Evaluation of MERRA-2-based Ozone Profile Simulations with the Global Ozonesonde Network

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O_3 Hindcasts Using MERRA-2 (1980-2016)

- We use ozonesonde data from global networks to evaluate the O_3 profiles in two model simulations (1980-2016) that use NASA's Modern-Era Retrospective Analysis for Research Applications, Version 2 (MERRA-2; Gelaro et al., 2017; J. Climate) meteorology and Global Modeling Initiative (GMI) chemical mechanisms:

M2 GMI Replay (Orbe et al., 2017)

- 0.625°x0.5°horizontal resolution, 72 vertical levels
- Uses Replay technique to recalculate u, v, T, and p from 3hr average MERRA-2 fields (two forecasts per time step)

GMI CTM (Strahan et al., 2016)

- 1°x1.25° horizontal resolution, 72 vertical levels
- Driven by 3hr average MERRA-2 meteorology fields in a traditional offline CTM
- Uses a newer version of the GMI chemical mechanism

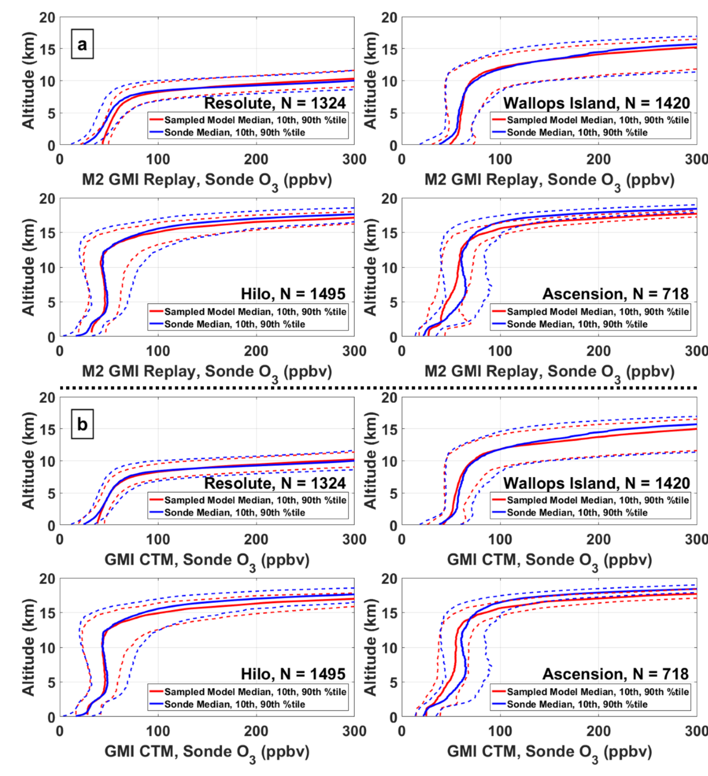

Fig. 1: Example comparisons of median, 10th, and 90th percentile O_3 profiles at four sites for M2 GMI Replay (top, a) and GMI CTM (bottom, b). Sonde O_3 is in blue, with coincident model O_3 output in red. Sites shown here represent four latitude regions: Polar (Resolute), Midlatitude (Wallops Island), Subtropical (Hilo), and Tropical (Ascension).

1) How well do models driven by MERRA-2 meteorology simulate historical O_3 (1980-2016) from the surface to the lower stratosphere (LS)?

2) Are there major differences in how Replay and CTM simulate O_3? How do differing GMI chemical mechanisms in the models affect comparisons with ozonesonde data?

Model/Ozonesonde Comparisons

- **Fig. 2** shows the median differences between modeled and ozonesonde O_3 at 38 sites from surface-8 km (~50,000 total profiles) for **M2 GMI Replay** (top) and **GMI CTM** (bottom)
- **M2 GMI Replay** (top) shows an average lower-tropospheric O_3 bias of +10 ppbv. **GMI CTM** (bottom) surface O_3 biases are small
- Both models show much lower O_3 in the tropical troposphere compared to ozonesondes (>25% low at Atlantic sites like Ascension and Natal)

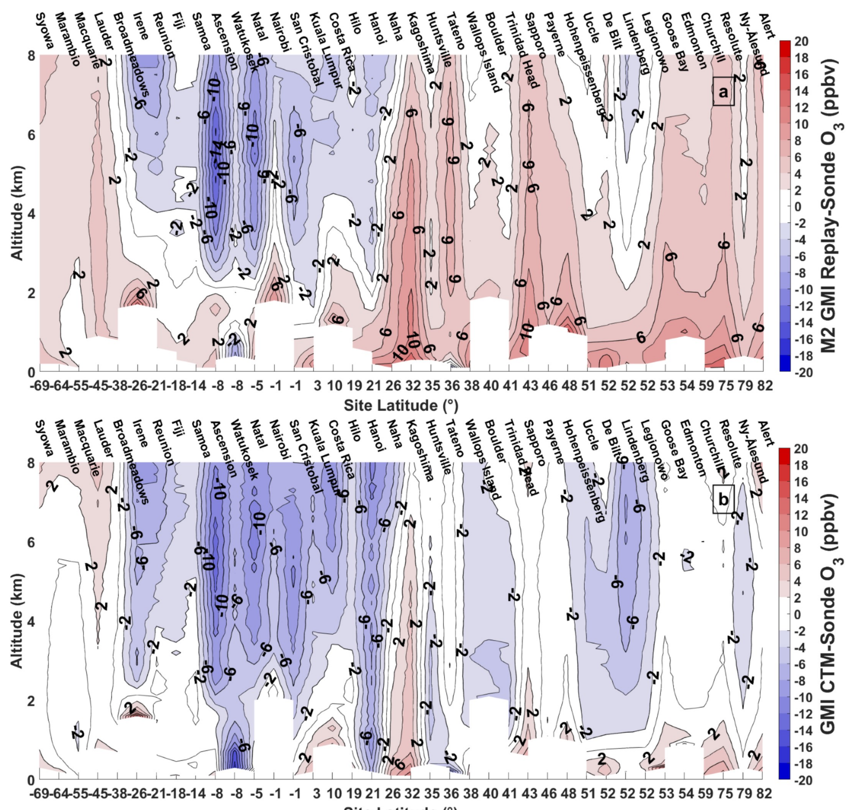

Fig. 2: Latitude-height curtains of median O_3 mixing ratio differences between all ozonesonde profiles and coincident M2 GMI Replay (top) and GMI CTM (bottom) O_3 profiles. Blue colors indicate that the modeled O_3 is biased low, and red colors indicate that the model is biased high.

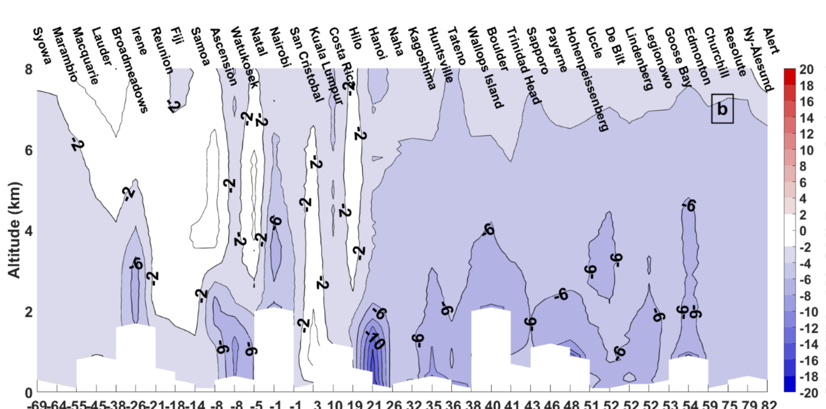

Fig. 3: Latitude-height curtain of median O_3 mixing ratio differences between GMI CTM and M2 GMI Replay O_3 profiles. Blue colors indicate that the GMI CTM O_3 is on average lower than M2 GMI Replay throughout the low-to-mid troposphere for all latitudes.

- [GMI CTM - M2 GMI Replay] O_3 shows that **GMI CTM tropospheric O_3 is lower** at all latitudes (**Fig. 3**, right)
- This appears to be a consequence of a newer GMI chemical mechanism, which reduces surface O_3 biases to near-zero

The "Tropical Wave-One" O_3 Feature

- The wave-one is a persistent, longitudinal feature in tropical tropospheric O_3 (**Fig. 4**, top) that results from the ascending branch of the Walker Circulation (low O_3) in the western Pacific, and seasonal biomass burning and descending air (high O_3) over the Atlantic
- Both models reproduce the longitudinal O_3 pattern (**Fig. 4**, middle), but model biases are larger than -15 ppbv (-25%; **Fig. 4**, bottom) in the tropical Atlantic mid-troposphere, where biomass burning effects are common
- This likely indicates that the model transport of O_3 associated with the Walker Circulation is accurate, but that both models greatly underestimate biomass burning-produced O_3. These low biases are unchanged over the last 20 years

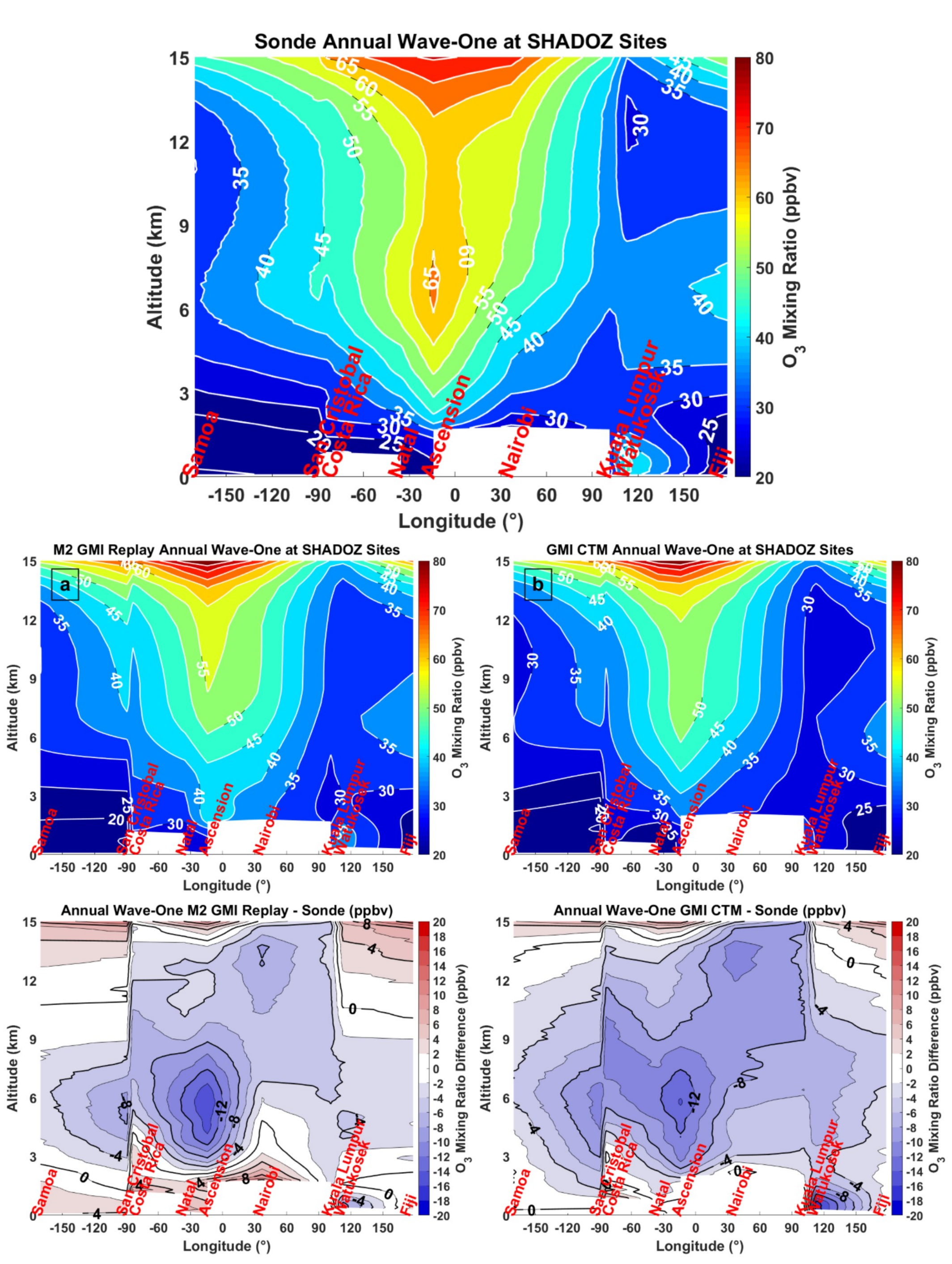

Fig. 4: Longitude-height cross sections of the "Tropical Wave-One" O_3 feature. The top panel shows the ozonesonde measurements at several Tropical (and one Subtropical; Fiji) locations. Column (a) shows the coincident M2 GMI Replay Wave-One Feature, and the median O_3 mixing ratio bias. Column (b) is the same as (a), but for GMI CTM. The site locations are listed on each panel.

Assimilation Changes (ATOVS Transition)

- Profile comparisons of M2 GMI Replay and GMI CTM with ozonesondes show changes from 1980-2016 (**Fig. 5**, right)
- In general, tropospheric biases compared to ozonesondes are getting smaller, but a LS shift is evident in 1998
- Starting in 1998, the MERRA-2 assimilation system incorporates data from a new generation of satellite sounders, known as **ATOVS** (Advanced TIROS Operational Vertical Sounder; first on NOAA-15)
- The change from TOVS to ATOVS introduced a step change in O_3, particularly in GMI CTM (**Fig. 5**, circle on bottom)
- The shift in LS O_3 in GMI CTM leads to a ~10 Dobson Unit (DU) increase in midlatitude total O_3, worsening the agreement among models, and sondes/satellites
- **Fig. 6** (below) shows total column O_3 comparisons with the satellite-based Merged Ozone Dataset (MOD). M2 GMI Replay shows a relatively stable O_3 record; GMI CTM shows a large jump in total O_3 after 1998

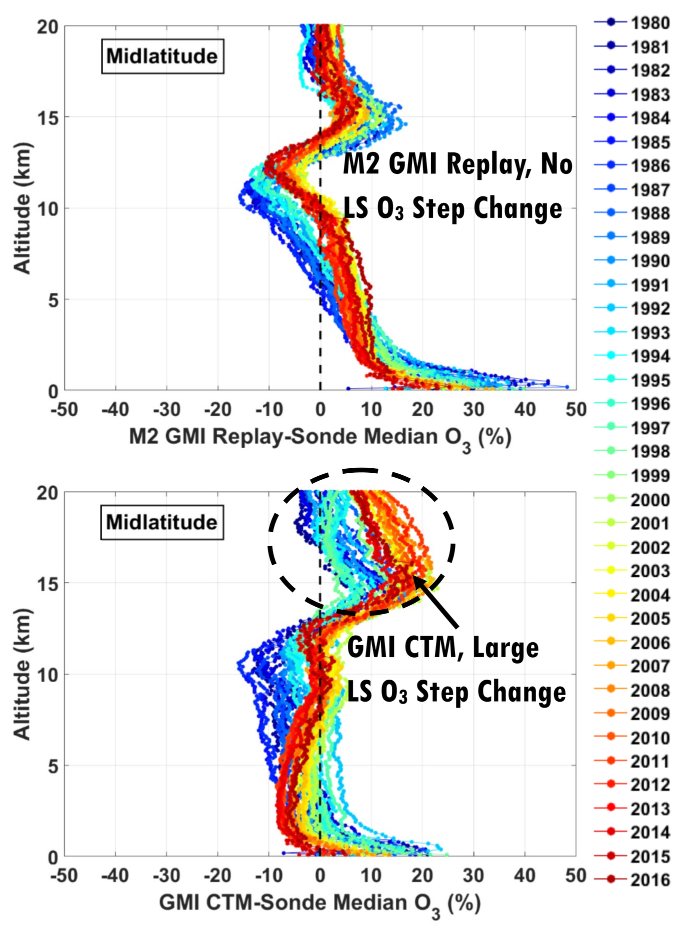

Fig. 5: Median percent O_3 differences with altitude for M2 GMI Replay (top) GMI CTM (bottom) by year from 1980 to 2016 (colors). A black circle highlights the step change in GMI CTM lower stratosphere O_3. Comparison is composited from 19 midlatitude ozonesonde sites.

- Comparisons of the tracer "ST80_25" (**Fig. 7**, top panel) shows that GMI CTM is transporting more air from the mid-stratosphere to the lower stratosphere than M2 GMI Replay
- The tracer differences have a distinct periodicity that follows the Quasi-Biennial Oscillation (QBO; **Fig 7**, bottom panel). This is the same pattern observed in the total O_3 differences between GMI CTM and satellites in **Fig. 6**
- It appears that GMI CTM transports too much O_3 to the midlatitude LS, particularly during the westerly phase of the QBO (see arrows on **Fig. 7**)
- M2 GMI Replay LS and total O_3 is mostly unaffected by the ATOVS transition in 1998, at least compared to GMI CTM

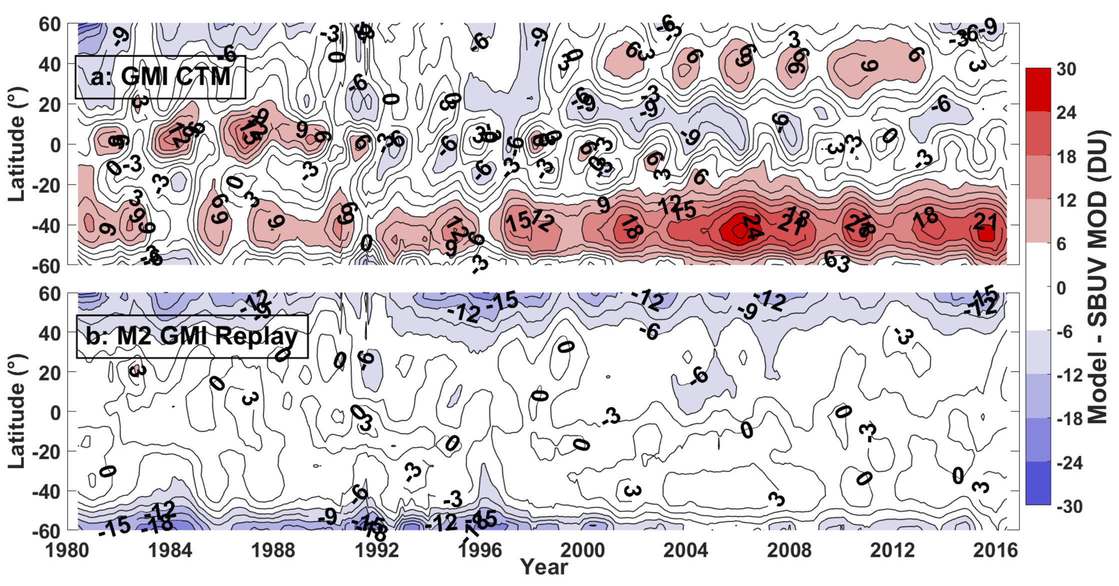

Fig. 6 (Top): 12-month zonal means of differences between modeled and SBUV MOD total O_3 columns. Panel (a) shows GMI CTM, and panel (b) shows M2 GMI Replay.

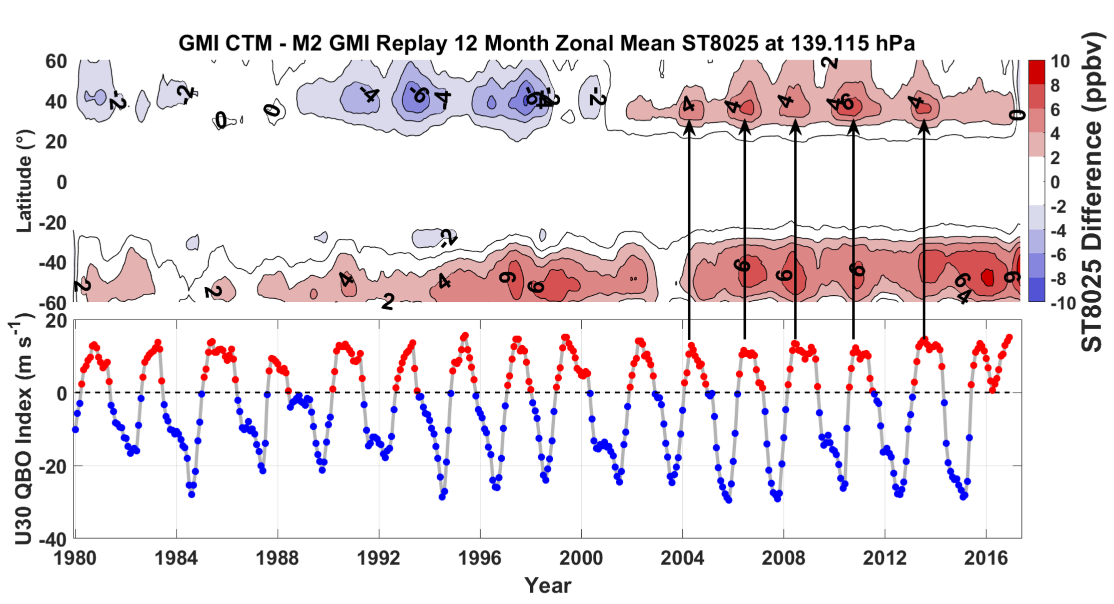

Fig. 7 (Bottom): 12-month zonal mean differences in the GMI CTM and M2 GMI Replay ST80_25 stratospheric tracer at the 139 hPa model level. Bottom Panel: The U30 QBO Index colored by positive (red; westerly phase) and negative (blue; easterly phase). Arrows on the Figure indicate the alignment of peak westerly phase values with maximum differences in ST80_25 tracers.

Summary/Future Approaches

- Compared to ozonesonde data (1980-2016), both M2 GMI Replay and GMI CTM show strong negative O_3 biases in tropical tropospheric O_3, though the modeled O_3 is highly correlated with sonde data (not shown here). Model biases with ozonesondes generally become smaller in recent years in the model simulations
- M2 GMI Replay near-surface O_3 is biased high by 10-30% at all latitudes. An updated GMI chemical mechanism in the GMI CTM reduces the high O_3 bias to near-zero. A new Replay model run using the updated mechanism will be completed soon to isolate the effects of CTM vs. Replay
- The incorporation of ATOVS satellite data into MERRA-2 starting in 1998 causes a large step change in LS O_3. This is most prevalent in the GMI CTM, which transports too much O_3 to the midlatitude LS. We will investigate potential changes to the model stratospheric circulation, and investigate why M2 GMI Replay appears to be less affected by the assimilation change than GMI CTM

Acknowledgments

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Select References:

- **Ozonesonde Data Sets:** Stauffer, R. M., A. M. Thompson, and J. C. Witte (2018), Characterizing global ozonesonde profile variability from surface to the UT/LS with a clustering technique and MERRA-2 reanalysis, *J. Geophys. Res. Atmos.*
- **M2 GMI Replay:** Orbe, C., L. D. Oman, S. E. Strahan, et al. (2017), Large-scale atmospheric transport in GEOS replay simulations, *J. Advances in Modeling Earth Systems.*
- **GMI CTM:** Strahan, S. E., A. R. Douglass, and S. D. Steenrod (2016), Chemical and dynamical impacts of stratospheric sudden warmings on Arctic ozone variability, *J. Geophys. Res. Atmos.*