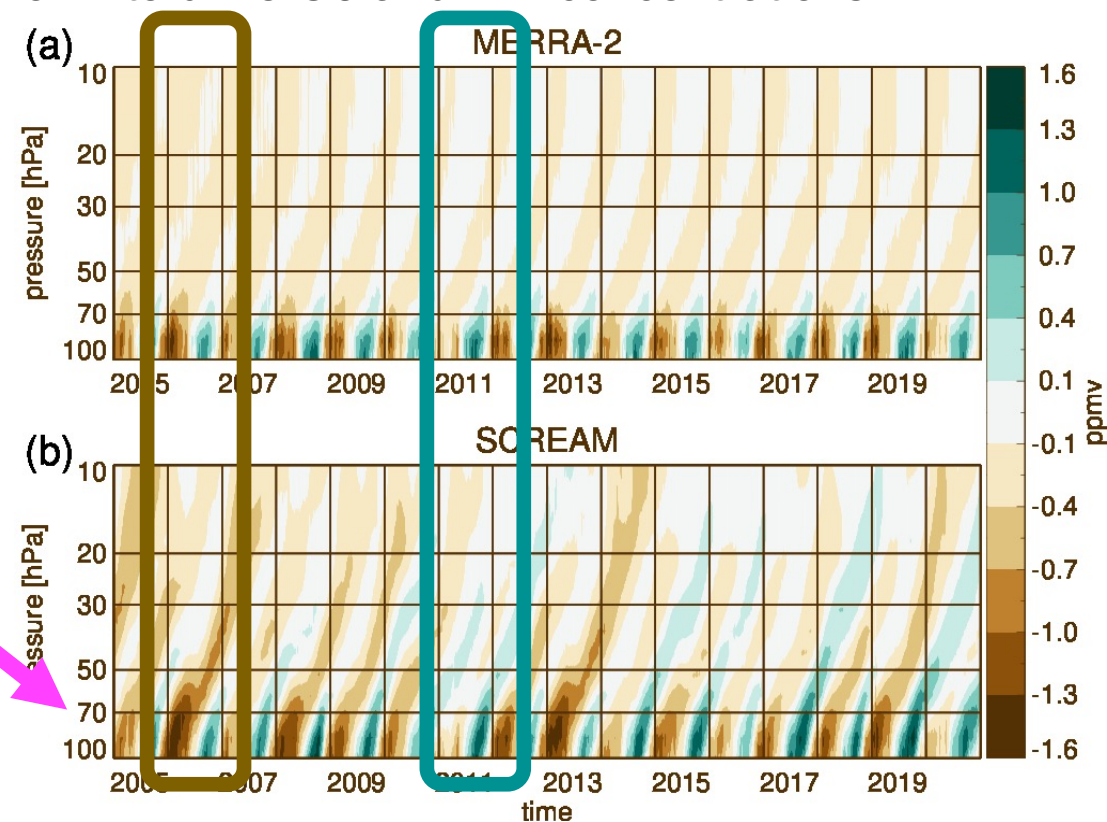
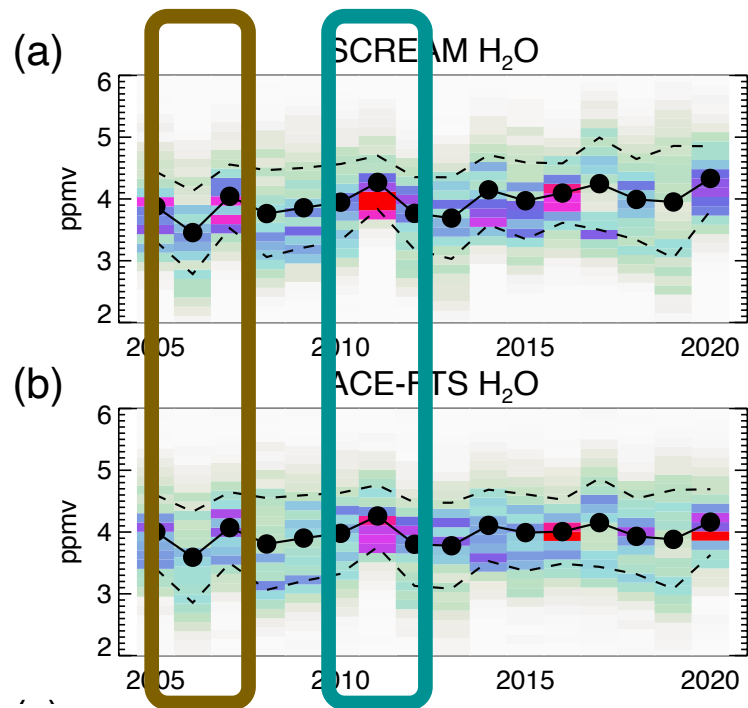
1. Statistical trend analysis of O₃ and WV profiles
 - For WV, a decrease in the stratosphere during the early 2000s and its impact on climate is documented but the long-term trend for WV is contested depending on the observation source -- NOAA's frost-point hygrometers (FPH) or single or merged-satellite datasets.
 - In order to evaluate the long-term trends in O₃ and WV, time series of monthly means and the root-mean-square error from the corrected reanalysis concentrations for different vertical levels will be examined.



Scientific Objectives

2. Process-based analysis by meteorological phenomenon

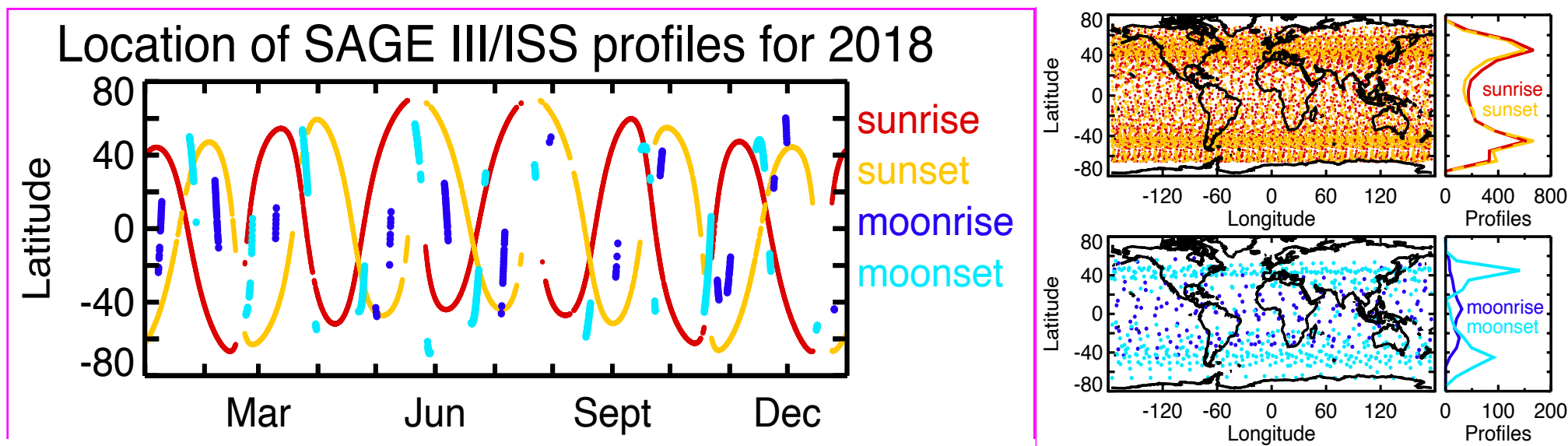
- We will look at large-scale teleconnection patterns and circulation pathways to ensure we identified trends correctly from signals of natural variability. Through this analysis with combined chemistry and meteorology products, we can identify possible circulation changes during a variety of dynamical conditions known to drive O₃ and WV concentrations.



Scientific Objectives

3. Chemical data assimilation of O₃ and WV profiles

- SAGE data is likely suitable for assimilation into GEOS using the CoDAS framework.
- Results will be evaluated against independent observations including other satellite retrievals, sonde and lidar measurements

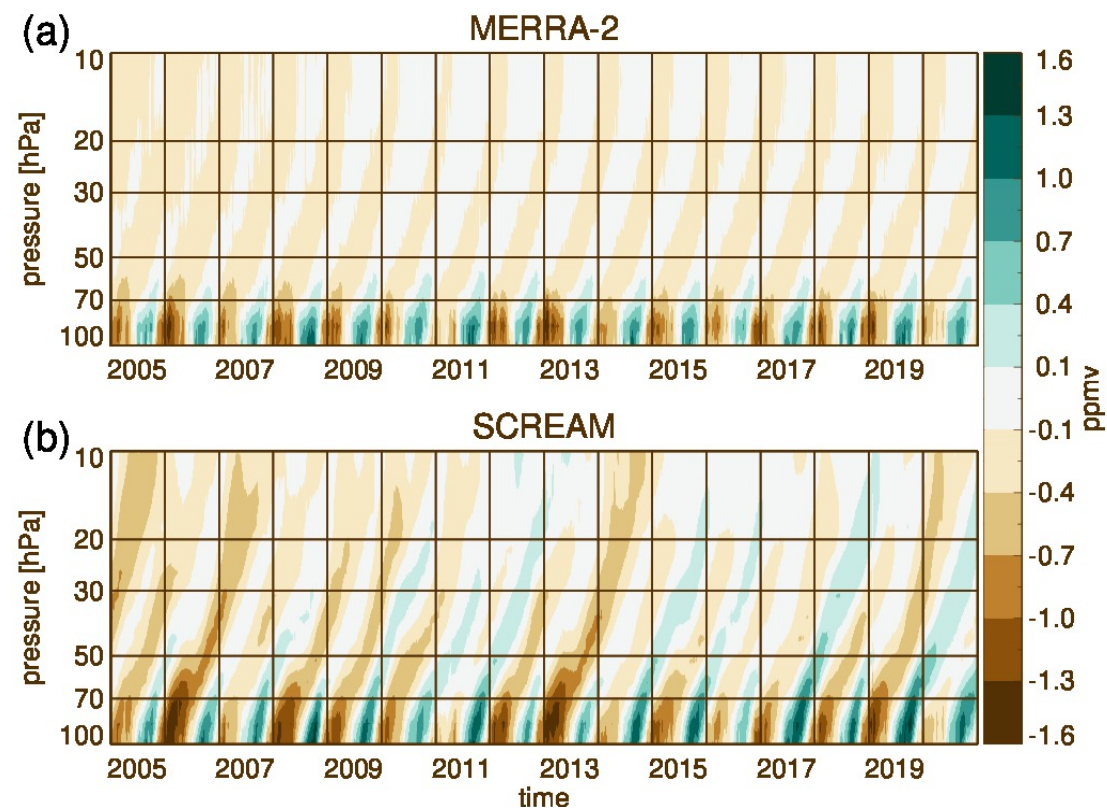


Scientific Objectives

3. Chemical data assimilation of O₃ and WV profiles

- Same set up as GEOS SCREAM

1. SAGE + AURA: SAGE O₃ and WV and MLS v5 profiles and OMI TCO
2. SAGE post-Aura: SAGE O₃ and WV with alternative limb-sounding profiles and total ozone (e.g., OMPS)
3. SAGE-only post-Aura: SAGE O₃ and WV
4. Coupled Chemistry and Meteorology Model (no CoDAS; similar to MERRA2-GMI)





Thank you!