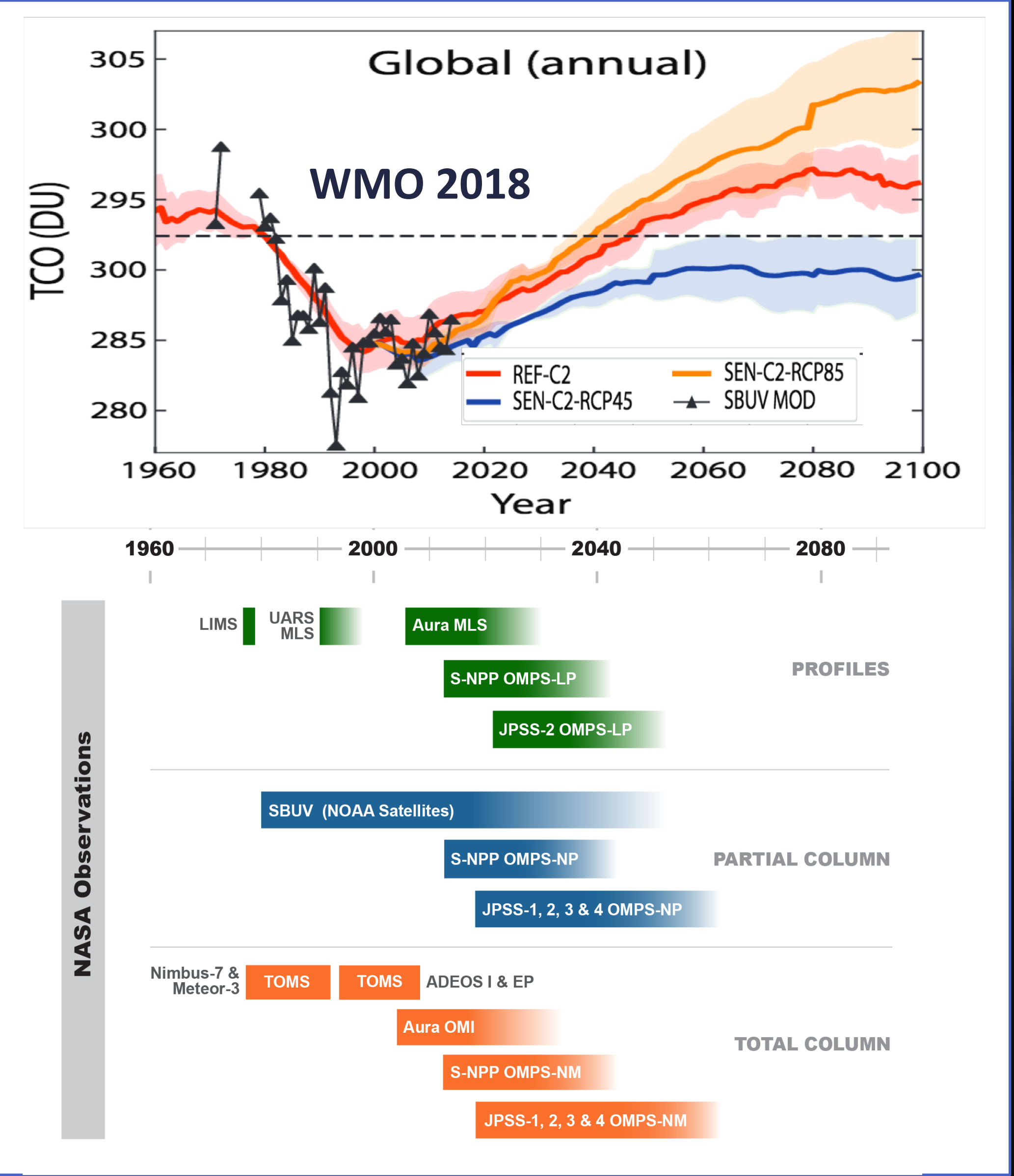


Tackling the challenges in the representation of trends and long-term variability in future stratospheric chemical reanalyses

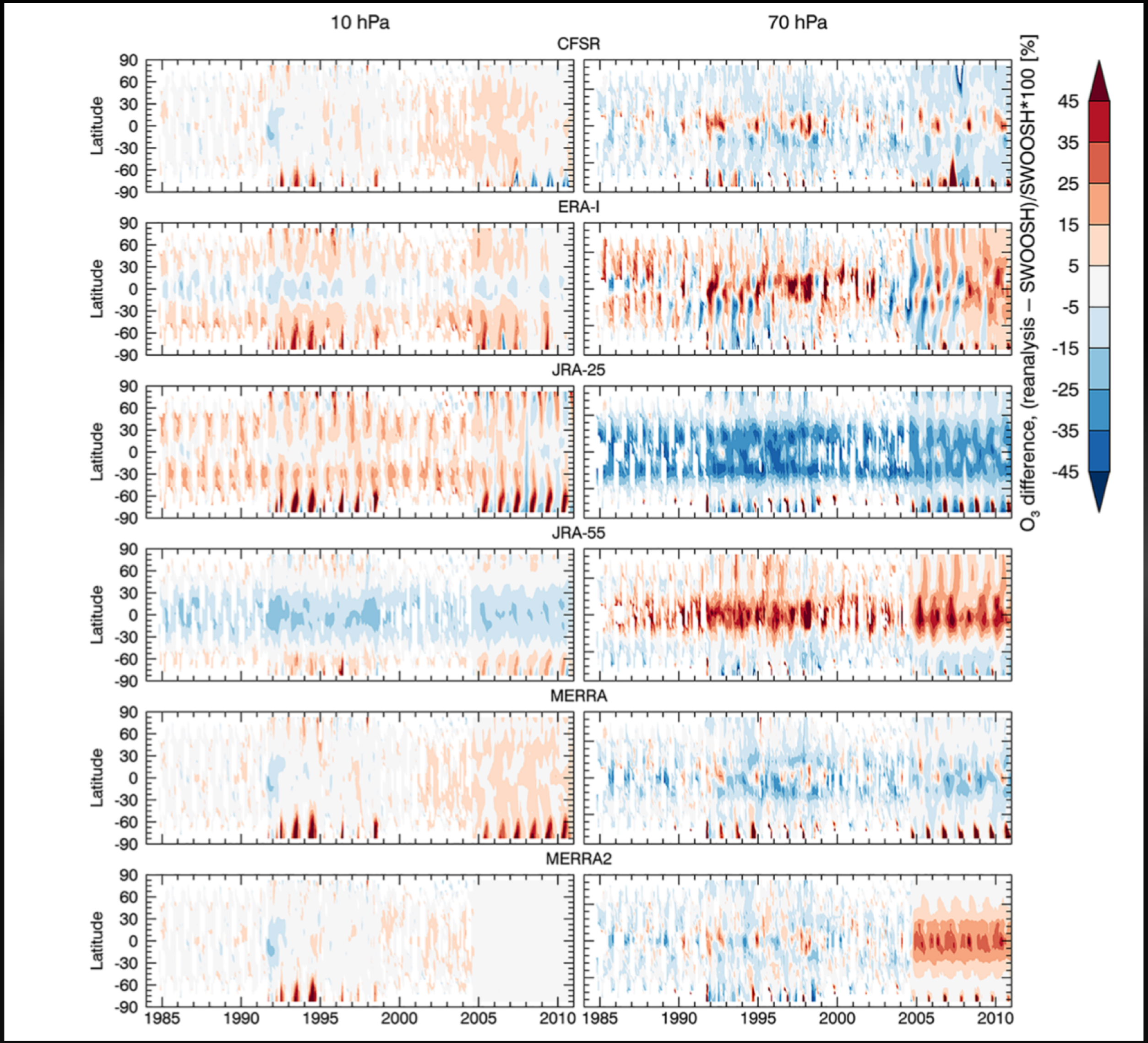
K. Wargan & collaborators

Outline

- Continuity of ozone in reanalyses for trend studies: addressing changing observing systems and representation of transport
- Stratospheric chemical reanalysis work at the GMAO
- Laundry list of thoughts and questions about the theme

SPARC-DAWG Workshop, 2019, Theme 1: chemical reanalysis

Discontinuities and drifts

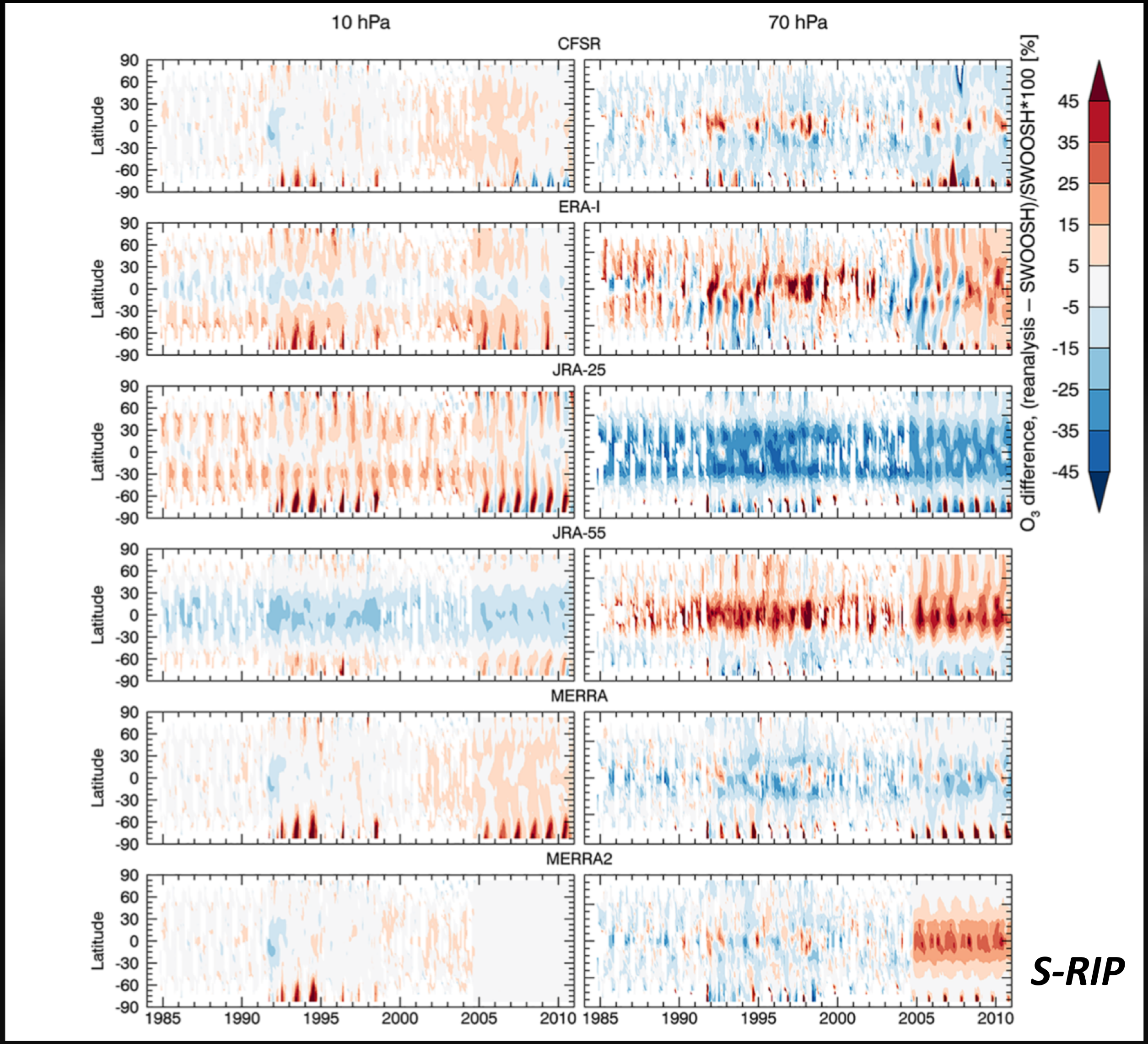


Davis et al. 2017

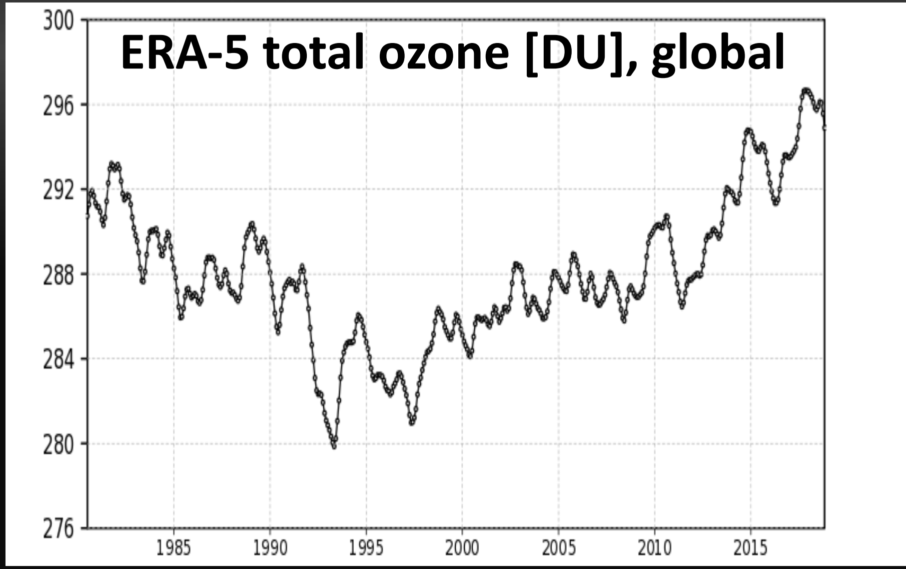
Differences between six major reanalyses and the SWOOSH.

Step changes in observations have consequences for studies of the long-term ozone variability

Discontinuities and drifts



Differences between six major reanalyses and the SWOOSH.
Step changes in observations have consequences for studies of the long-term ozone variability

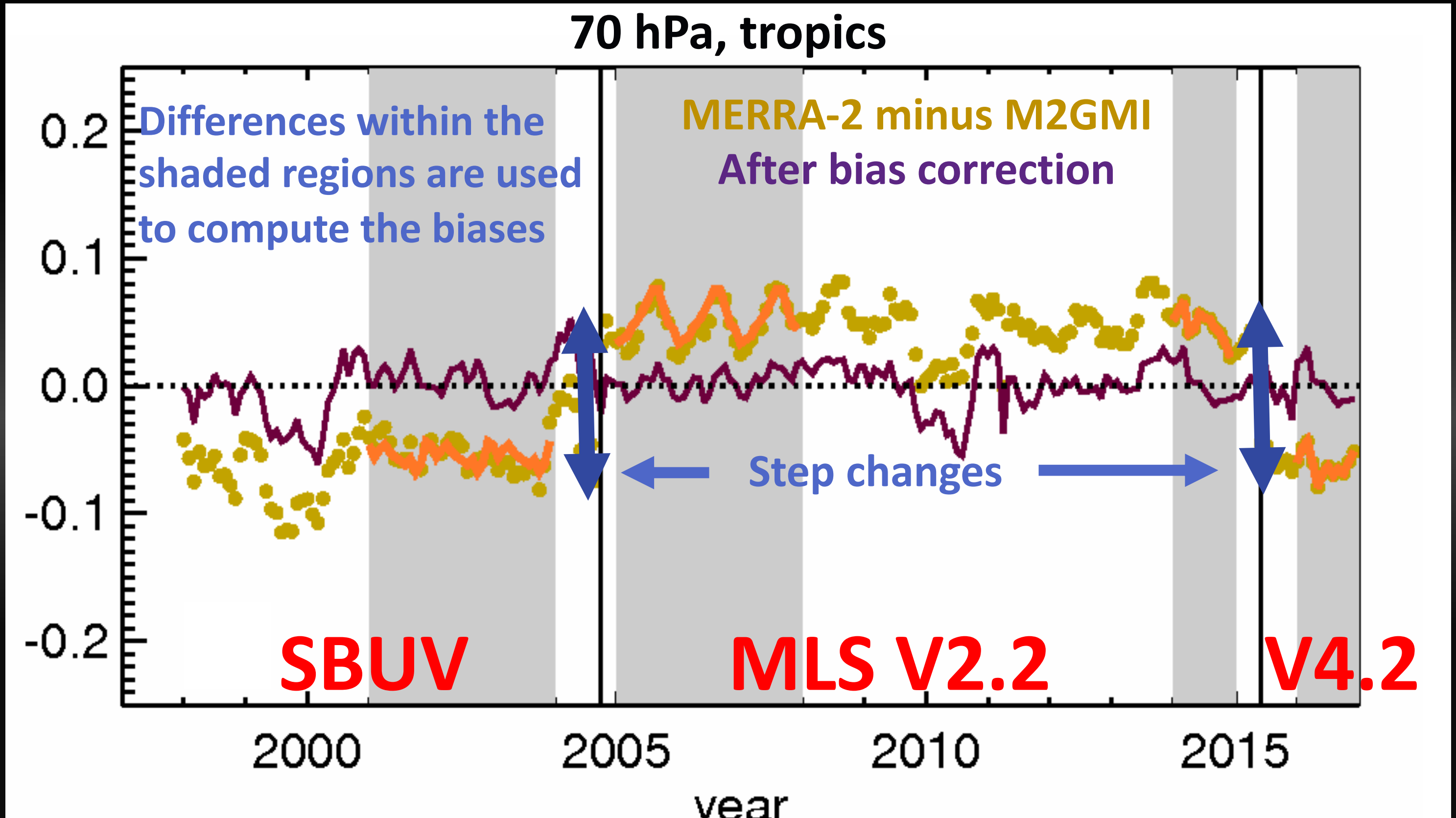


The uptick in the past decade not supported by observations

Davis et al. 2017

Correction of discontinuities

MERRA-2 – M2-GMI difference

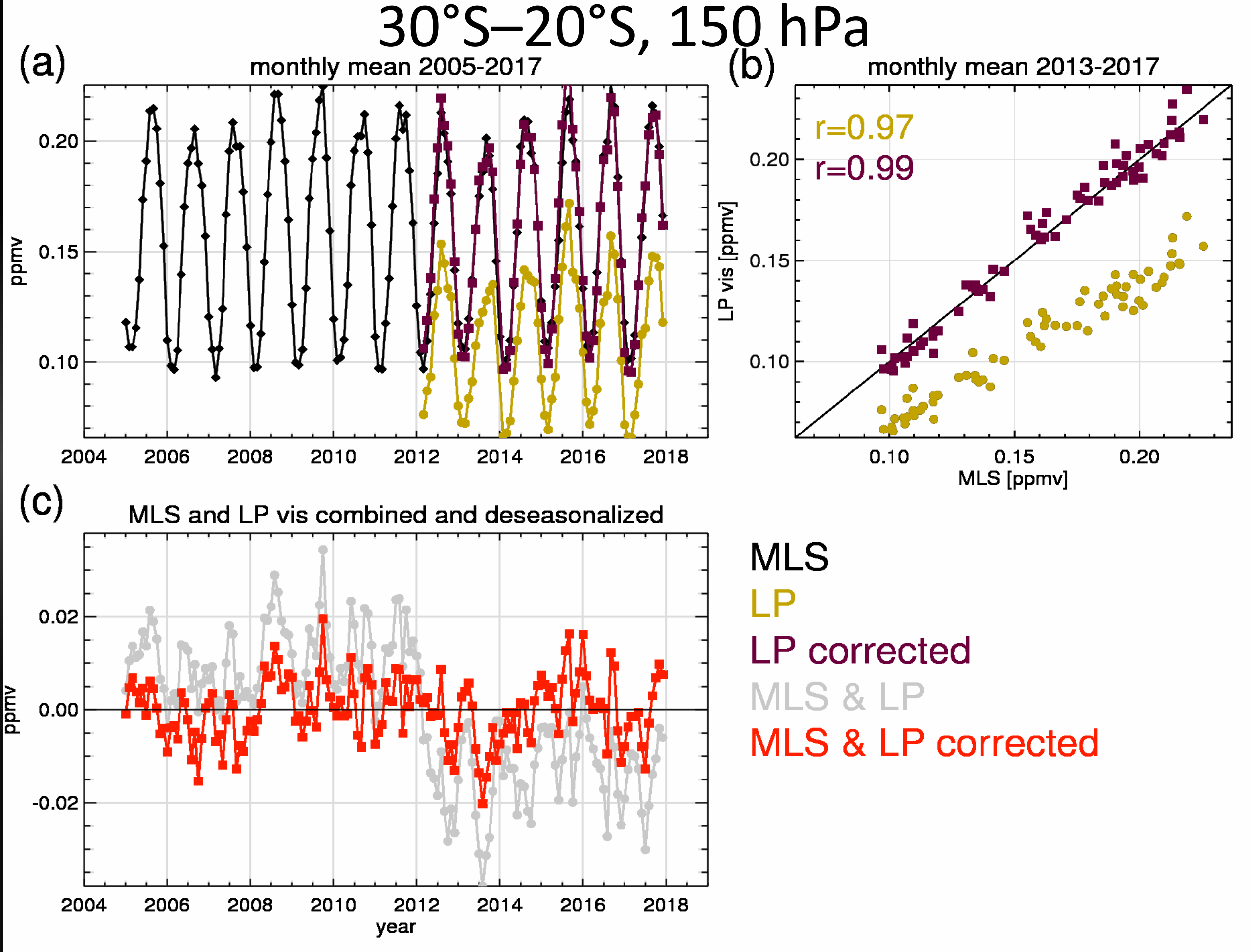


Wargan et al., 2018

In this approach we use a chemistry model simulation driven by assimilated meteorology (M2GMI) as a transfer standard to correct step changes in MERRA-2 ozone that arise from changes in the observing system.

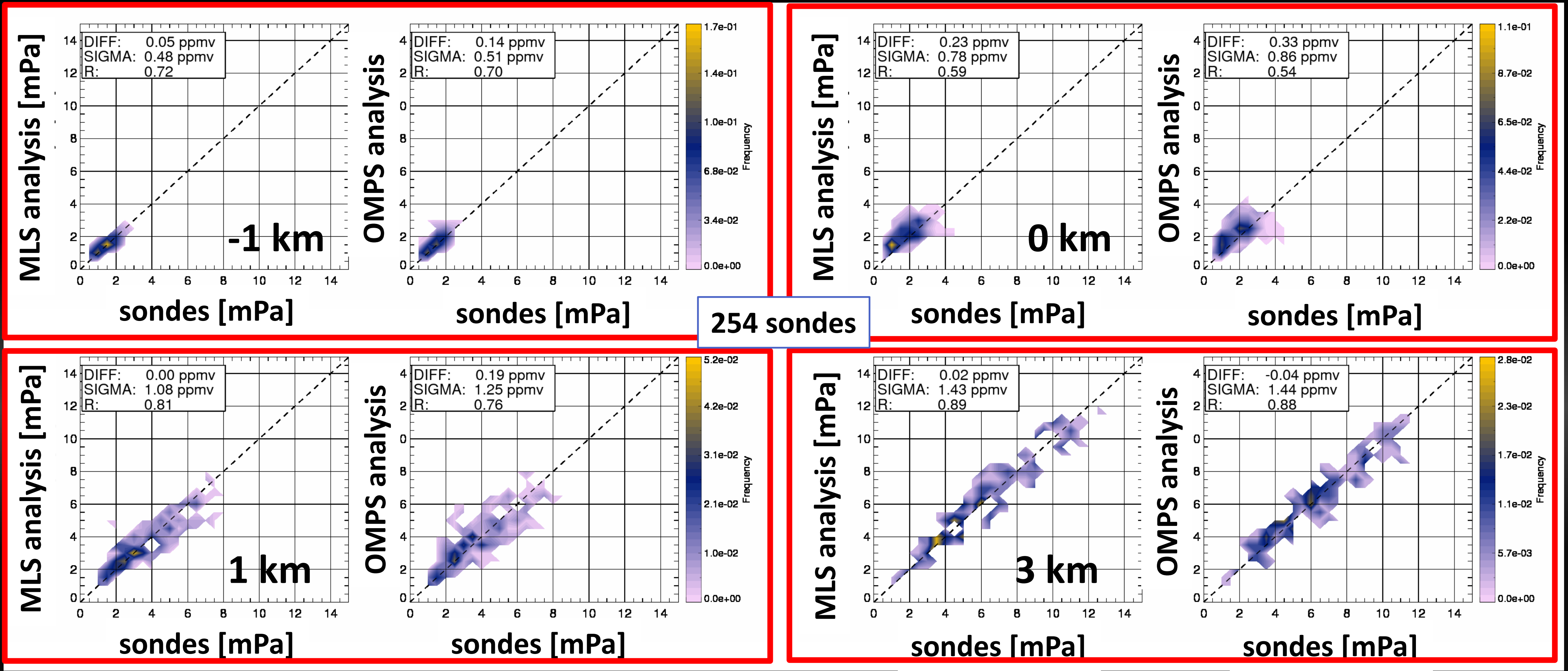
It would be preferable to have a reanalysis output that is already discontinuity-free.

Homogenization of MLS and OMPS-LP data for reanalyses

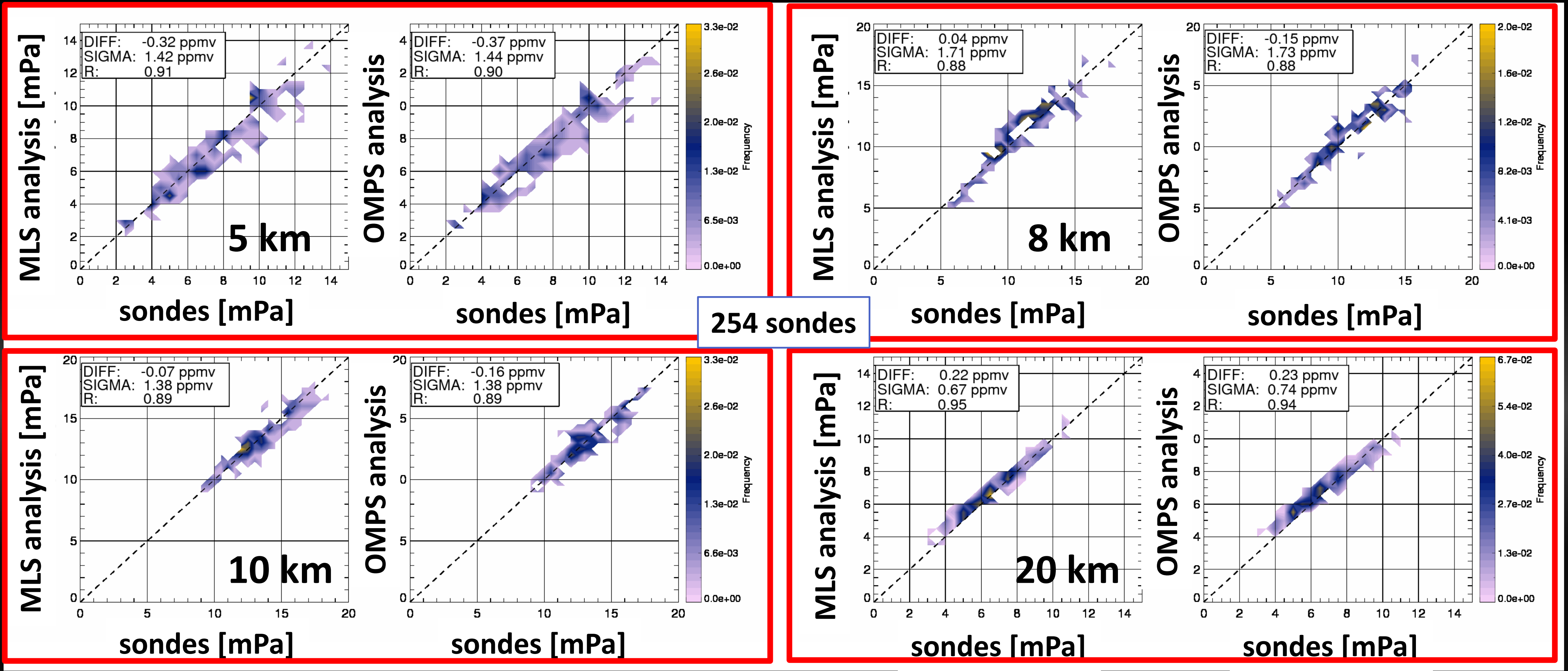


- OMPS Limb Profiler on Suomi NPP (2012–present) and planned for JPSS-2, 3, & 4 well into the 2030s
- Switching from MLS to OMPS-LP (or to assimilating both) would lead to a discontinuity
- The discontinuity is eliminated by simple homogenization
- Assimilation of the homogenized data will eliminate the discontinuity but not the drift in OMPS-LP (not shown)

Sean suggested assimilating water vapor and ozone homogenized the way it was done in SWOOSH



Joint probability distributions of global ozonesonde data and the two analyses at different levels relative to the tropopause. MLS and OMPS-LP analyses exhibit very similar characteristics



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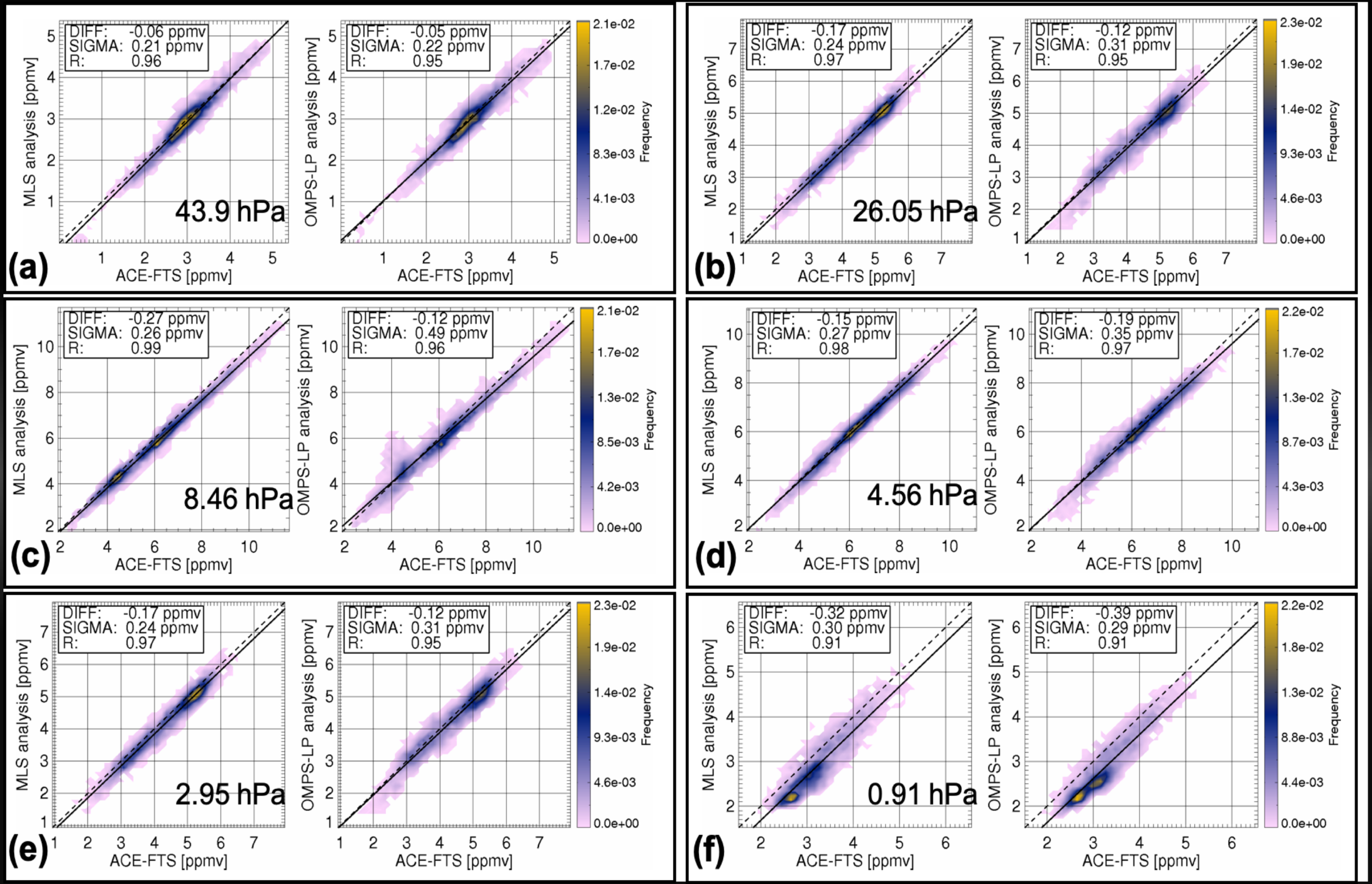


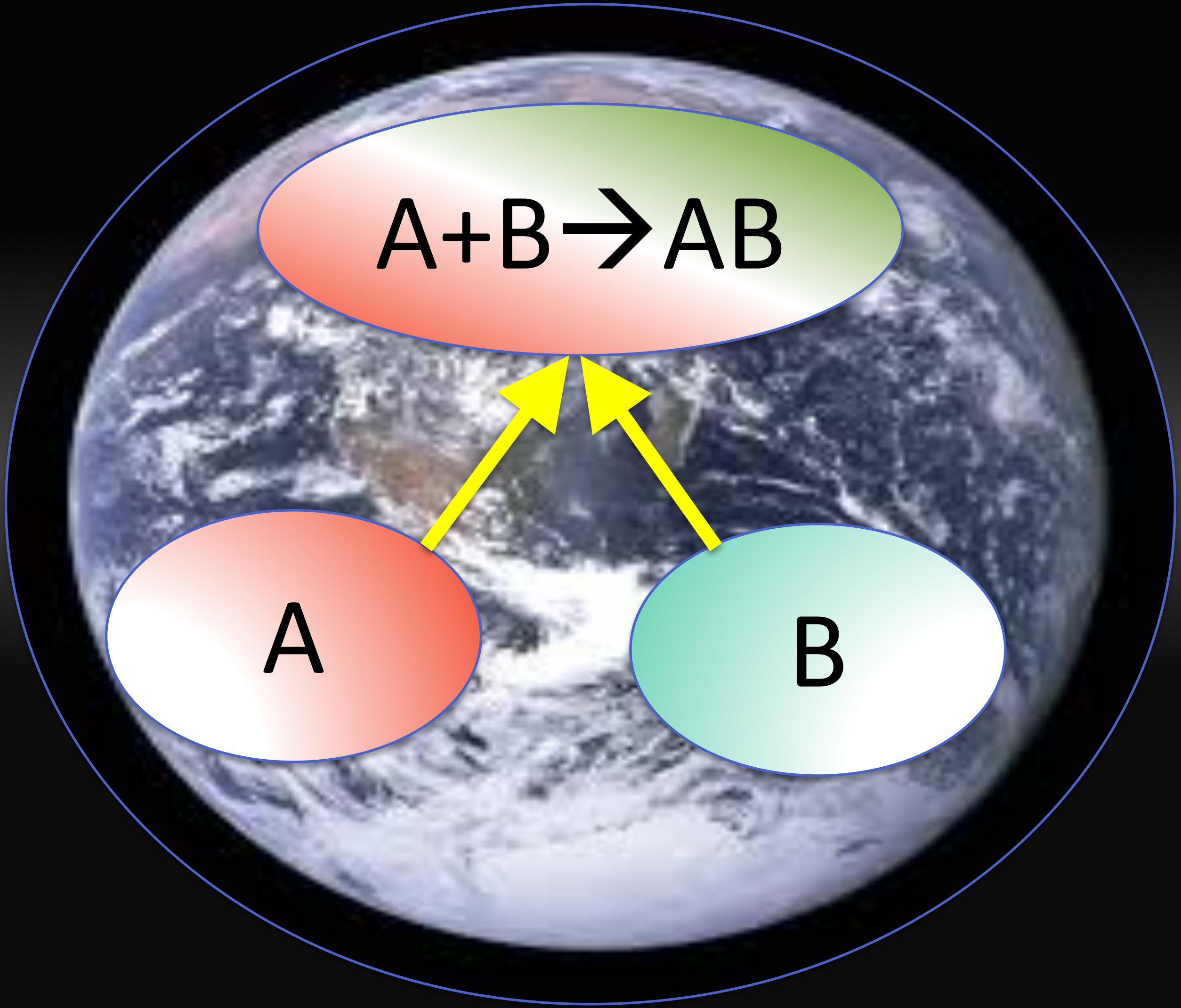
Joint probability distributions of global ACE-FTS ozone and the two analyses at selected pressure levels. MLS and OMPS-LP analyses exhibit very similar characteristics

…and the analyses perform very well, within estimated ACE-FTS/MLS uncertainties

Points made so far

- Achieving continuity of reanalysis ozone

Transport



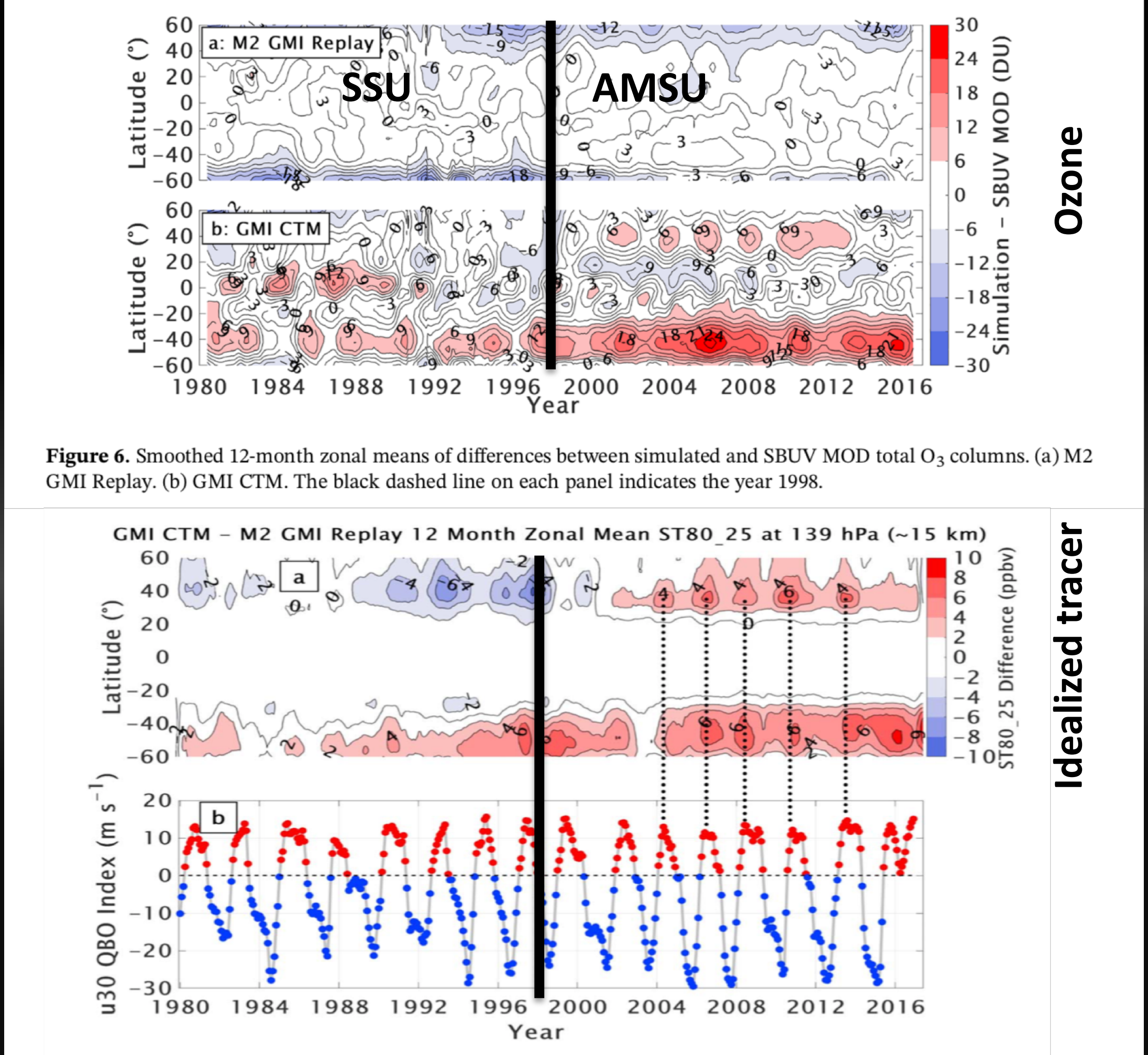


Figure 6. Smoothed 12-month zonal means of differences between simulated and SBUV MOD total O_3 columns. (a) M2 GMI Replay. (b) GMI CTM. The black dashed line on each panel indicates the year 1998.

Stauffer et al. 2019

Two ways of doing specified dynamics:

- CTM
- 'Replay'

Both driven by MERRA-2, both use versions of the GMI chemistry model; CTM has somewhat updated chemistry

Very different response to the 1998/1999 observing system change (TOVS/ATOVS transition), apparently related to QBO-induced transport.

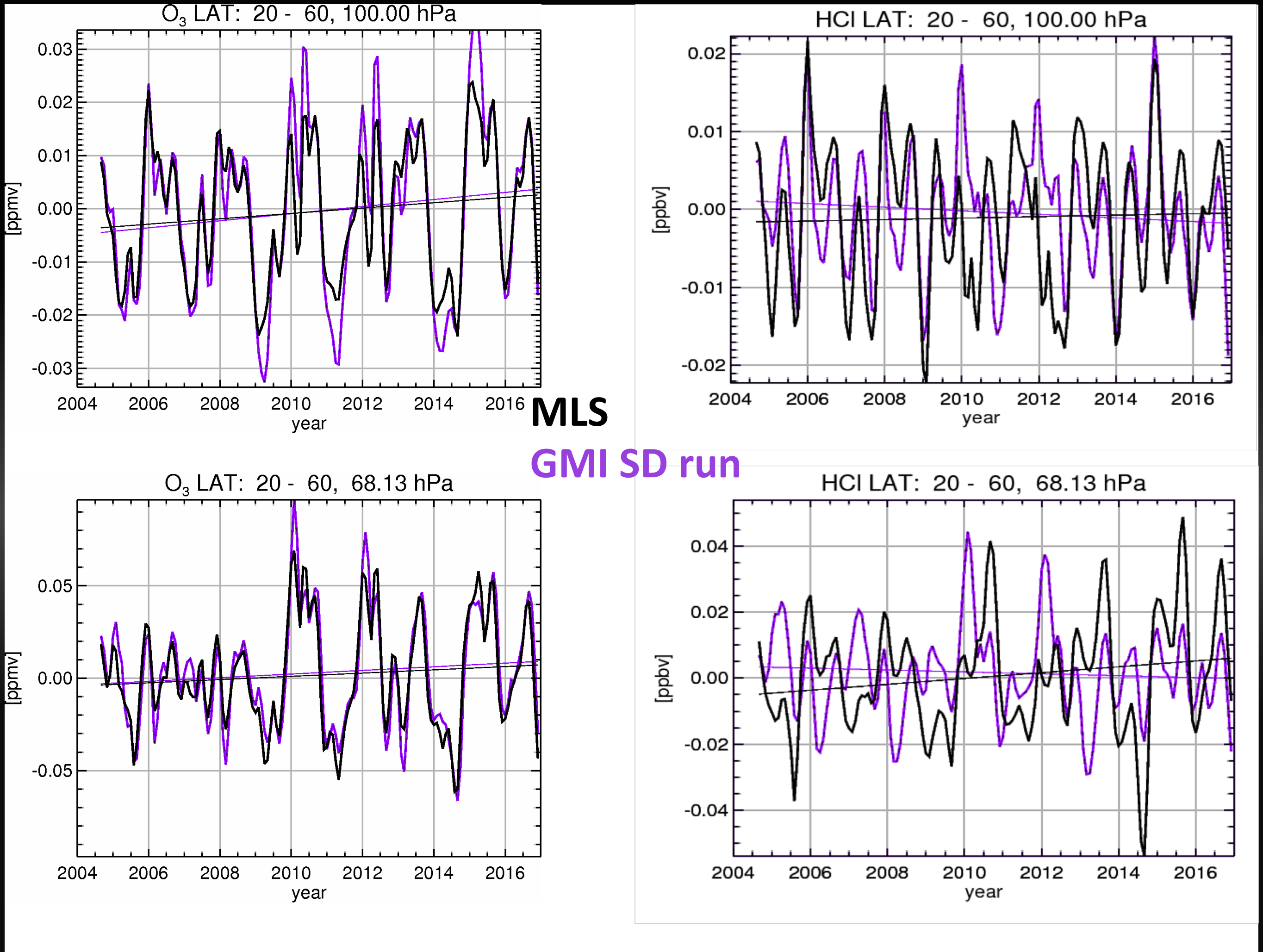
It matters how specified dynamics is done

QBO fit

Ozone

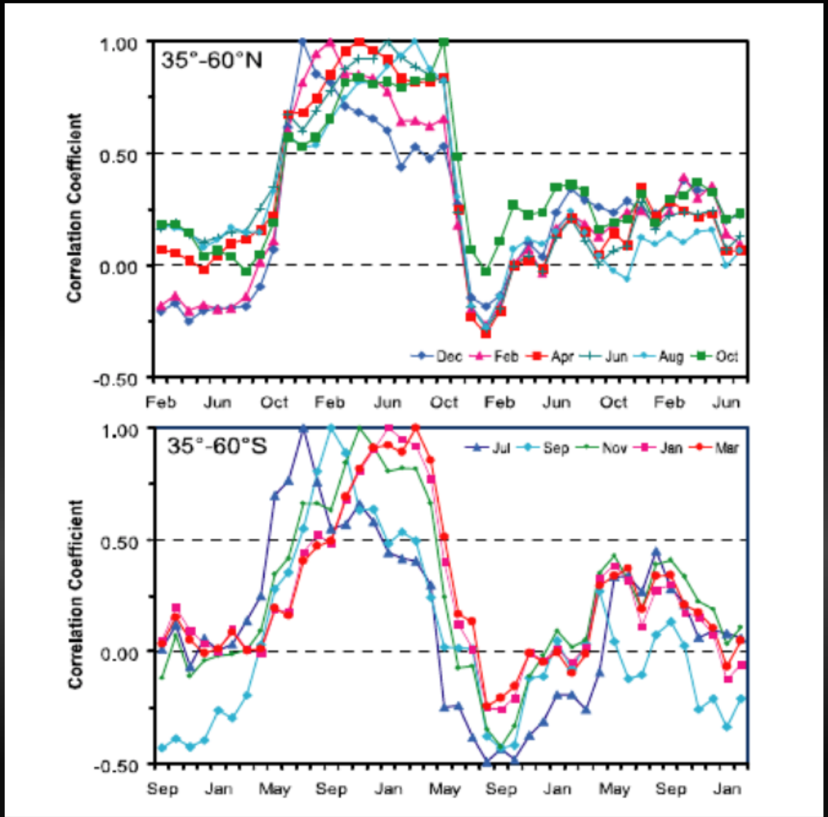
HCl

autumn ozone "resetting"



Good QBO fit for ozone

Bad for HCl



Fioletov & Shepherd 2003

Nothing like this for HCl.

There is no one such thing as transport

Points made so far

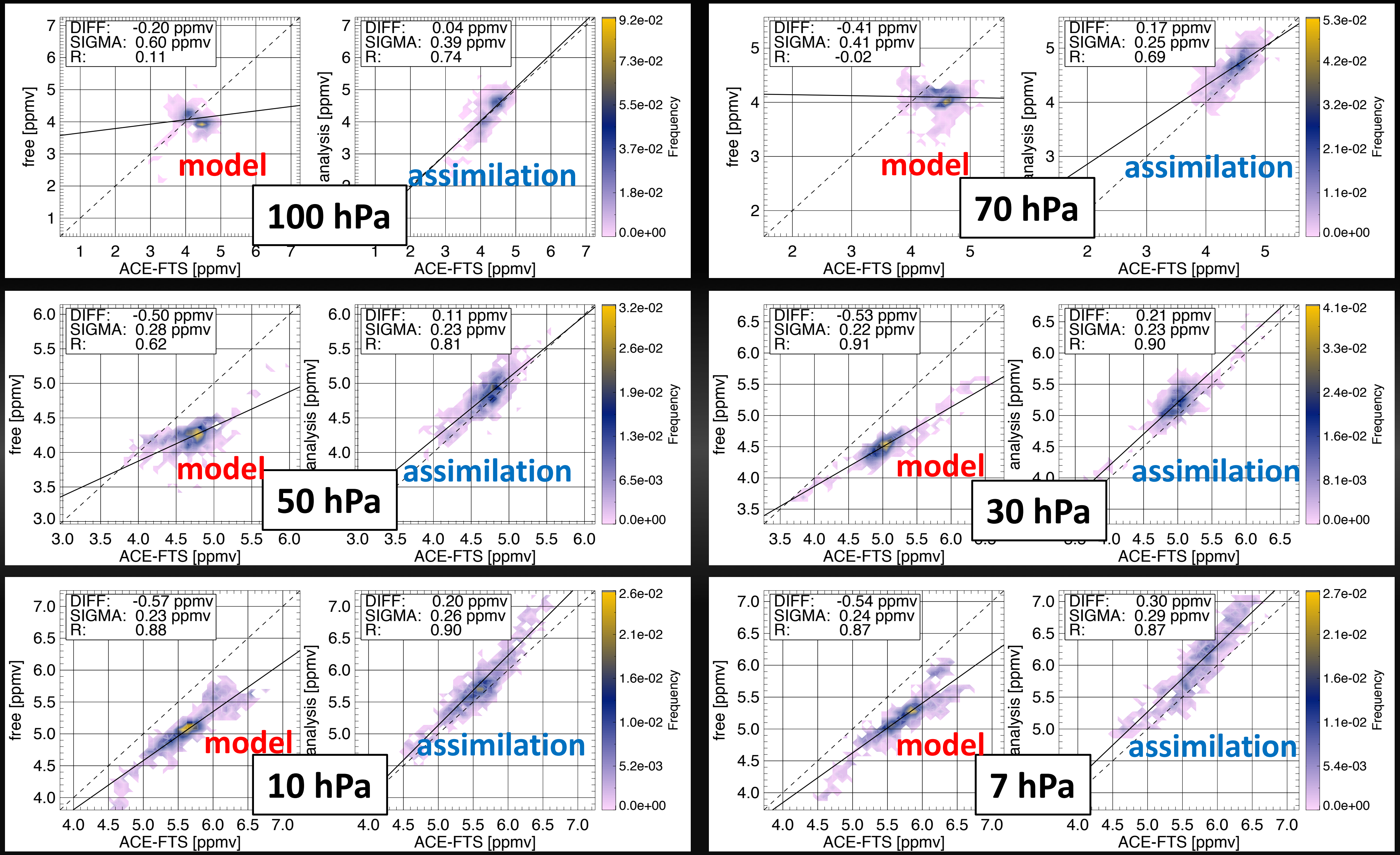
- Achieving continuity of reanalysis ozone
- Importance of transport

A GEOS chemical reanalysis of the stratosphere: work in progress

- 4-year project funded by MAP (Modeling, Analysis, and Prediction)
- A significant extension of NASA GMAO's GEOS Data Assimilation System to include assimilation of several stratospheric constituents beyond ozone
- Currently assimilating: water vapor, HNO_3, HCl from **MLS**
- Planning: N_2O and potentially ClO
- **Goal:** produce an MLS mission-long reanalysis of the stratosphere for chemistry, composition and transport studies. Note, this is similar to the BASCOE Reanalysis of Aura MLS v2 (BRAM2)
  - **Perform a high-resolution multiyear scientific analysis of polar processing during winter and spring in both hemispheres**
  - **Assess the predictability of polar stratospheric ozone and water vapor (WV) fields on short to seasonal time scales**
  - **Investigate the lower stratospheric WV budgets and WV-ozone interactions in the middle latitudes**

Data assimilation system

- This work uses a version o the GEOS general circulation model with a stratospheric chemistry model driven by MERRA-2 meteorology; GMAO analyses to date have used a simple parameterized chemistry scheme
- The chemistry model, StratChem:
  - 51 transported and 17 derived species
  - 149 gas-phase and 39 photolysis reactions
  - Reaction rates follow the recommendations in *JPL 2015*
  - Includes a PSC scheme and heterogeneous reactions
- Currently assimilating ozone, water vapor, HNO3, and HCl data from MLS and total ozone from OMI

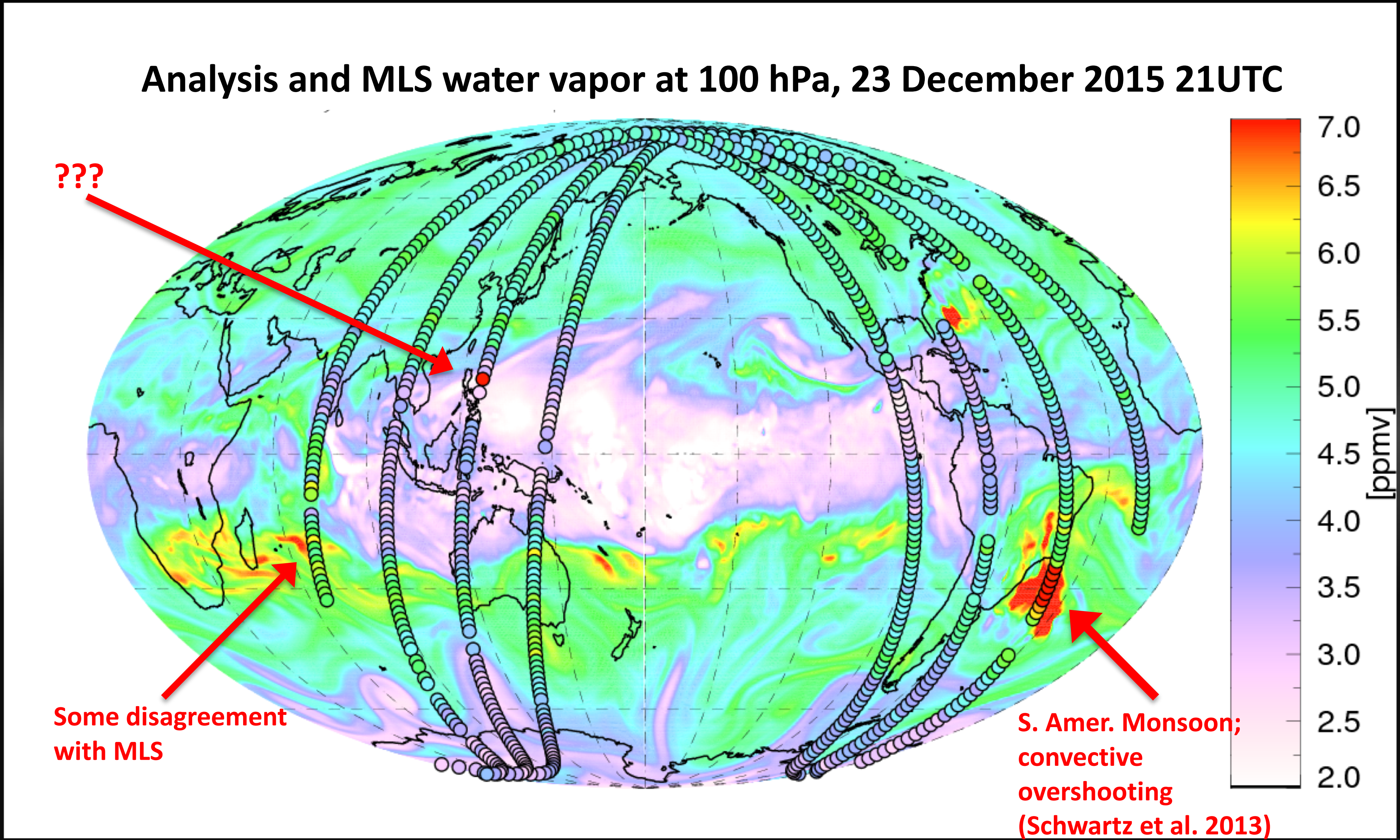


Water vapor

Joint probability distributions: ACE-FTS vs. free run and ACE-FTS vs. assimilation.

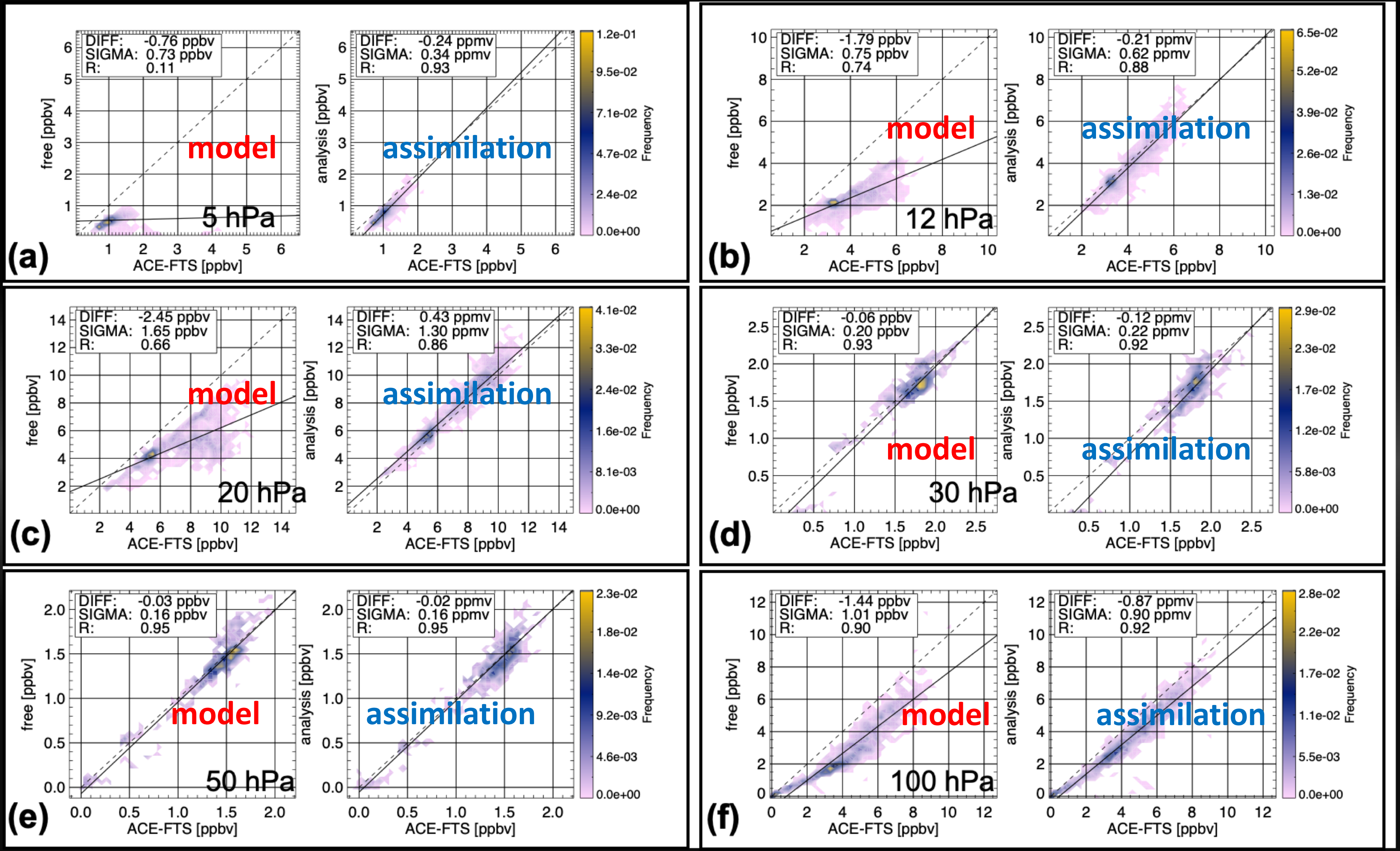
Large positive impact of the assimilation on all statistics at pressures > 50 hPa

Assimilation improves the mean at all levels compared to the model



Good fit to the assimilated data, although there are some outliers. This is the first time stratospheric water vapor has been successfully assimilated in GEOS-DAS.

MLS observations are color-coded by mixing ratio



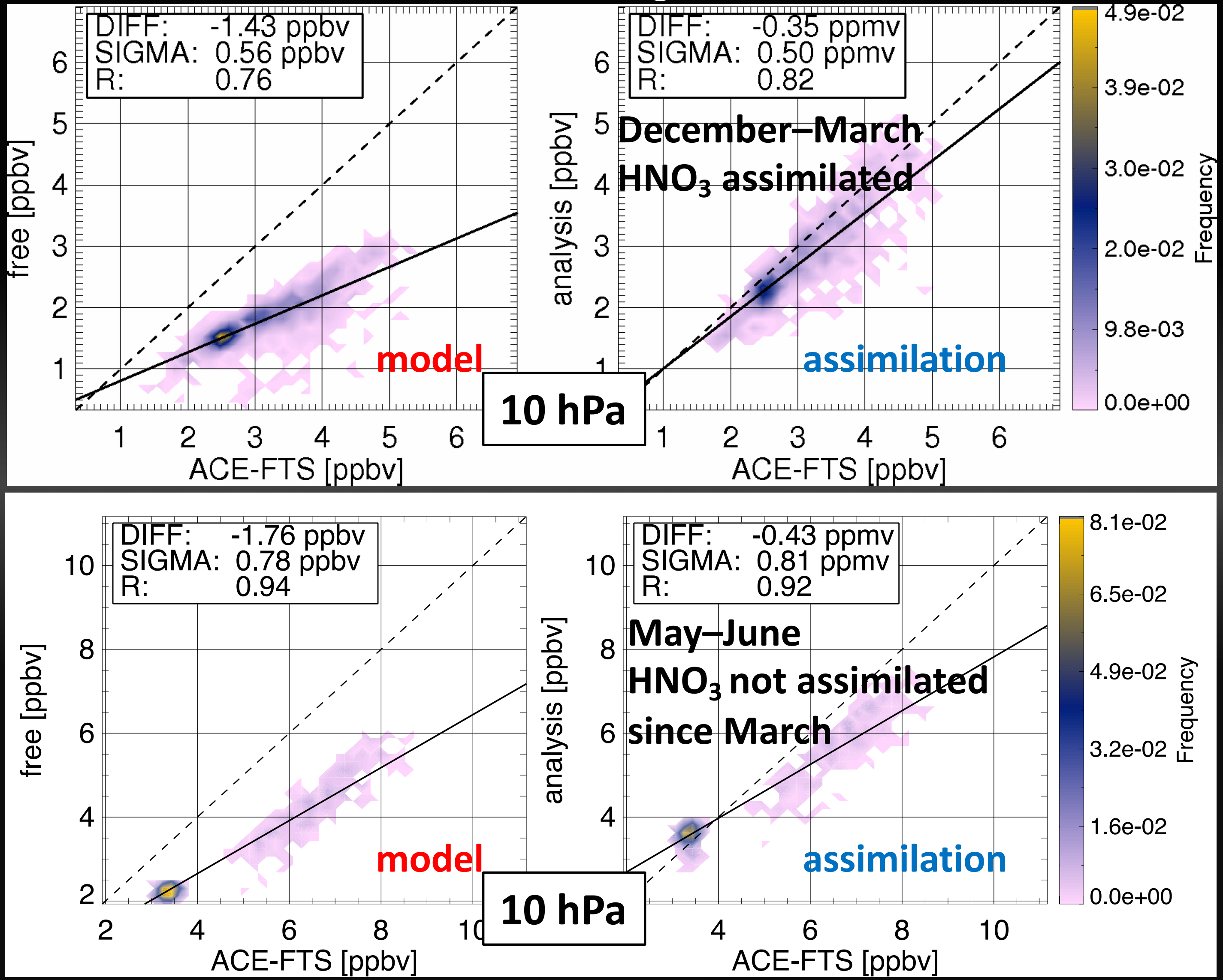
HNO_3

Joint probability distributions: ACE-FTS vs. free run and ACE-FTS vs. assimilation.

Assimilation improves difference standard deviations and correlations in the upper and middle stratosphere.

It improves the mean difference almost everywhere.

HNO_3



An example of feedback through chemistry

Assimilation has lasting effects on the mean HNO_3 several months after the system ceased to see the data. This is very long compared to its chemical lifetime (~1 day).

Predictability

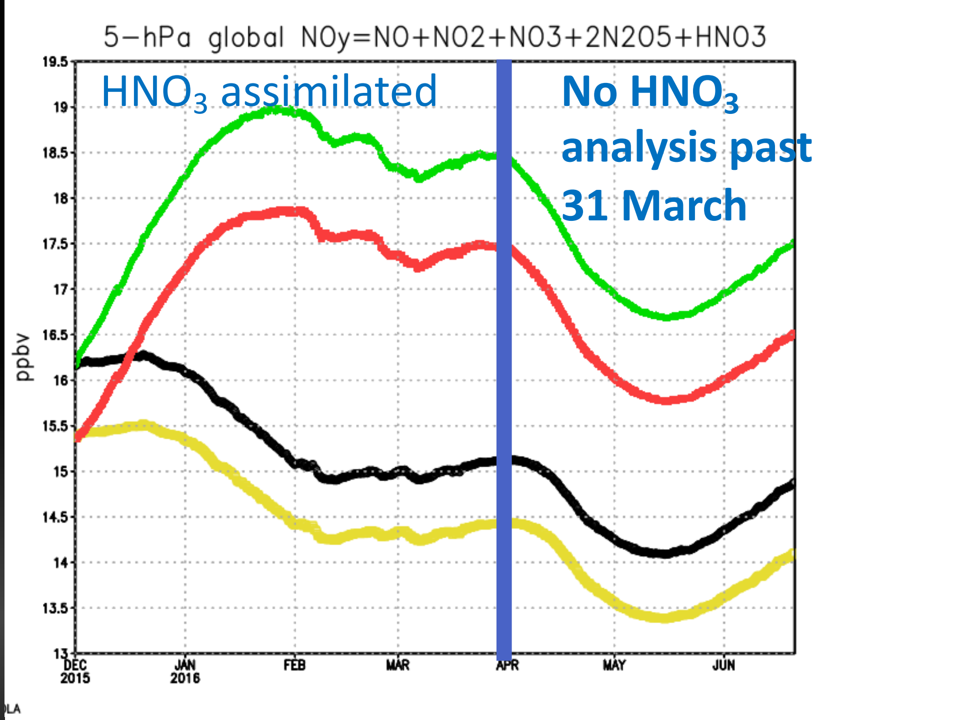
Assimilation of HNO_3 alters the NO_y budget.

NO_y =

$= NO+NO_2+NO_3+$

$+2N_2O_5+HNO_3+ClONO_2$

So, is this good news?



$NO+NO_2+NO_3+2N_2O_5+HNO_3$ free

$NO+NO_2+NO_3+2N_2O_5+HNO_3$ assimilated HNO_3

$NO+NO_2+NO_3+2N_2O_5$ free

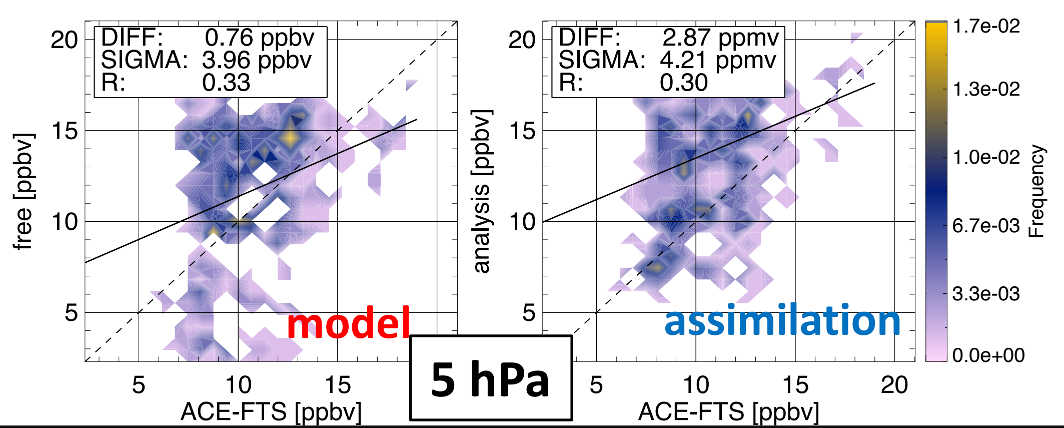
$NO+NO_2+NO_3+2N_2O_5$ assimilated HNO_3

HNO_3 assimilation affects total NO_y and nitrogen partitioning.

This reduces HNO_3 bias but does it improve the other nitrogen species? Not in StratChem

NO, NO_2, N_2O_5 are poorly represented in StratChem but also in GMI. How about other models?

$NO+NO_2+2N_2O_5$



Points made so far

- Achieving continuity of reanalysis ozone
- Importance of transport
- Interconnectivity, predictability, and feedbacks in chemical DA; impact on non-assimilated species

Challenges, questions

- MLS and MIPAS provide observations of many key constituents for chemical reanalyses of the stratosphere, 2003 (to be generous) to present. What happens when MLS is gone? Connection with Theme 3.
- More fundamentally: what is the minimal set of observed stratospheric constituents?
- What is the best strategy for eliminating systematic differences between data sources?
- What do we do about drifts (MLS WV and N_2O, OMPS-LP ozone)
- Focus on transport:
  - Do we assimilate constituent data into a SD simulation? What's the right way to do specified dynamics to achieve fidelity of transport?
  - Do we assimilate constituents within a full data assimilation system (along with meteorology)? Is that computationally feasible?
  - In either case, how do we address discontinuities in the analyzed meteorology?
- What is the impact of constituent assimilation on non-assimilated species/families? How well are the latter represented? Implications for predictability

Potential discussion points

- What science questions can stratospheric chemical reanalyses address?
  - A comprehensive assessment of what a reanalysis can and cannot do would be useful
  - How can we effectively communicate all this to other researchers?