National Aeronautics and
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Developing a continuous ozone record through the SAGE and Aura satellite missions with NASA reanalysis products

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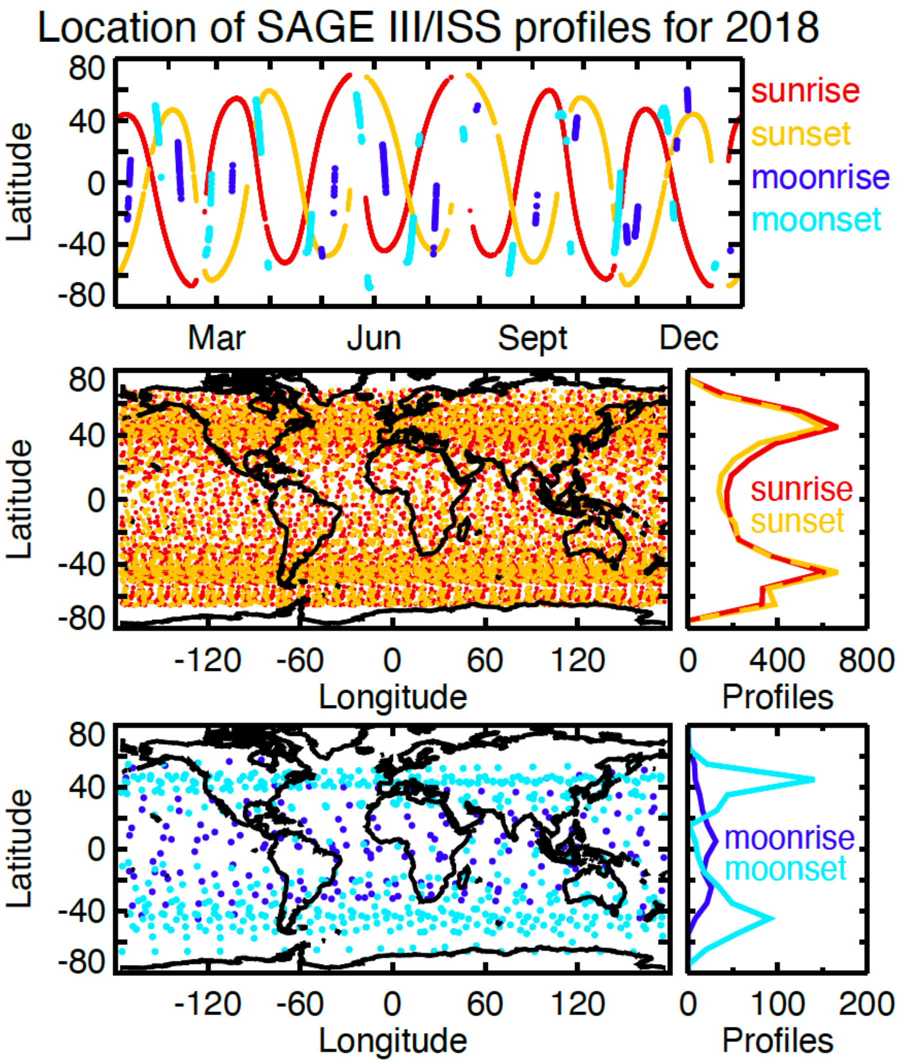
Background and Research Objectives

- Propose connecting the gap between SAGE II and SAGE III/ISS instruments using NASA reanalysis O_3 products
  - 17-year gap between SAGE II and SAGE III/ISS instruments
  - Account for changes in the reanalysis observing system

- Data assimilation produces global, vertically resolved fields by combining observations from multiple sensors
  - Strong theoretical foundation
  - Less sensitive to sampling biases and orbital drifts than merged observation datasets



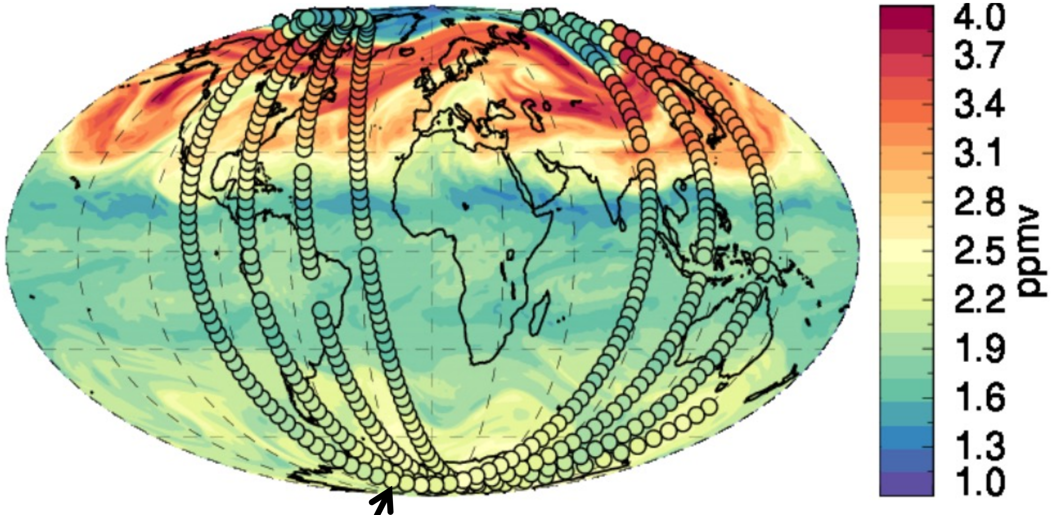
MERRA-2 Background

- High resolution global dataset
  - 50 km horizontal resolution (0.5º latitude × 0.625º longitude)
  - 72 vertical levels up to 0.01 hPa

- Product of the GEOS data assimilation system
  - Assimilates aerosol optical depth, ozone, and meteorological observations
  - Simplified ozone production and loss rates

- Ozone observing system:
  - 1980 – 2004: SBUV instruments
  - 2004 – present: Aura MLS profiles and OMI total column

Reanalysis O_3 at 500 K potential temperature level



Wargan et al. (2023)

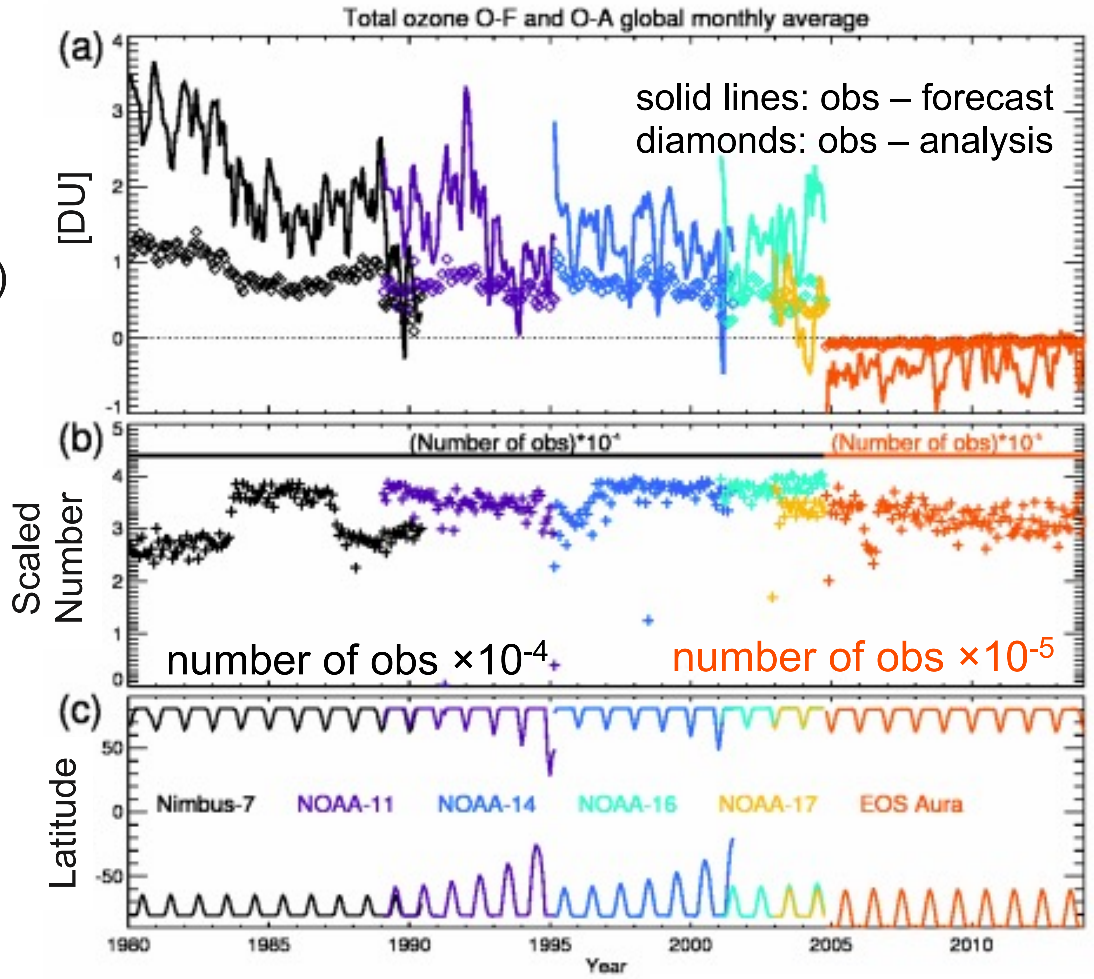
Aura MLS observations

MERRA-2: Modern-Era Retrospective Analysis for Research and Applications, version 2 (Gelaro et al., 2017)

Changes in MERRA-2 Observing System

- Transition to Aura O_3 observations in 2004
  - SBUV instruments 1980 – 2004
  - Aura MLS and OMI 2004 – present
  - Introduced a discontinuity in record with respect to SAGE II record (Wargan et al., 2017)

- Account for changes in the MERRA-2 observing system
  - Transition to Aura O_3 observations in 2004 using a chemical model
  - Investigate impact of meteorological updates in 1995 and 1998 using SAGE II



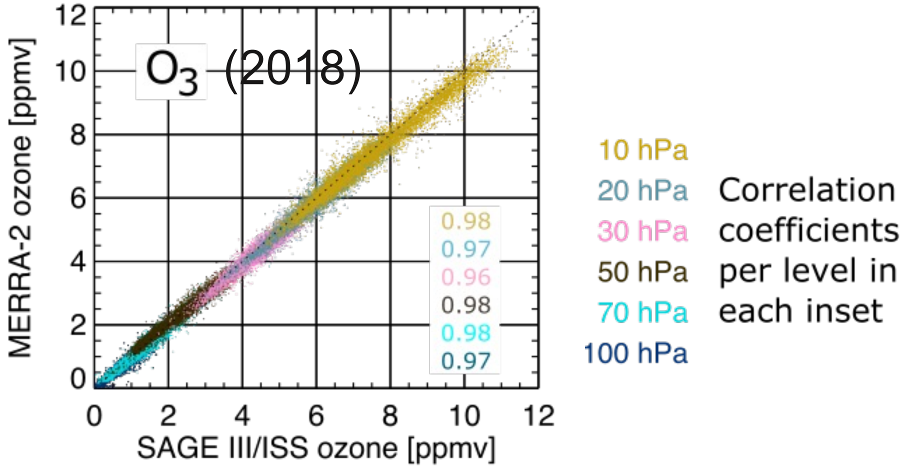
McCarthy et al. (2016)

MERRA-2: Modern-Era Retrospective Analysis for Research and Applications, version 2 (Gelaro et al., 2017)

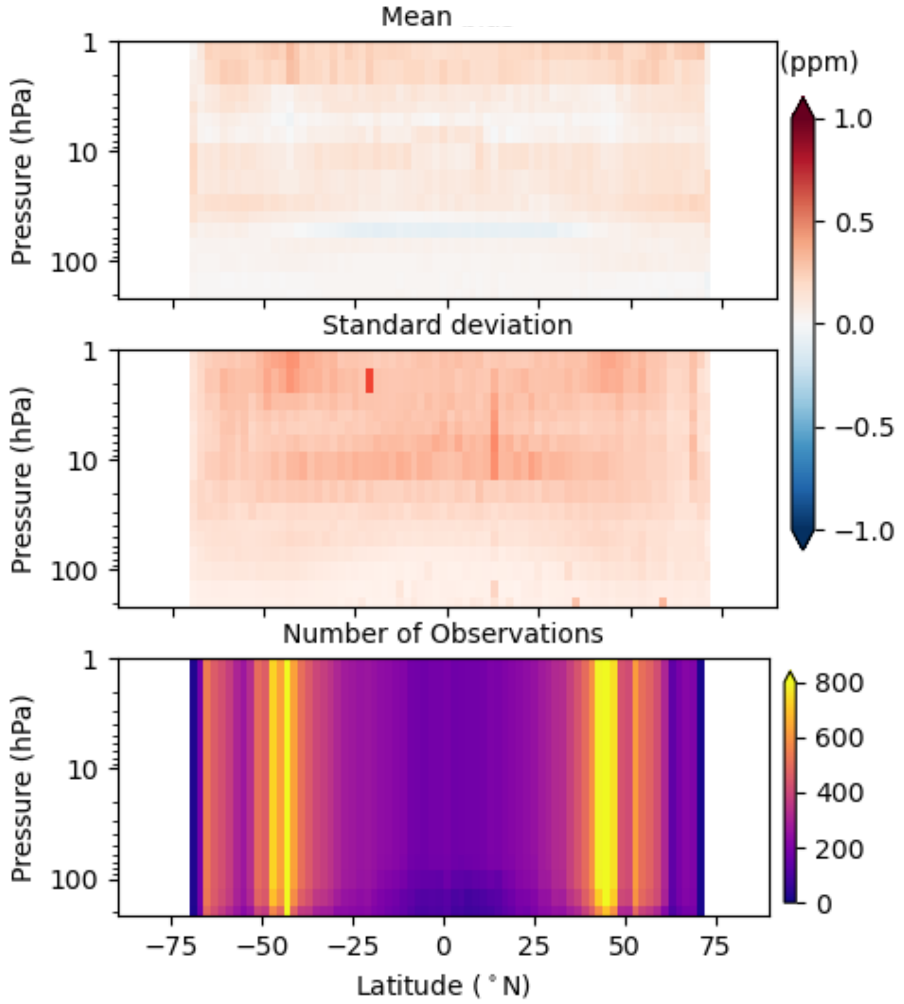
MERRA-2 and SAGE III/ISS

- MERRA-2 independently validated using SAGE solar occultation measurements
  - Well correlated, slightly lower than SAGE III/ISS solar occultation measurements
  - Stable MERRA-2 product for SAGE III/ISS

- Ozone fields above 5 hPa:
  - Reduced sensitivity of assimilation to observations (e.g., Wargan et al., 2023)



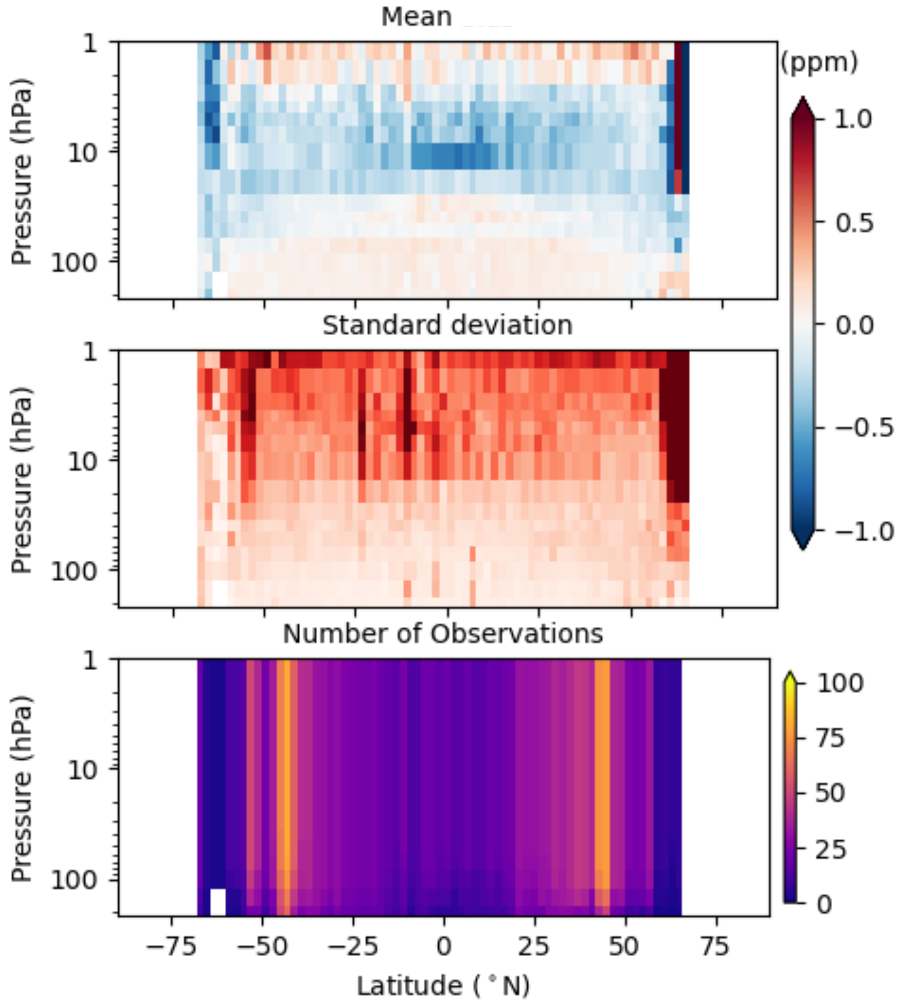
Solar SAGE III/ISS – MERRA-2 O_3 (2017 – 2022)



MERRA-2 and SAGE III/ISS

- Stable MERRA-2 product during SAGE III/ISS record (2017 – 2022 shown)
  - Limited coincident observations for lunar occultation validation
- Ozone fields above 5 hPa:
  - Reduced sensitivity of assimilation to observations (e.g., Wargan et al., 2023)
- Preliminary comparison to SAGE III/ISS lunar occultation measurements
  - Low bias with respect to MERRA-2 around 10 hPa
  - Larger standard deviation about the mean bias

Lunar SAGE III/ISS – MERRA-2 O_3
(2017 – 2022)

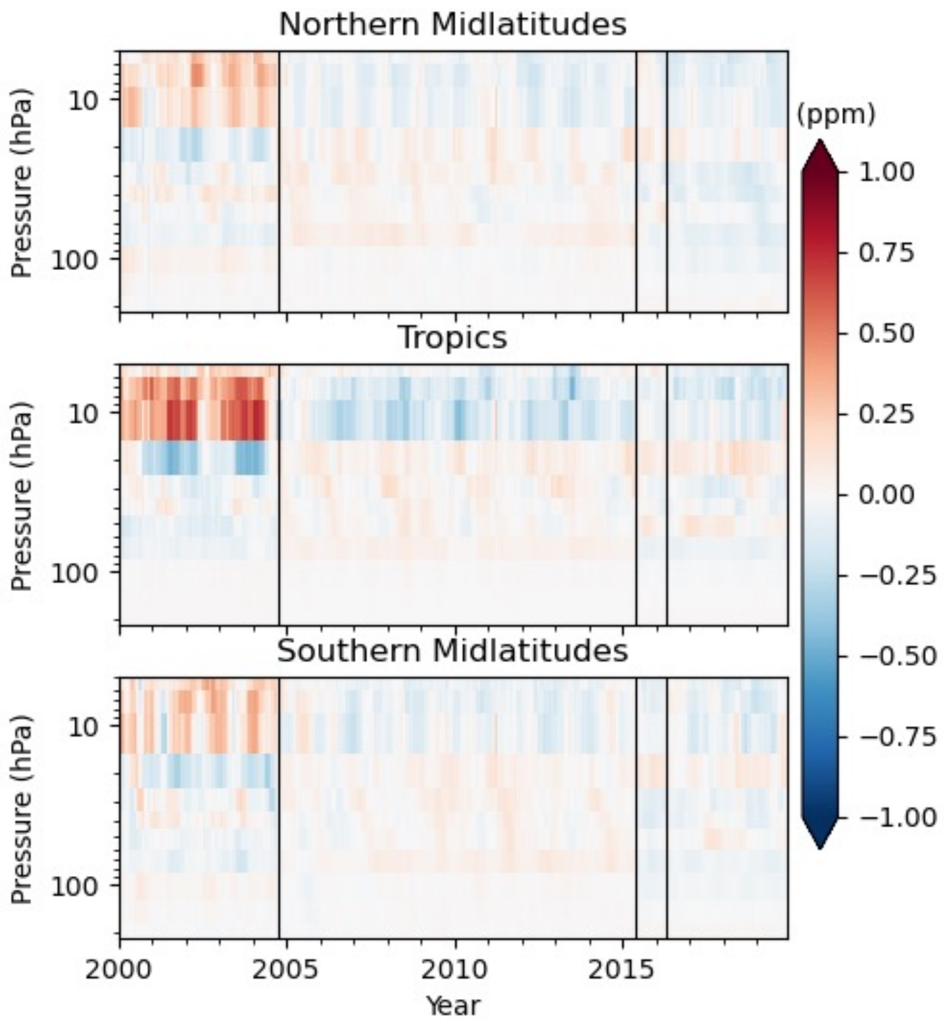


Aura era discontinuities

- Updates to O_3 observation system introduce discontinuities in the record
  - 2004: Inclusion of Aura MLS and OMI
  - 2015: Updates in MLS version
  - 2016: Turn off MLS assimilation in lower pressure levels

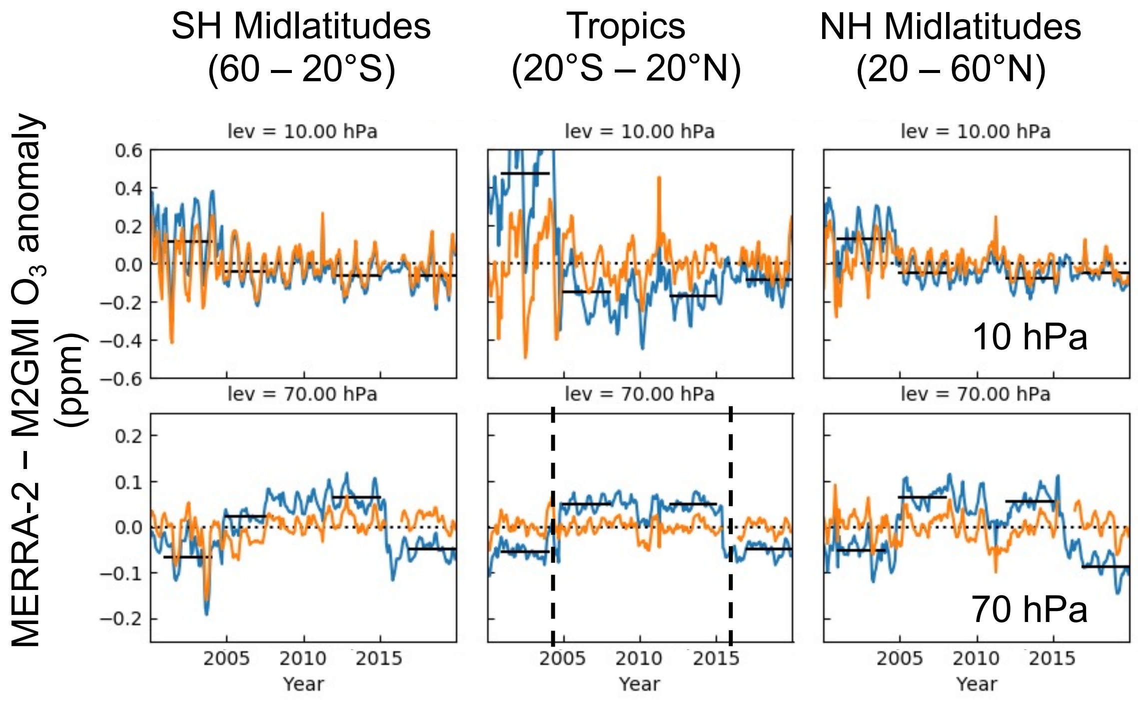
- MERRA-2 GMI as a transfer function across Aura-era discontinuities (Wargen et al., 2018)
  - MERRA-2 meteorology
  - O_3 calculated within Global Modeling Initiative (GMI) chemical mechanism (no ozone data assimilation)

MERRA-2 − M2GMI O_3 anomalies



Aura era discontinuities

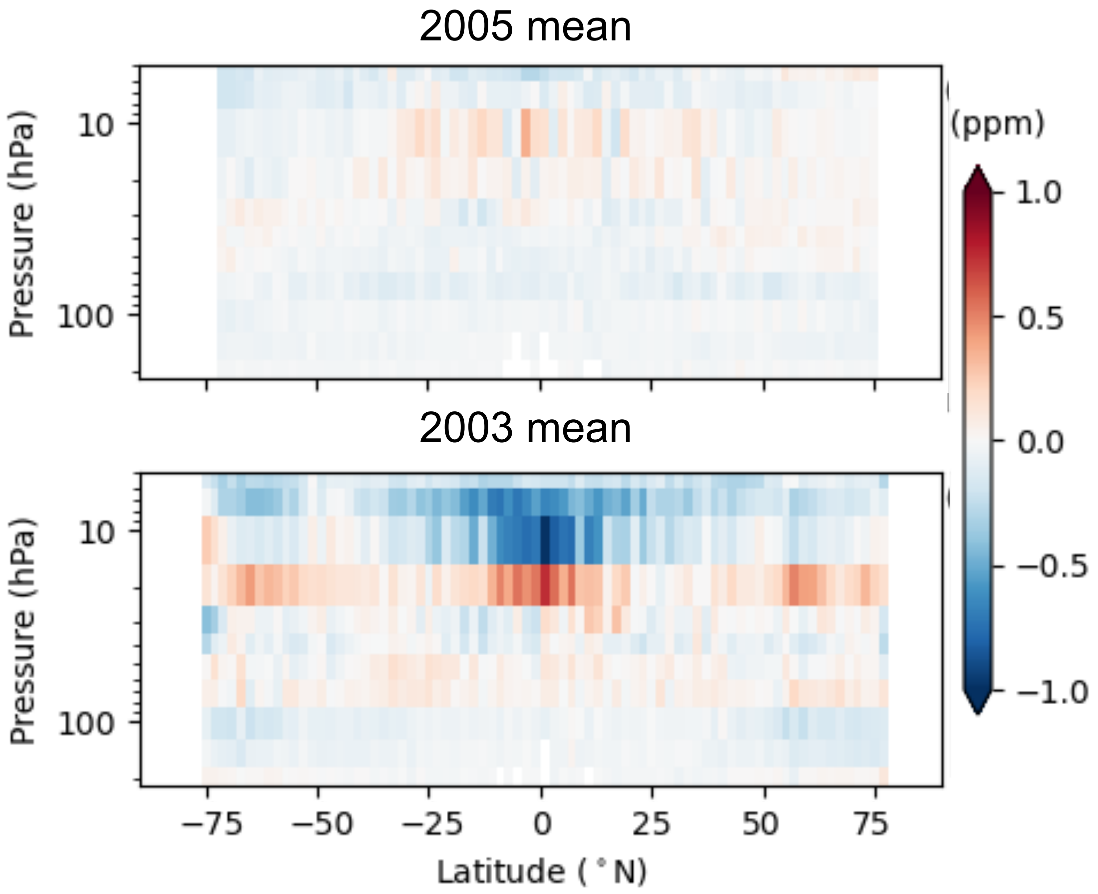
- Use M2GMI as a transfer function across each O_3 observing system update
  - Find the difference between MERRA-2 and M2-GMI before and after updates
  - Corrected MERRA-2 fields are stable with respect to M2GMI
  - Able to reproduce and extend findings of Wargan et al. (2018) from 2017 to 2022



Extension to SAGE II (1980 – 2005)

- From MERRA-2 validation:
  - Agreement with SAGE II improves in 2005 following inclusion of Aura observations (Wargan et al., 2017)

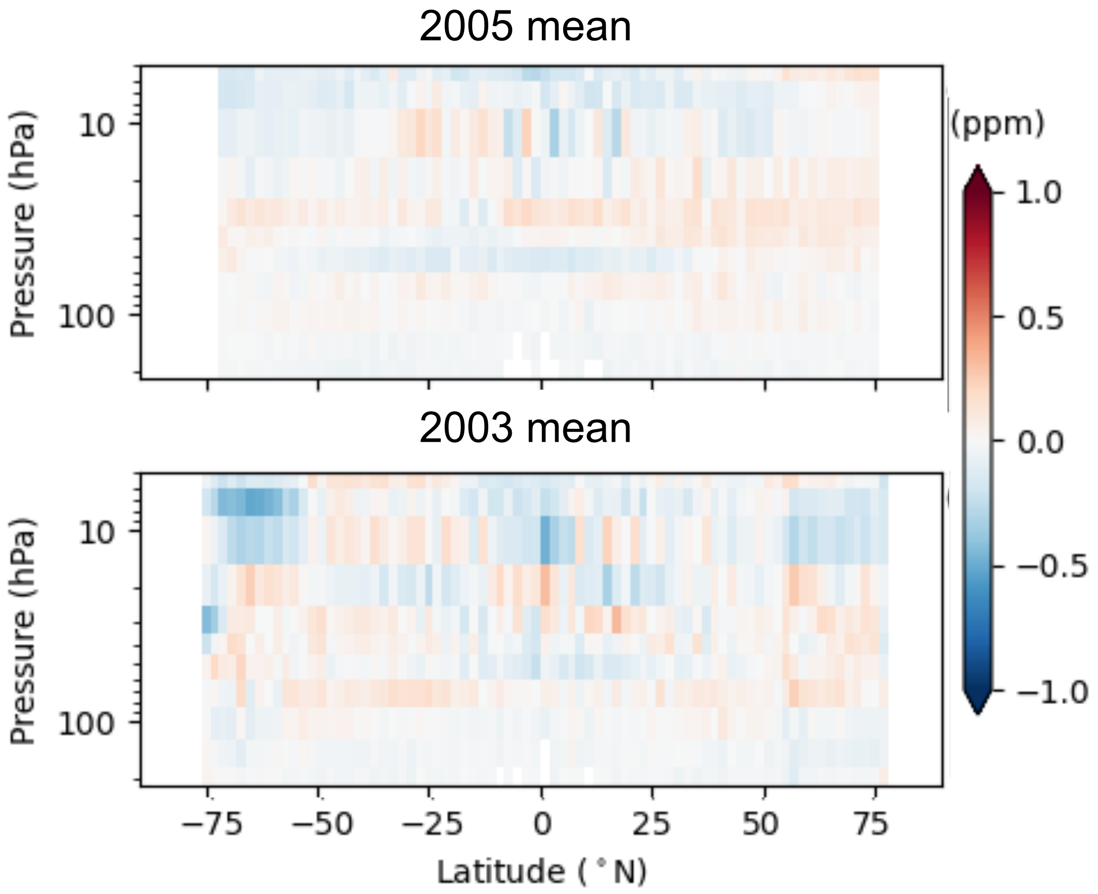
MERRA-2 − SAGE II solar O_3



Extension to SAGE II (1980 – 2005)

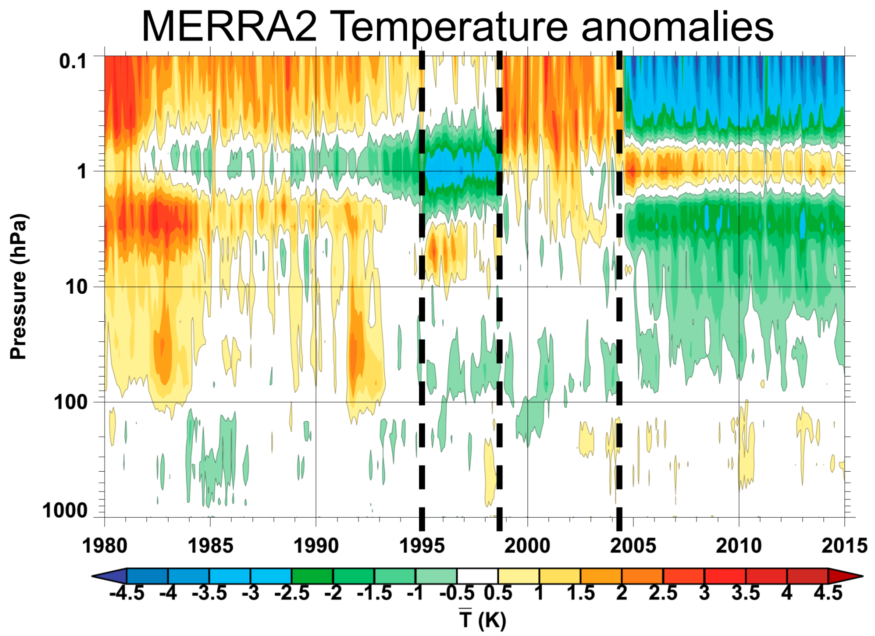
- From MERRA-2 validation:
  - Agreement with SAGE II improves in 2005 following inclusion of Aura observations (Wargan et al., 2017)
- Extend corrected MERRA-2 record:
  - 2015/2016 update influences O_3 in the lower stratosphere
  - From 2004 bias corrections, MERRA-2 is more stable with respect to SAGE II

Corrected MERRA-2 − SAGE II solar O_3

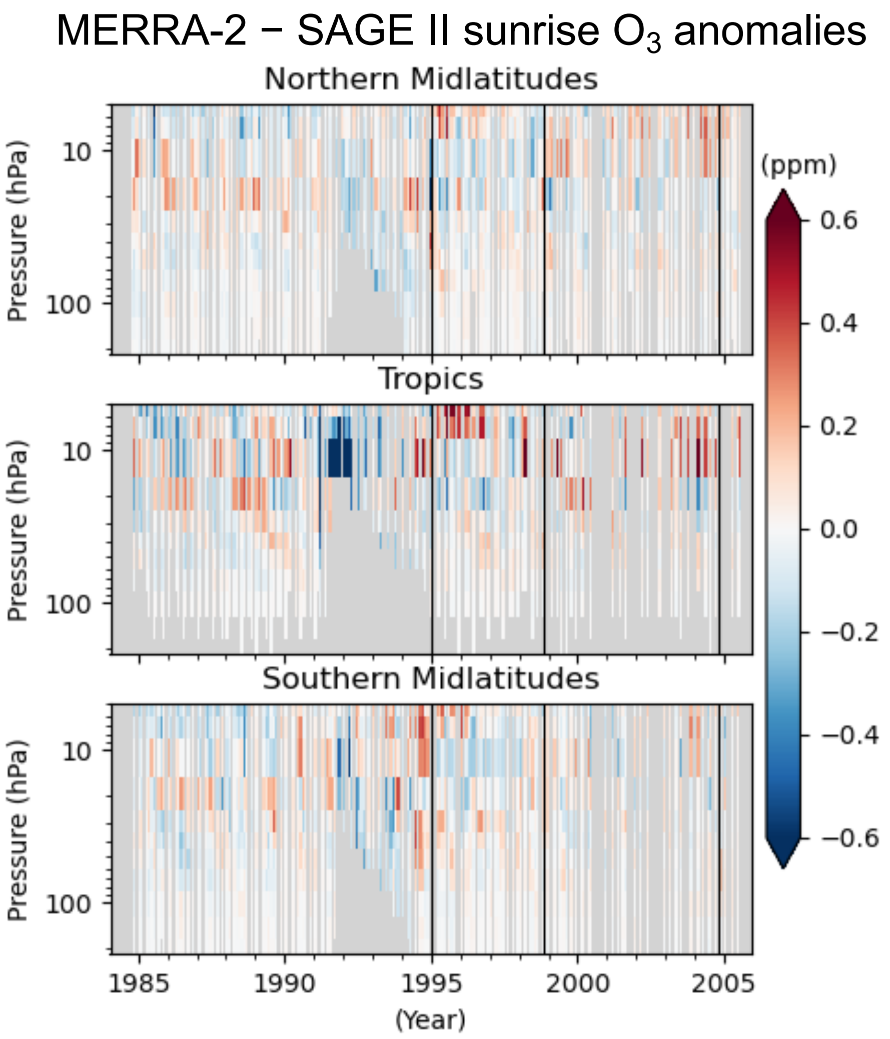


SAGE II era discontinuities

- Evaluate impact of temperature discontinuities on MERRA-2 ozone fields
  - Potential to impact M2-GMI O_3 via meteorology
  - Use SAGE II record as a transfer function



Gelaro et al. (2017)

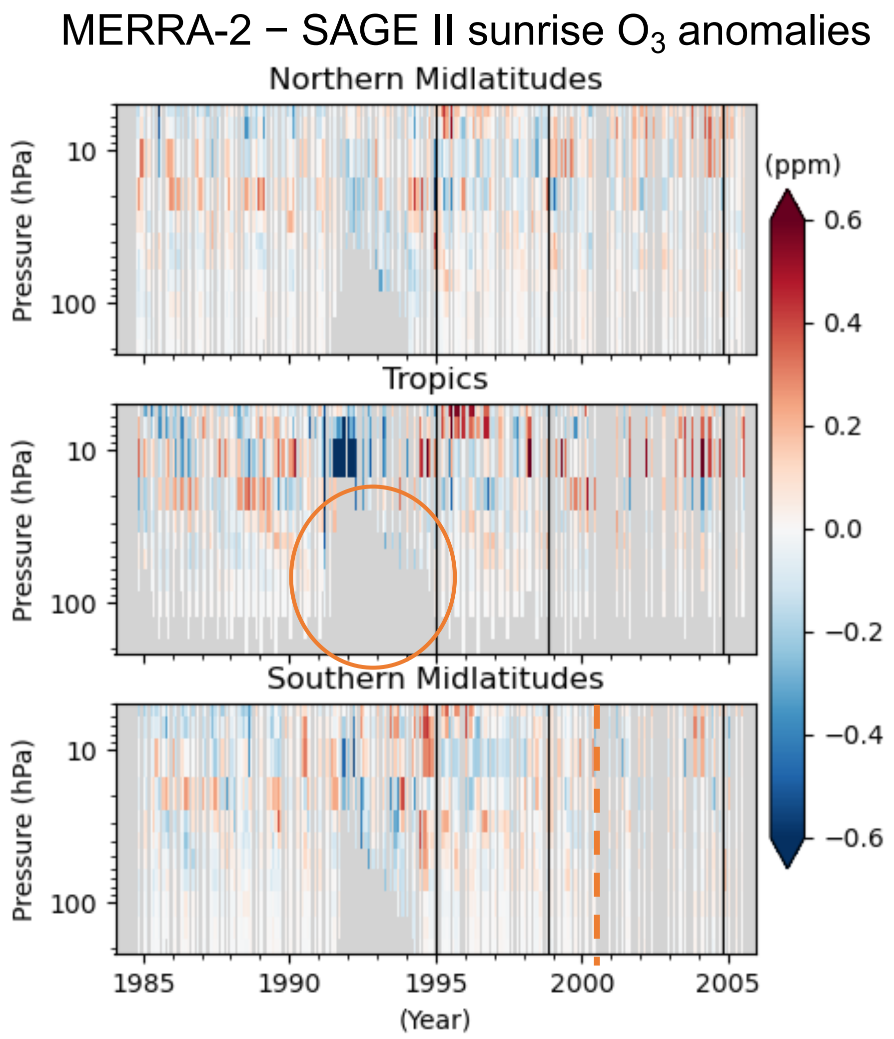


SAGE II era discontinuities

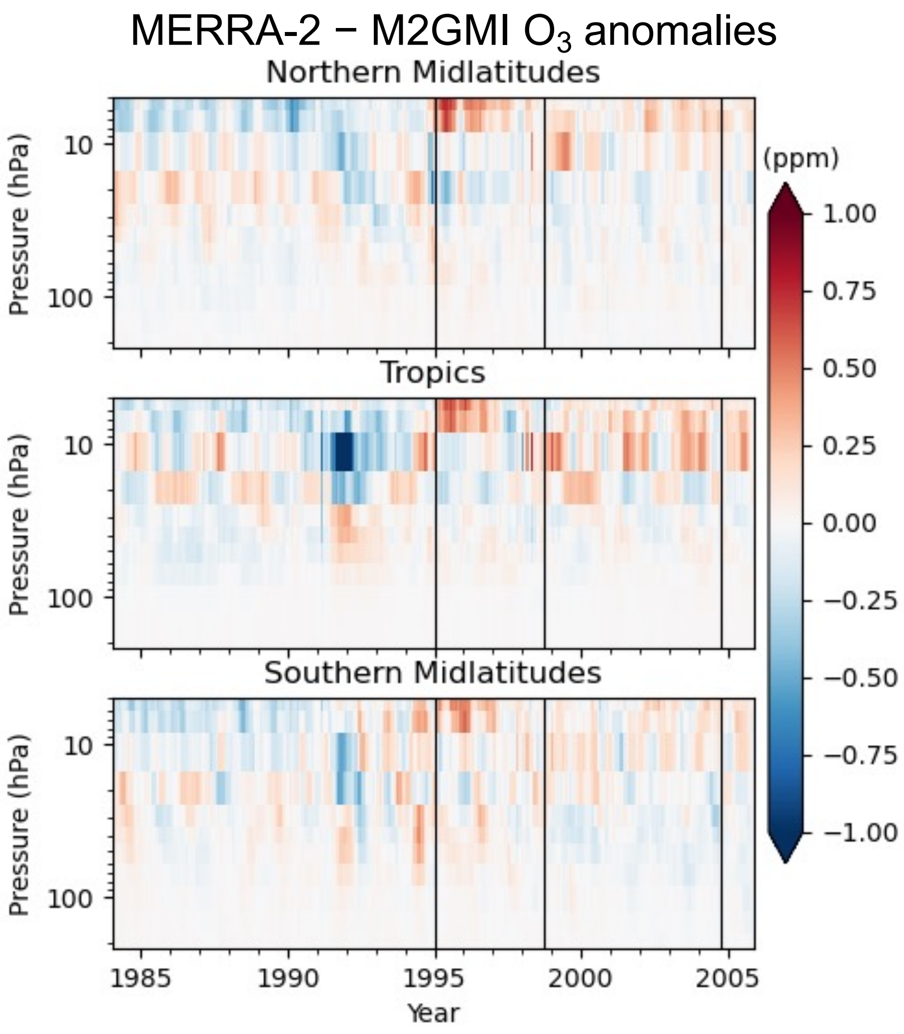
- Evaluate impact of temperature discontinuities on MERRA-2 ozone fields
  - Potential to impact M2-GMI O_3 via meteorology
  - Use SAGE II record as a transfer function

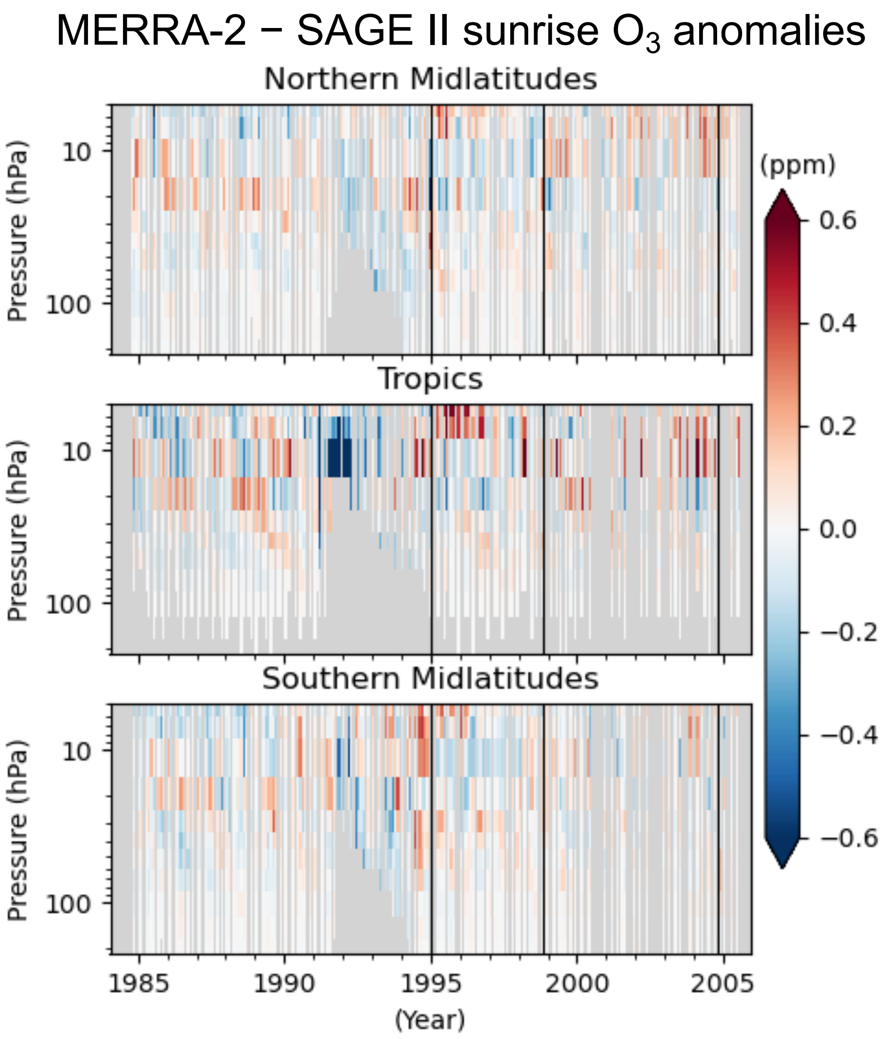
- Prior to 1995 meteorological update:
  - Interferences from 1991 Pinatubo eruption
  - Additional loss of SAGE II data in 1993/1994

- Following 1998 meteorological update:
  - SAGE II outage in 2000, returns at half sampling (2001 – 2005)



SAGE II era discontinuities

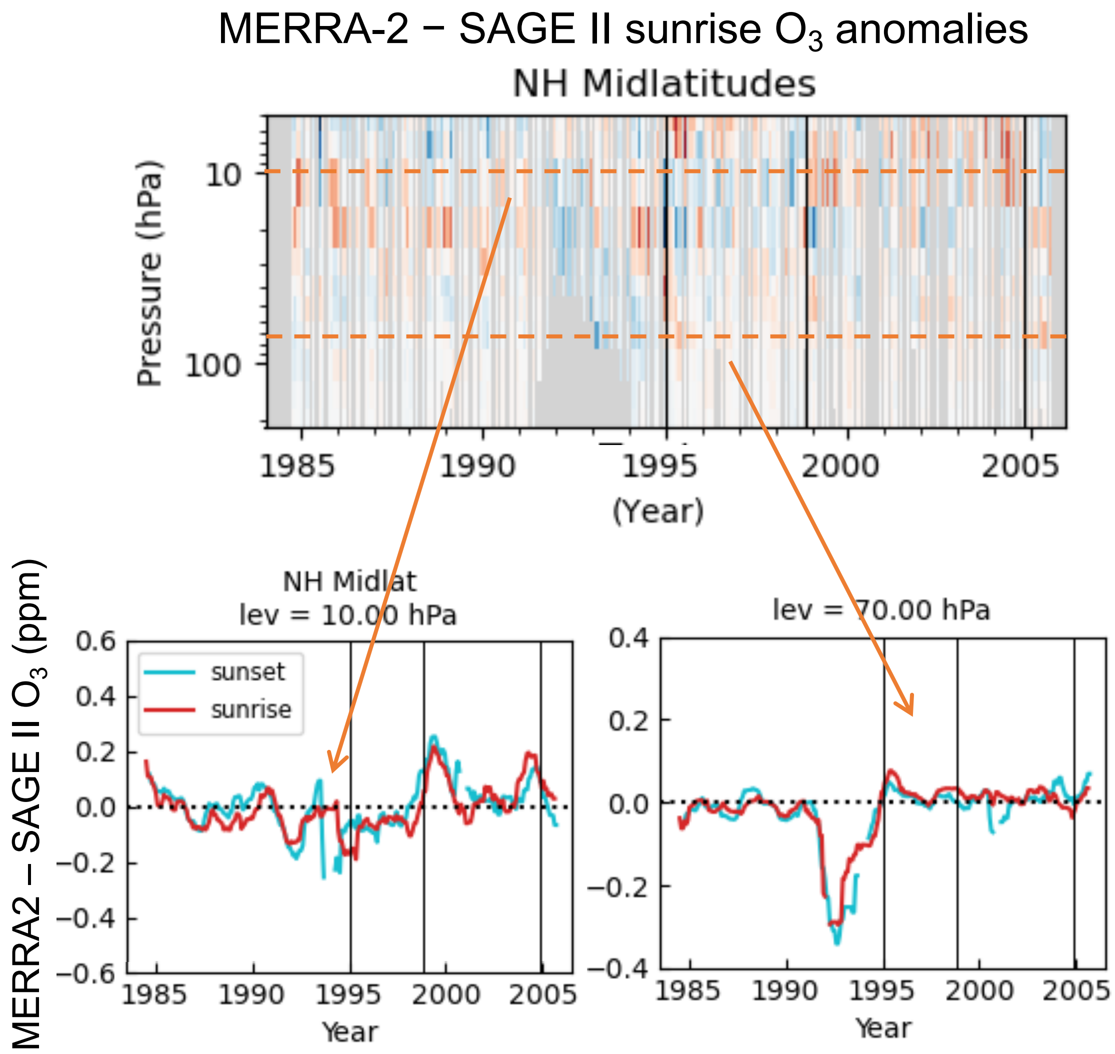




Future Directions

- Stable record with respect to SAGE II between 10 to 100 hPa
  - Ambiguous detection of discontinuities associated with meteorological updates
  - Test sensitivity of trends to bias correction across 1998 update

- Continue to evaluate SAGE III/ISS lunar occultation measurements
  - Explore temporal and seasonal patterns
  - Connect to SAGE III/M3M mission (2002 – 2005)



Backup

SAGE III/ISS Water Vapor assimilation
(Knowland et al., *in prep*)