Multidecadal changes in the UTLS ozone from the MERRA-2 reanalysis and the GMI chemistry model

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Introduction

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- But that’s no different than looking at trends using diverse observations: one needs to account for the discontinuities.

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What can we say about this using models and reanalyses?
- Can we confirm it?
- Mechanisms...?
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Motivation

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  - GEOS atmospheric general circulation model
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- **M2-GMI (MERRA-2 Global Modeling Initiative) simulation**
  - GEOS Replay simulation for the 1980-2016 constrained by MERRA-2 U, V, T, P
  - full Stratospheric and Tropospheric chemistry from the Global Modeling Initiative (GMI) chemical mechanism; **ozone is NOT assimilated**
  - Also includes a suite of idealized tracers for transport studies

All three are run at 0.625° x 0.5° resolution, have well-resolved ozone consistent with assimilated meteorology. A full set of meteorological fields can help interpret the behavior of tracers.
Dealing with discontinuities

Main relevant discontinuities in the MERRA-2 observing system

1998
- Introduction of AMSU radiances: Not evaluating trends before 1998

2001

2004
- Introduction of MLS and OMI data

2007

2011

2014
- MLS V2.2 replaced with v4.2

2017

Results for the SBUV → Aura switch in 2004

Using M2-GMI to bias correct MERRA-2

Bias correction is applied to all major step changes in MERRA-2 and GEOS-RPIT
Comparison with selected ozonesondes

Annual mean anomalies: ozonesondes, MERRA-2, M2-GMI and GEOS-RPIT

The sonde data are reprocessed with the Skysonde algorithm [Sterling et al., 2017] to account for changes affecting long-term records [ftp://aftp.cmdl.noaa.gov/data/ozwv/Ozonesonde/].

Good overall agreement between MERRA-2, M2-GMI, GEOS-RPIT and the sondes.

Large interannual variability dominates but simple linear fit has negative slopes at Trinidad Head and Boulder.

MERRA-2 ozone compares well with independent data in the LS [Wargan et al., 2017].
Ozone trends

\[ y(t) = \alpha_0(t) + \alpha_1(t)t + \alpha_2(t)QBO_1(t) + \alpha_3(t)QBO_2(t) + \alpha_4(t)TSI(t) + \alpha_5(t)MEI(t) + \alpha_6(t)AERO(t) + \epsilon(t) \]

\[ \alpha(t) = c + \sum_{k=1}^{2} a_k \cos \frac{2k\pi t}{12} + b_k \sin \frac{2k\pi t}{12} \]

Seasonal cycle included in all coefficients

Ozone trends in Dobson units/km/decade in tropopause-relative coordinates

- MERRA-2 and GEOS-RPIT have similar trend patterns:
  - Positive in the middle and upper stratosphere
  - Negative in the 0-10 km layer (above the tropopause) at midlatitudes
  - Alternating (positive/negative) in the tropics

- -0.66 DU/decade in the SH and -1.25 DU/decade in the NH midlatitudes

- The trends are small compared to interannual variability

- The MLR (blue) is doing a good job reproducing the ozone evolution (black)
This is what we have so far

After correcting for step-changes in the observing system, MERRA-2 and GEOS-RPIT show negative ozone trends in the lower stratosphere (LS) at midlatitudes in agreement with Ball et al., 2018

So what’s going on here?
In the lower stratosphere the st80_25, ozone and e90 trend patterns are remarkably similar (but with the opposite sign for e90, as expected from reversed gradients)

- Stronger and reaching further in the northern hemisphere
- Tropical-extratropical dipole
- Trends extend into the upper troposphere in the southern hemisphere

This suggest that the ozone trend pattern is also likely driven by changes in the LS circulation
Can this trend pattern arise from changes in the tropopause height?

An upward shift of the tropopause results in a positive e90 anomaly in the lower stratosphere.

*Abalos et al., 2017*

Zonal mean in pressure coordinates

In tropopause-relative coordinates: The effect of tropopause shifts is removed in tropopause-relative coordinates.

The remaining trends must be due to changes in the LS circulation.
Putting it all together

![Graph showing e90 trend relative to the tropopause 1998-2016 with pressure and geographic latitudes on the x-axis and years on the y-axis.](image)
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- Advection by the residual circulation
- Two-way quasi-isentropic transport

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The e90 trend pattern implies an intensification of two-way transport as the dominant mechanism for this tracer

The same mechanism would lead to the observed lower stratospheric ozone trends between 1998-2016
Conclusions

• After correcting for step-changes in the observing system, MERRA-2 shows negative ozone trends in the lower stratosphere (LS) at midlatitudes in agreement with Ball et al., 2018

• The evolution of idealized tracers in the specified dynamics M2-GMI simulation strongly suggests an intensification of two-way transport in the LS as the likely mechanism

• This is the first step towards a comprehensive use of modern reanalyses to ozone trend studies; much more work to be done

Wargan et al., 2018, Recent decline in lower stratospheric ozone attributed to circulation changes, submitted to GRL
backup
Some items to think about

• To make the argument more quantitative we need to find a good way to calculate tracer budgets from simulations/reanalysis with assimilated meteorology (an elusive goal so far)

• What are the effects of step-changes in radiance observations in MERRA-2 on tracer transport?
  • Extending the analysis back to 1980: how to deal with the major discontinuity in 1998 (introduction of microwave observations from AMSU)?
  • Can these step-changes have an impact on transport that lasts for several years? What is the magnitude of that effect?

• We may be able to confirm (or disprove) an intensification of two-way mixing in further analyses of tracer observations in the LS seen in the M2-GMI simulation

• Beyond the zonal mean: 3-D analysis
Bias-correcting (homogenizing) the reanalysis

On pressure levels [ppmv]

Using M2-GMI to bias correct MERRA-2

Using MLR with a step function proxy

Bias to be subtracted