Response to Anonymous Referee #2

General comment #1:

- P6 L19-20: Since you include tropical upwelling as part of the TST, I would suggest including extratropical downwelling as part of the STT. You actually include it in the classification in Section 4.5 when referring to trends in the time series, so why not explicitly include it from the beginning?

  P6 L31-33 now reads: "Exchanges in the extratropics and tropics, however, are associated with other processes, such as extratropical cyclones, stratospheric intrusions, downwelling in the extratropics and upwelling in the tropics."

General comment #2:

- P10 L19: In the analyses of the annual cycle, I would suggest separating three regions: tropics, NH extratropics, SH extratropics. As it is, the annual cycle is mixing several different mechanisms and perhaps this alternative separation would provide clearer insights on the causes of the differences among reanalyses.

  Based upon the suggestion, we adjusted the annual cycles as recommended and found that the differences in NH TST were eliminated (updated Figure 9). Furthermore, the tropical annual cycles (updated Figure 10) reveal more separation between the reanalyses and show two preferred modes of TST: weakly bimodal for JRA-55 and ERA-Interim and unimodal for both MERRA reanalyses. These changes take place from P10 L25 to P12 L9 in the revised manuscript. The revised figures are provided below.

  Figure 9:

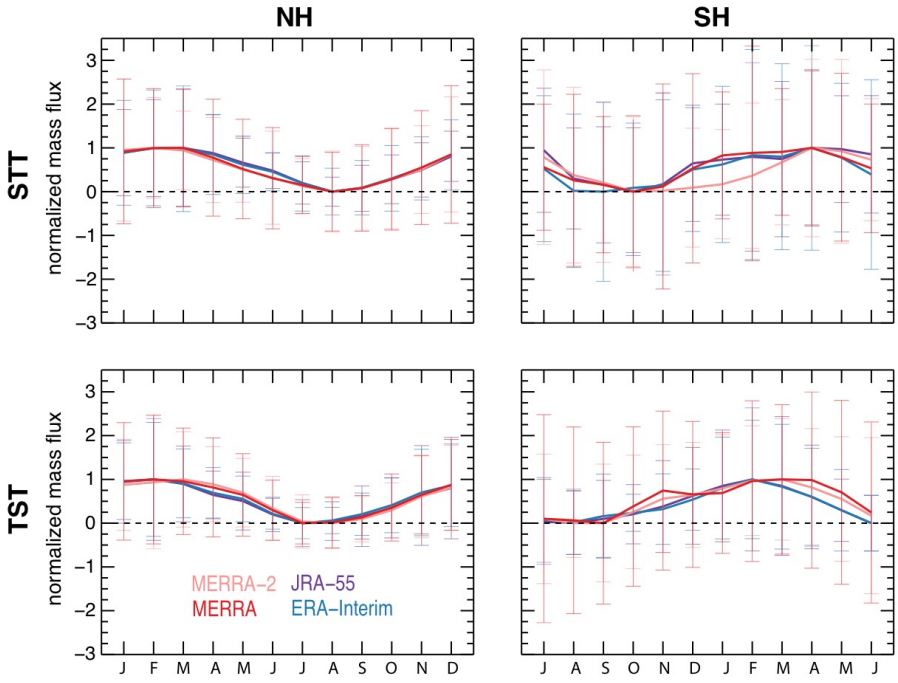
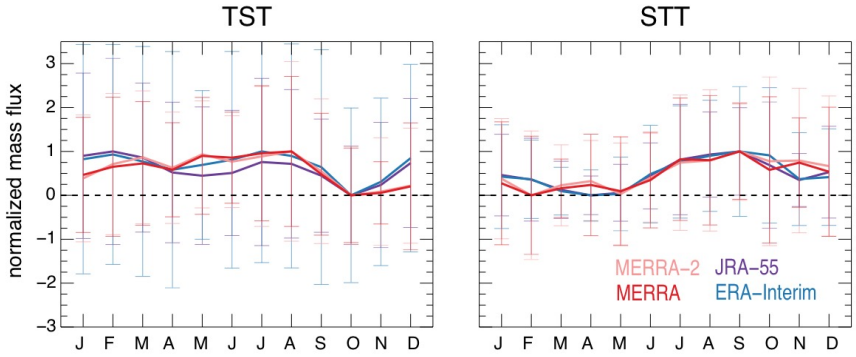


Figure 10:



Specific comment #1:

- P12 L21-26: How do the results in this study compare to previous studies explicitly looking at the BDC in reanalyses (Abalos et al. 2015 JGR-A, Miyazaki et al. 2016, ACP)?

  P13 L4-11 now reads: "Changes in the speed of the BDC have been examined in previous studies. For example, Abalos et al. (2015) evaluated the dynamics of the BDC using ERA-Interim, JRA-55, and MERRA and show that there is general agreement in a strengthening BDC over the period 1979-2012 by 2-5% per decade. Observational studies show decreases in tropical stratospheric water vapor, ozone, and temperature observed by satellite, which also corresponds to an increase in tropical upwelling associated with an accelerated BDC (Randel et al., 2006). Chemistry- climate models have also indicated an acceleration of the BDC over time (e.g., Austin and Li, 2006). These previous reanalysis, observational, and modeling studies are consistent with the results from ERA-Interim and JRA-55 here, while MERRA-2 is in disagreement and MERRA does not indicate changes in the BDC over time in our analysis."

Specific comment #2:

- Section 4.6.2 Diagnostics: I am missing some discussion at the end of the section connected these diagnostics to the previous results shown in the paper. For instance, are the differences in tropopause height and/or jet location consistent with more extratropical TST in MERRA?

  We have significantly altered section 4.6.2 in the revision and attempted to better connect the diagnostics with STE results.

Specific comment #3:

- Section 5.2 Discussion: Please add some discussion on how your estimates compare quantitatively with previous works highlighted in the introduction.

  P16 L21-29 now reads: "Third, as referred to in the Introduction, large quantitative uncertainties in STE exist from previous Eulerian and

Lagrangian STE studies. In particular, estimates for STE have often been limited to specific regions or time periods or based on inadequate and/or incomplete methods (compared to that possible with current methods and computational abilities). Here, we found that mean net STE magnitudes also range considerably when an equivalent method is applied to multiple modern reanalyses (e.g., see Table 1). However, few previous studies enable direct comparison with our estimates. In particular, the alternative PV-based approach by Škerlak et al. (2014) is arguably the most direct, where ERA-Interim net STE integrated globally over the 15 yr period in our study is approximately 1.48×10^{17} kg/yr downward (STT), while it is about 3.5 times smaller (4.2×10^{16} kg/yr) in the Škerlak et al. (2014) study. These differences do not necessarily suggest that one method is superior to the other, but that two largely similar Lagrangian approaches can yield substantially different results due to the employed troposphere-stratosphere boundary (e.g., see Figs. 2 & 3)."

Technical comments/suggestions and responses:

- P1 L15: "has important and significant": perhaps redundant?
  This has been changed to "has significant"

- P1 L20: although water vapor is a greenhouse gas, is it considered a pollutant?
  Thank you for pointing out this misleading remark. This has been revised to "water vapor and tropospheric pollutants, such as carbon monoxide, …"

- P5 L13: "pvu" should be PVU
  Corrected.

- P5 L16: "about 750 m in the extratropical UTLS to about 1100 m in the tropical UTLS". You could specify an approximate range of altitudes corresponding to the extratropical and tropical UTLS.
  We have now specified approximate altitude ranges at P5 L27.

- P5 L23: "6 billion". It is better to write $6\bullet10^{9}$, to avoid confusion with the word billion.
  Done.

- P6 L4: "affects" should be effects.
  Done.

- P8 L17: "East Pacific should be West Pacific, right?
  Yes, this has been corrected.

- P9 L31: "…STE mass flux" I suggest adding (TST-dominant)
  Done.

- P11 L28: “normalize” usually refers to dividing by the time mean, while what you did was compute the anomalies with respect to the mean.

  P12 L13-14 now reads: “In Fig. 13, global time series of STT anomalies and TST anomalies are shown with respect to their mean mass fluxes (i.e., 15-yr means are removed).”

- P12 L17: suggestion for clarity: “… show increasing vertical STT in the extratropics and TST in the tropics, whereas…”

  Done.

- P15 L27: suggestion: remove “there to be”

  Done.

- P15 L29-30: Sentence not clear, rephrase

  P16 L8-9 now reads: “Taken together, these physical and dynamical differences may be significant sources of variability for climatological analyses and it is likely that they contribute to some of the STE differences observed in this study.”