Multidecadal changes in lower stratospheric ozone: variability vs. trends

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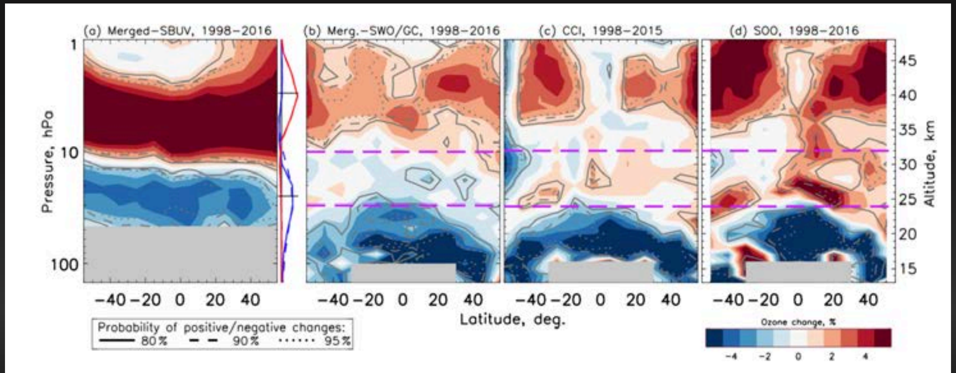
AGU 100 FALL MEETING Washington, D.C. | 10-14 Dec 2018

Motivation

- Stratospheric ozone is recovering following reductions of ozone depleting substances now confirmed (WMO 2018)
- There's a controversy regarding recent changes in ozone in the lower stratosphere (LS): Ball et al. 2018 report continuing decline of LS ozone between 1998 and 2016.



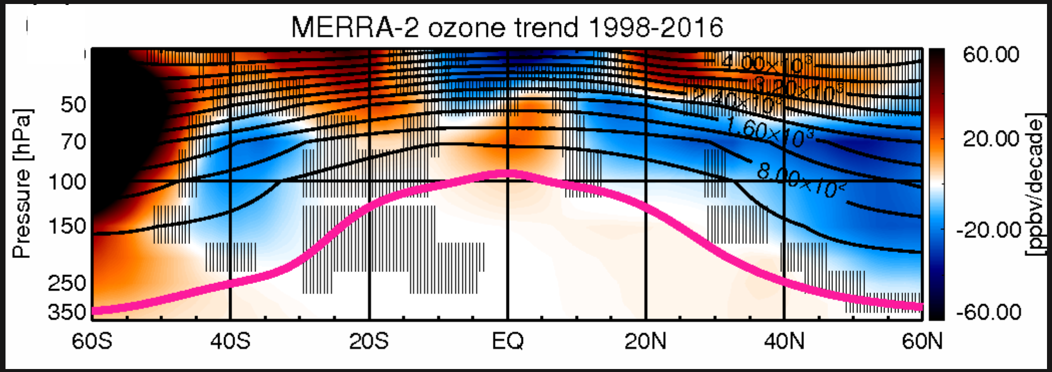
Ball et al. 2018

What can we say about LS ozone changes over the last two decades using NASA's reanalysis and models?

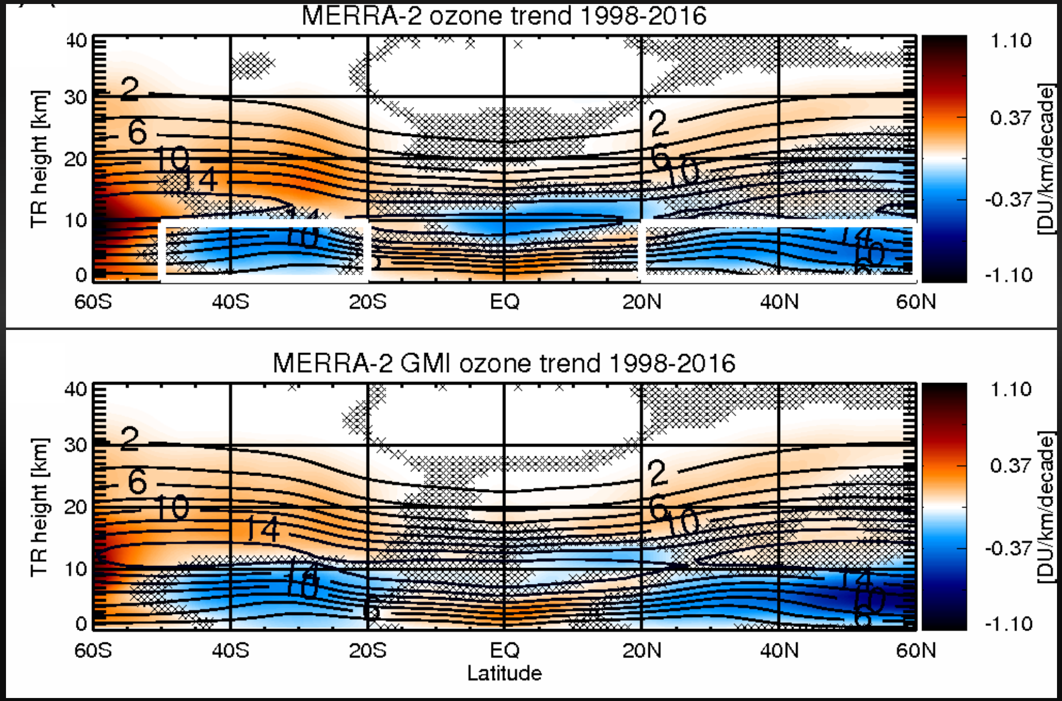
MERRA-2 reanalysis and models

- MERRA-2 (Modern-Era Retrospective Analysis for Research and Applications, Version 2)
  - Global Atmospheric reanalysis produced by NASA GMAO
  - 1980–present
  - Includes assimilated ozone data (SBUV, MLS, OMI instruments)
- Specified dynamics (SD) chemistry model simulation driven by MERRA-2 (M2GMI). The simulation uses the Global Modeling Initiative chemistry model. Ozone **not** assimilated
- Ensemble of model simulations
  - GEOS general circulation model, same as in the SD simulation
  - “StratChem” stratospheric chemistry model
  - Boundary conditions from observations: climate change signal included

Ozone mixing ratio trends (colors)



Tropopause-relative partial column trends



NASA's MERRA-2 reanalysis ozone **corrected for discontinuities** in observations shows negative trends in parts of the extratropical lower stratosphere (LS) between 1998 and 2016

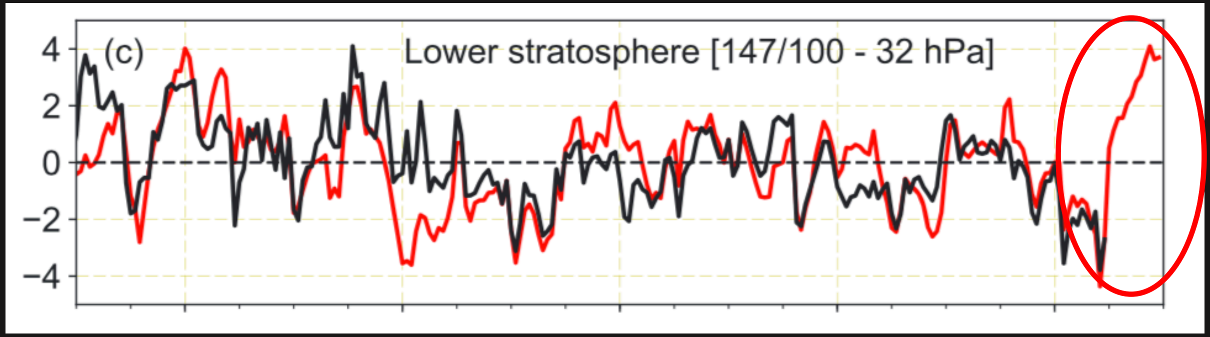
Discernible trends in ozone partial column in the LS but not strong enough to cancel the recovery trend in the stratospheric column

Specified dynamics (SD) chemistry model simulation driven by MERRA-2 reproduces the trends.

Wargan et al. 2018

Does 2017 make a difference?

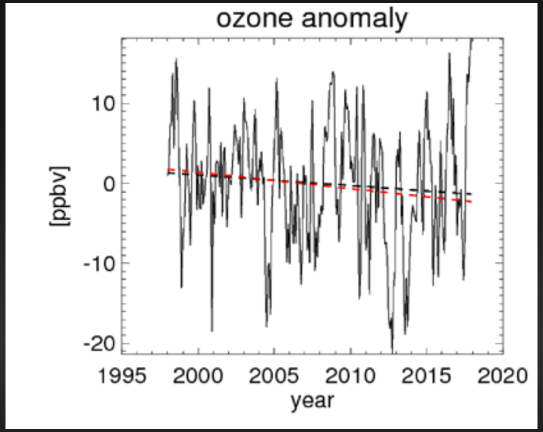
Chipperfield et al. 2018



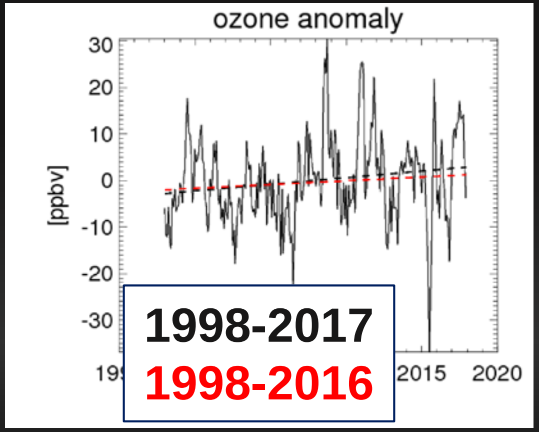
Large uptick in 2017

MERRA-2

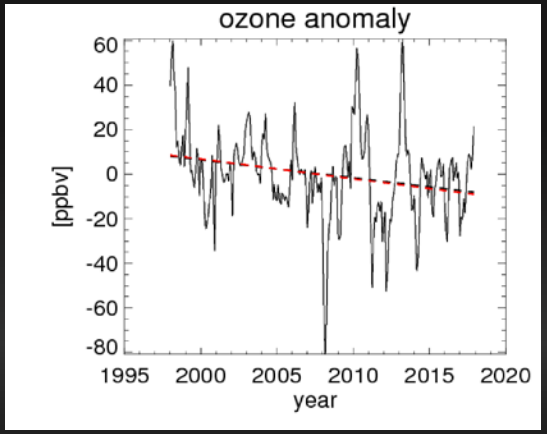
50S-20S, 150 hPa



10S-10N, 100 hPa



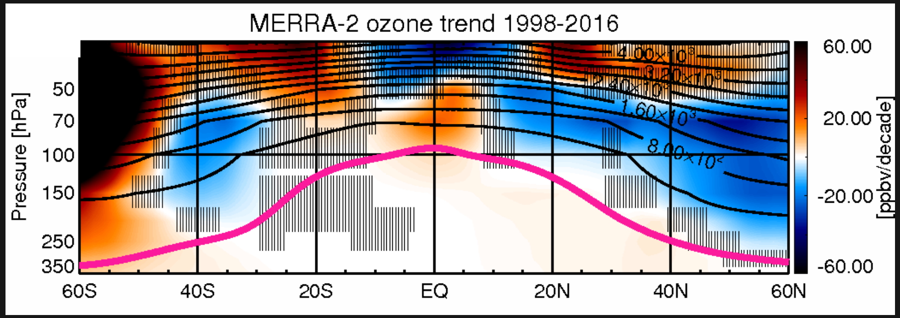
20N-60N, 150 hPa



Including 2017 in MERRA-2 trend analysis:

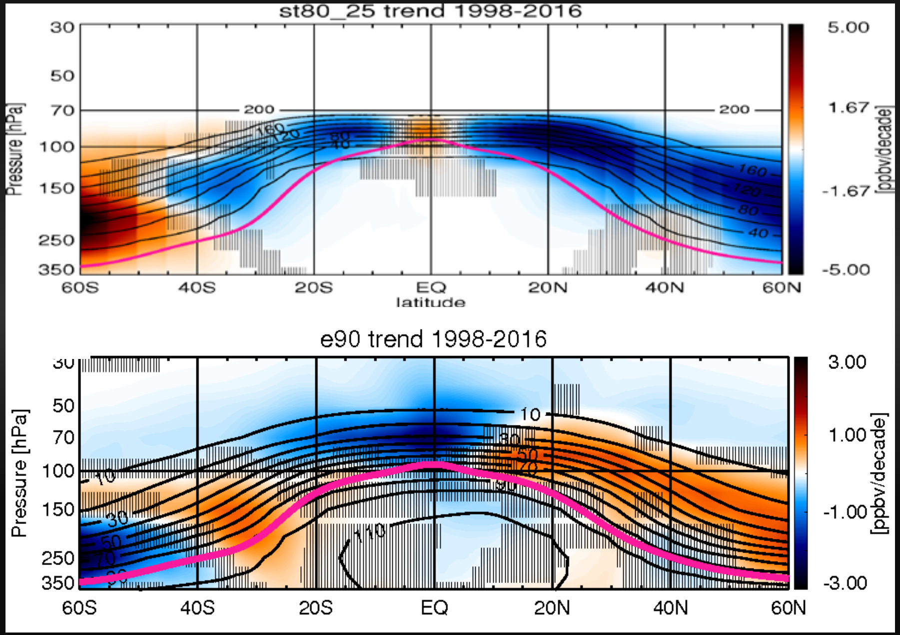
- The uptick confined to southern hemisphere 50 – 30 hPa; trend still negative in the lowermost stratosphere
- No effect in the northern hemisphere

Ozone



MERRA-2 ozone

Idealized transport tracers



ST80_25: Source at p<80 hPa sink at the tropopause

e90: Source at the surface, constant loss rate of 90^{-1} $days^{-1}$

Chemistry or transport? What caused LS ozone changes between 1998 and 2016?

- LS trend patterns consistent between ozone and idealized tracers
- Patterns **not** consistent with changes in residual circulation
- Trends likely result from an intensification of eddy mixing between tropics and extratropics

Wargan et al. 2018

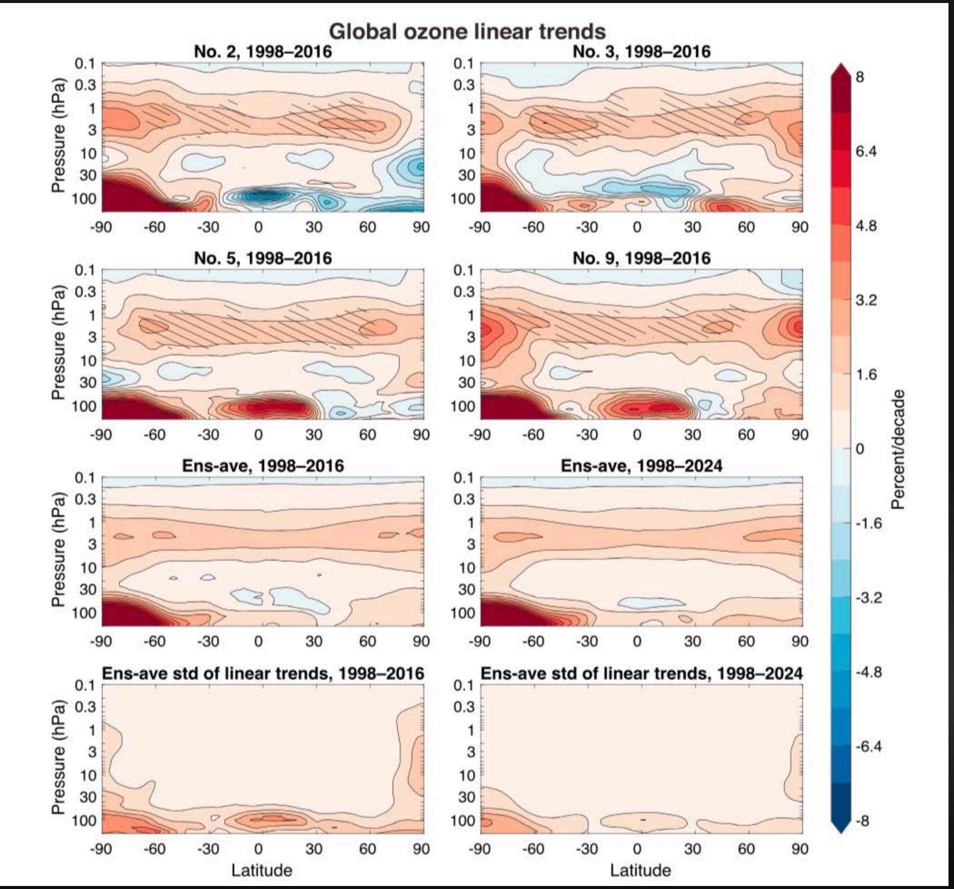
(Transient) response to climate change
OR
Unforced variability?

Stone et al. 2018:

- Observed apparent LS trends likely result from large variability there.
- Trends become positive in longer simulations

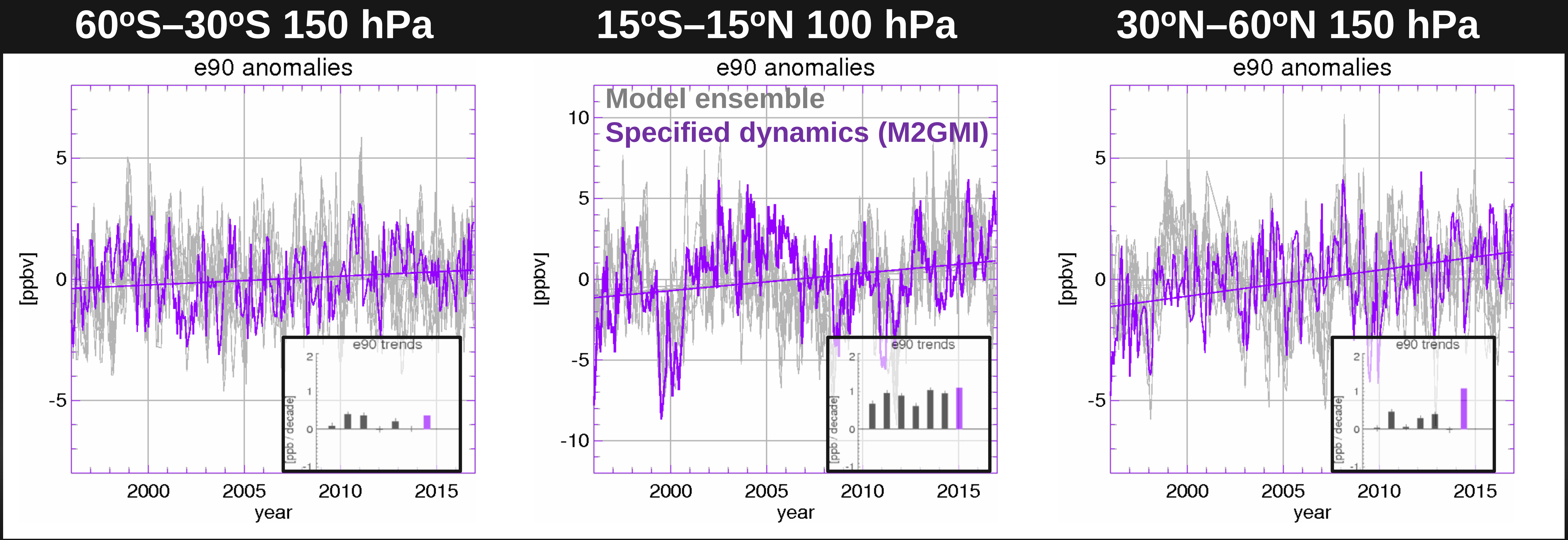
This presentation:

- Focus on transport in the LS 1996-2016
- Ensemble of model simulations forced by observed boundary conditions
- Idealized transport tracer, e90
- "trends" calculated as simple linear fit



Stone et al. 2018

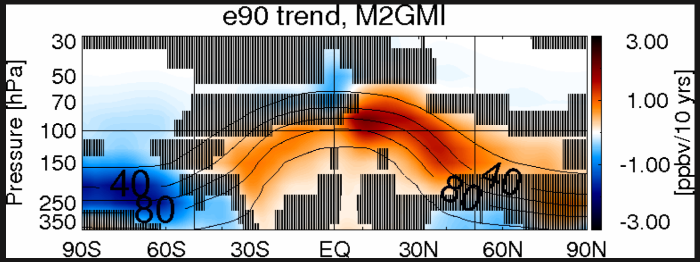
e90 trends (1996–2016) in the lower stratosphere



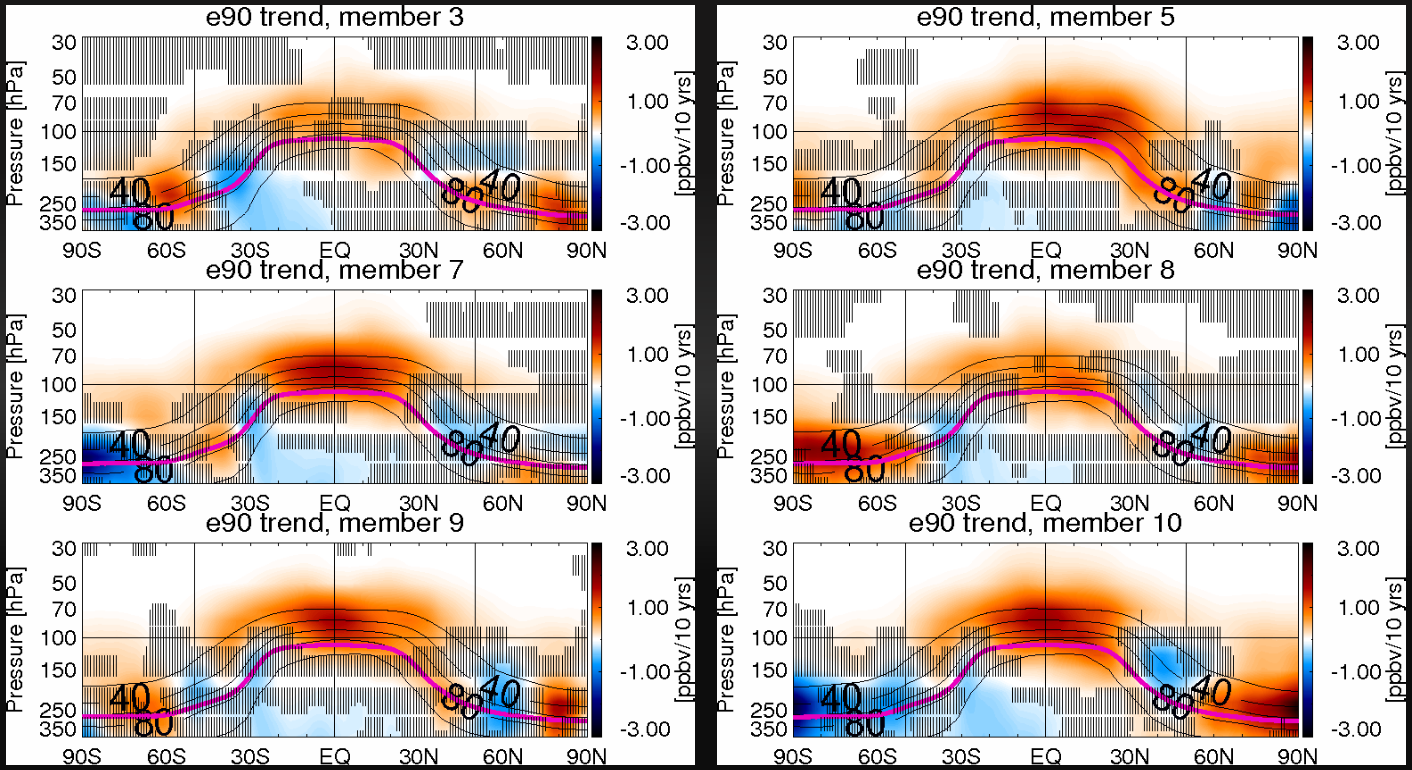
- Simulations and SD exhibit similar amount of variability at the selected levels, including low-frequency changes forced by the boundary conditions.
- SD shows stronger positive trends in the northern hemisphere.

e90 trends (1996–2016) in the lower stratosphere.

Specified dynamics



Model ensemble



All ensemble simulations exhibit positive e90 trends in the tropics.
Extratropical trends vary among ensemble members.
Some simulations show e90 increase at middle latitudes in partial agreement with SD.

Some systematic differences remain

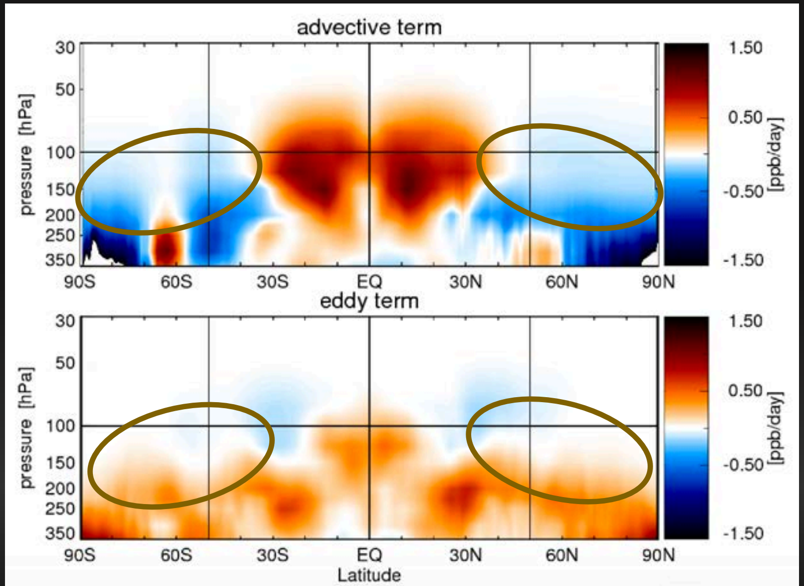
- **Middle latitude trends patterns**
- **Tropopause trends (not shown)**

Does the model represent long-term transport changes correctly?

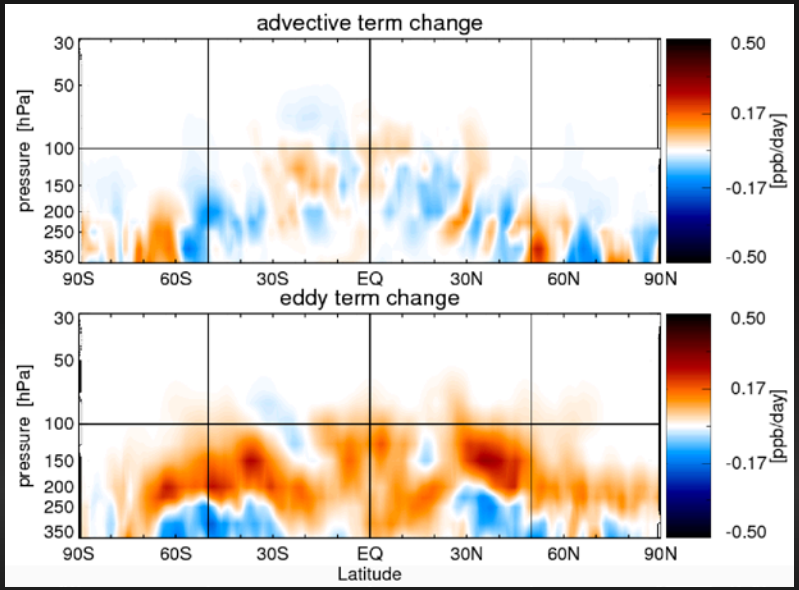
Transformed Eulerian Mean tracer budget for e90

$$\bar{\chi}_t = -\bar{v}^* \bar{\chi}_y - \bar{w}^* \bar{\chi}_z + e^{z/H} \nabla \cdot \boldsymbol{M} + \text{chemistry}$$

2010–2013 mean transport terms



Change between 1996–1999 and 2010–2013



- Extratropical tracer budget maintained by a balance between advective and eddy terms, both driven by wave breaking.
- Intensification of the eddy transport between the late 90s and 2013 qualitatively consistent with positive trend in e90 and with negative trend in extratropical ozone.

Intensification of eddy transport / two-way mixing is supported by evidence in literature (*Bönisch et al. 2011; Diallo et al. 2012; Ray et al., 2014, Ploeger et al., 2015*)

Summary

- Bias corrected ozone from the MERRA-2 reanalysis: positive trend in the upper and middle stratosphere and decline in the extratropical lower stratosphere (LS), 1998-2017
- LS decline attributed to circulation changes
- Idealized tracers in Chemistry Climate Model ensemble simulations with observed boundary conditions:
  - Variability in good agreement with specified dynamics (SD) simulations
  - 1996-2016 tracer trends and budget analysis indicate intensification of eddy transport into the extratropics in some of the ensemble members
  - **There are important and significant differences between long-term transport changes in the free-running ensemble and SD simulation**

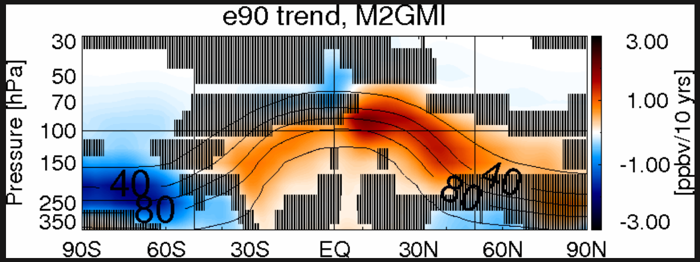
This is work in progress

Backup

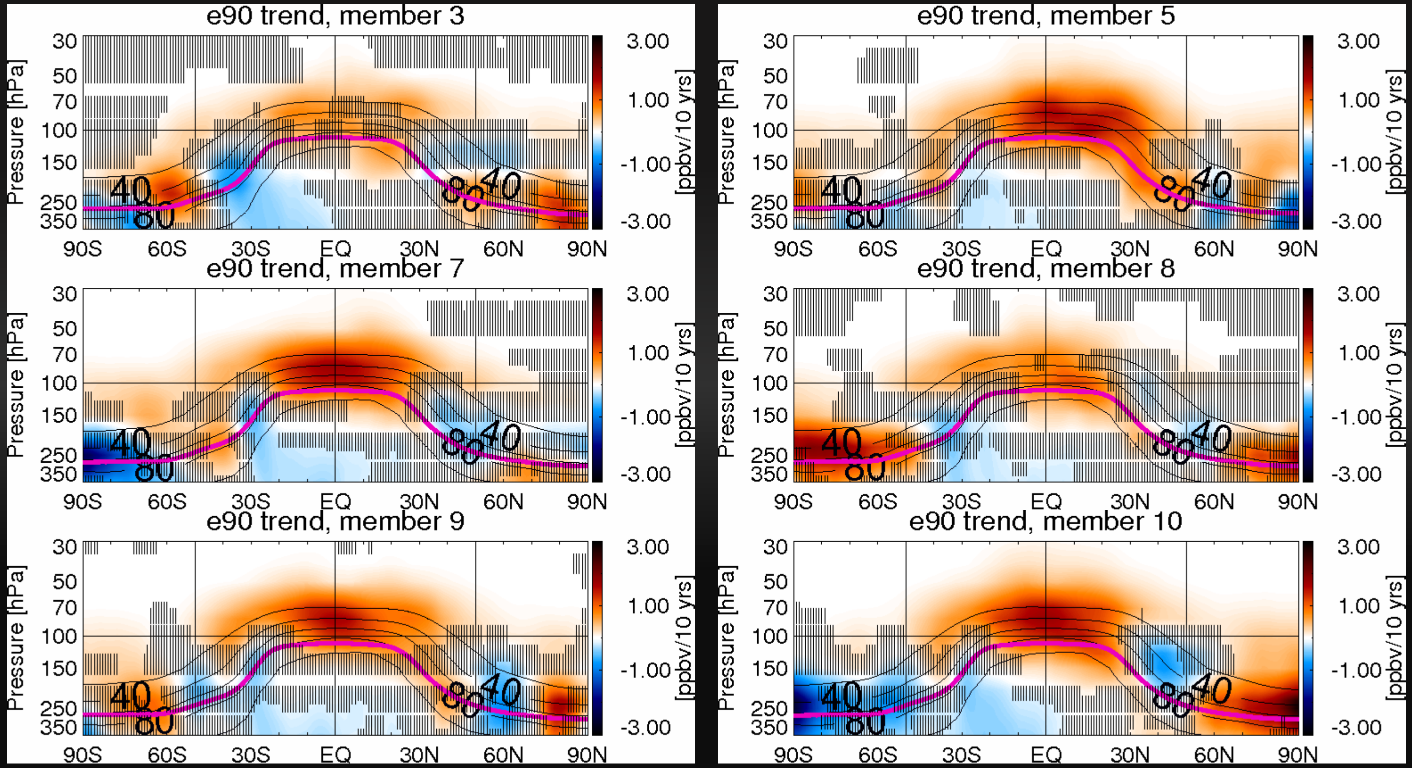
e90 trends (1996–2016) in the lower stratosphere. Pressure coordinate

All ensemble simulations exhibit positive e90 trends in the tropics.
Extratropical trends vary among ensemble members.
Some simulations show e90 increase at middle latitudes in partial agreement with SD

Specified dynamics

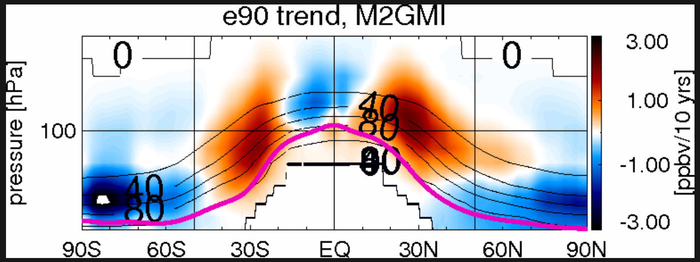


Model ensemble

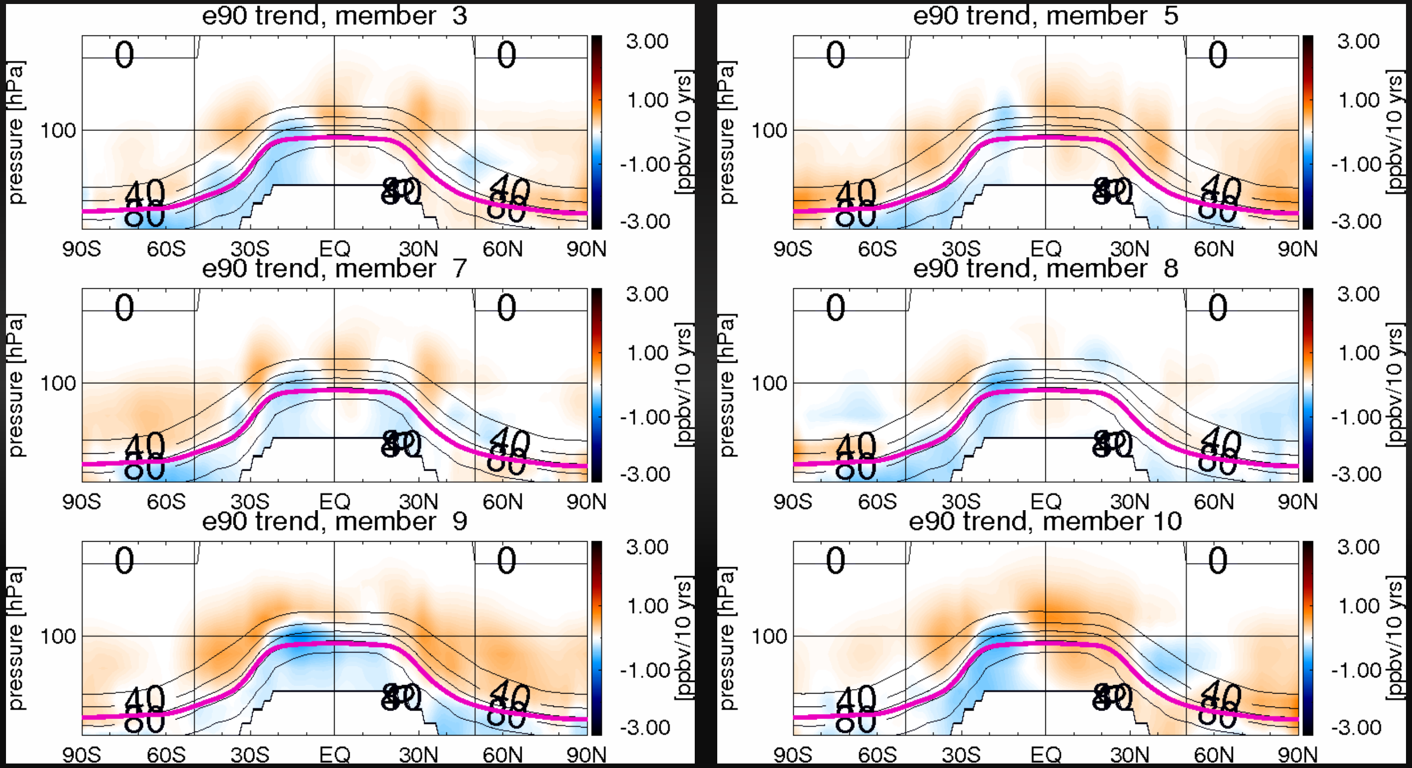


e90 trends (1996–2016) in the lower stratosphere. Tropopause-relative coordinate

Specified dynamics



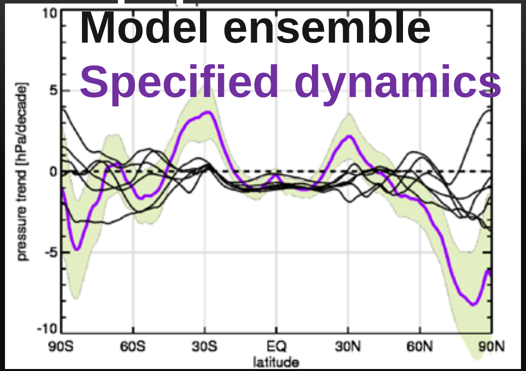
Model ensemble



Trends are weaker in the ensemble when changes in the tropopause pressure are taken into account.

The pattern and intensity different than in SD

Tropopause trends



Tropopause pressure trends vary among the ensemble members and different than in SD