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Interactive comment on "Relationship between Asian monsoon strength and transport of surface aerosols to the Asian Tropopause Aerosol Layer (ATAL): Interannual variability and decadal changes" *by* Cheng Yuan et al.

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Anonymous Referee #4

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This study uses the 15-year (2001-2015) NASA MERRA2 reanalysis data to investigate the interannual variability and the decadal trend of CO, carbonaceous aerosol, and dust in the Asian tropopause aerosol layer and their relationship to the Asian summer monsoon strengths during the 15-year time period. While this topic is interesting, I have some major concerns of the methods that lead to the conclusions (see below). I recommend authors reexamine the methods and revise the manuscript accordingly.

1) MERRA2 aerosol of individual species is not “reanalysis data”. For aerosols, only column AOD from MODIS and MISR have been assimilated in MERRA2, so it is appropriate to call the MERRA2 AOD as a reanalysis product. However, concentrations and AOD from individual aerosol species, such as CA and dust used in this paper, are not a part of reanalysis (more on that in comment #2 below). CO is completely from the model simulation without any assimilation of any observations. This aspect should be clearly stated that the datasets used in this study are not “reanalysis” datasets.

Response: We are grateful for your helpful comment and suggestions. We know that it is the total aerosol loading from the satellite that was assimilated data in the MERRA2, while their precursors and components were simulated by the GOCART model. Being the most widely used global chemical model, we’d regard the model’s outcome in terms of the breakdown of the proportions of aerosol species being most plausible, or to the best of knowledge available at least, as the model results have been assessed extensively. Of course, any model results can only be trusted to the extent to which actual measurements are input to the model. For the data of dust and carbonaceous aerosols, observational data are too limited (impossible to find observational data with the same kind of spatial and temporal resolution as MERRA2) to be used for our analysis. We have stated the limitations in the revised manuscript (see below).

2) MERRA2 aerosol species concentrations are not appropriate for intenrannual variability and long-term trend analysis. The reason is that the MERRA2 system had to adjust the model simulated total AOD to be close to the satellite observations during assimilation, but there is no speciated aerosol information from satellite data to allow changes of aerosol composition. As a result, all model simulated aerosol species had to be adjusted by the same factor, which can introduce artifacts for increase or decrease of individual aerosol mass or AOD. Such artifacts have been clearly demonstrated in Randles et al., 2017 (Fig. 5 for example). Therefore, the interannual variabil-

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Discussion paper

ity or long-term trends of individual aerosol species inferred from MERRA2 might be contaminated by the introduction of the non-physical corrections of individual aerosol species amount to match the total AOD from satellite during the assimilation process. One important practice is to take a look at the so-called “increments” from MERRA2 to see the interannual variability and trends of these increments for individual aerosol species and to assess what impacts the increments might have on the apparent dust and CA interannual variability and long-term trends.

Response: We agree with the limitation as stated which is clearly acknowledged in the revised manuscript. It is worth noting that we did not address the issues of climate change, but rather the variability (IAV and IDV/trend) driven by emissions, dynamical, physical and chemical processes, all of which are subject to changes spatially and temporally. Considerable efforts have made to assure their general soundness as many influential variables have been constrained by observations. In our previous research (Lau et al., 2018), we have validated the AOD, aerosol vertical distributions and precipitation from MERRA2 with MODIS, CALIPSO, and GPCP, respectively. Moreover, we have compared the CO horizontal distribution in the UTLS with MLS observation, results of comparison look good as well. Per your suggestion, we have conducted incremental analysis and found that the corrections are generally non-physical with little impact on our major conclusion. The following paragraph is added in the part of Summary:

There are limitations in using the MERRA2 aerosol species concentrations for intenrannual variability and long-term trend analysis. The MERRA2 system adjusts the model simulation according to the total AOD retrieved from satellite measurements during assimilation, but there is no speciated aerosol information from satellite data to allow changes of aerosol composition which is simulated by the widely-used chemical model of GOGART (Chin, 2000, 2002, 2016; Kim, 2017). As a result, all model simulated aerosol species had to be adjusted by the same factor, which can introduce artifacts for an increase or decrease of individual aerosol mass or AOD (Randles et al., 2017).

To test if the interannual variability or long-term trends of individual aerosol species inferred from MERRA2 might be contaminated by any non-physical corrections of individual aerosol species during the assimilation process. We have taken a look at the 'increment' for CA (BC+OC) and DU (Dust) from the MERRA2 dataset. Results show that in our research domain, the assimilation increments for CA and Dust aerosols are very small. In most cases, it is nearly zero and the ratio of the rest increment to the values of the model mean signal is less than 1%. Therefore, the model aerosol physics are likely to be reasonable.

Results shown in this paper are the beginning, and not final, which are useful to provide a better understanding in the context of model monsoon physics and aerosol processes and in providing guidance for future data analysis. When better and more data are available, our approach would be valuable for any follow-on pursuit on the same issue.

For the precipitation, MERRA2 provides model simulated and observations-based products, and it has been assimilated and validated with both GPCP and TRMM data, more details can be found in Reichle et al., (2017). For this research, we have validated our calculation in Figure 1b and 1c with TRMM, the result for comparison has been shown below. Similar results can be found from TRMM observational data analysis.

3) Definition of strong and weak monsoon years does not seem to be appropriate. This study uses the total precipitation amount within a selected region as a measure of monsoon strength, which is certainly one of the commonly used methods to define the monsoon strength. What does not seem to be appropriate is that the strength of the ASM is not based on the total precipitation amount but is based on the detrend anomaly of precipitation amount. For example, according to Fig 1c, 2015 is a weak monsoon year with a strength weaker than 2002. However, from Fig.1b, the precipitation in 2015 is 0.5 mm/day above the 2001-2015 average while that in 2002 is about 1.9 mm/day below the 15-year average, meaning that the JJA precipitation in 2015 is about 2.4 mm/day more than that in 2002, thus a much stronger monsoon year. If the total precip

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Discussion paper

amount is the criteria for indicating the SM strength, then the determination of strong or weak monsoon years should stick with that definition, not the detrend anomaly.

Response: Using the intensity of precipitation within a select region for separating IAV, IDV/trend is a very common method. In our analysis, the data record is relatively short when compared to other IDV climatological research, thus we cannot separate IDV and long-term trend. Our trend could be a part of the longer IDV, and probably contains emission (anthropogenic) effects, which may be reflected in the increasing monsoon strength itself, but we cannot isolate the emission effect directly since the emission inputs are not updated properly. In our analysis, the IAV variability is based on the detrended dataset and the trend based on the last 7 years compared with the first 7 years. An analogous approach is to identify the most dominant modes and the trend using EOF analysis. However, because of the short length of the dataset, the trend signal usually does not come out as a single mode, but always mixed with IAV and IDV. We used the composite and linear trend approach because it is simpler and more intuitive. We are careful in the paper, not to attribute causes to the trend, but rather say they are consistent with the IAV of monsoon strength as similarly defined, but based on separation time scales. The important point is that the strong years selected from the first (most dominant mode) may not be aligned exactly with those selected from the raw data. Because if we focus on the IAV, we don't want it to be contaminated by the "trend", at least in the linear sense, and vice versa. There is plenty of recent and past paper, where IAV, IDV and trend signals of the monsoons are separated by EOFs and/or methods similar to ours. The following is a few examples:

1. Chang C P, Zhang Y, Li T. Interannual and interdecadal variations of the East Asian summer monsoon and tropical Pacific SSTs. Part I: Roles of the subtropical ridge[J]. Journal of Climate, 2000, 13(24): 4310-4325.

2. Singhrattna N, Rajagopalan B, Kumar K K, et al. Interannual and interdecadal variability of Thailand summer monsoon season[J]. Journal of Climate, 2005, 18(11): 1697-1708.

3. Wang B, Wu Z, Chang C P, et al. Another look at interannual-to-interdecadal variations of the East Asian winter monsoon: The northern and southern temperature modes[J]. Journal of Climate, 2010, 23(6): 1495-1512.

4. Giannini A, Saravanan R, Chang P. Oceanic forcing of Sahel rainfall on interannual to interdecadal time scales[J]. Science, 2003, 302(5647): 1027-1030.

4) There is a lack of evaluation of the MERRA2 products used in this study to assess the quality of these products. Although observations of dust and CA in the ATAL region is rather limited (there are some aircraft data, though), MLS on Aura satellite has been producing CO in the UTLS since 2004. I wonder if the authors can take a look at the MLS data to see if they are showing similar interannual variability and decadal trend?

Response: We have done some validation based on observational data in our previous research (Lau et al., 2018). Per your suggestions, we have used the MLS CO data to verify our results, and the zonal cross-section of anomaly between SM (2007, 2010, 2011, 2013) and WM (2014, 2015) years is shown below. The concentration of CO is increased from mid-troposphere to the UTLS region, implying the transportation is enhanced during SM years.

Figure

Figure Caption. Longitude-height cross-sections (0°E-140°E) of CO (ppbv) anomaly between strong and weak monsoon years ('strong' minus 'weak') averaged over the southern portion of the AMA (25°N-35°N) during July-August.

It is worthy to be noted that the MLS CO data record is too short (only provide data after 2004 August), thus we don't have enough samples of SM and WM years, or EP and LP years as defined to do a meaningful IAV composite, and trend analysis. Also, it has been suggested by other research that the MLS CO has up to 30% uncertainties at 100 hPa (Livesey, 2008; Santee, 2017), thus in this case, single year data with large anomalies may dominate the mean. What's more, if there is a large change in

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Discussion paper

anthropogenic emissions, those changes will not be captured by MERRA2, because the emission inventories are not updated since the mid-2000s in the model. Therefore, the availability of observational data for certain type of aerosol is highly expected from us to use in further research to validate our current results.

Livesey, N. J., et al. (2008), Validation of Aura Microwave Limb Sounder O3 and CO observations in the upper troposphere and lower stratosphere, J. Geophys. Res., 113, D15S02, doi: 10.1029/2007JD008805.

Santee, M. L., G. L. Manney, N. J. Livesey, M. J. Schwartz, J. L. Neu, and W. G. Read (2017), A comprehensive overview of the climatological composition of the Asian summer monsoon anticyclone based on 10 years of Aura Microwave Limb Sounder measurements, J. Geophys. Res. Atmos., 122, 5491–5514, doi: 10.1002/2016JD026408.

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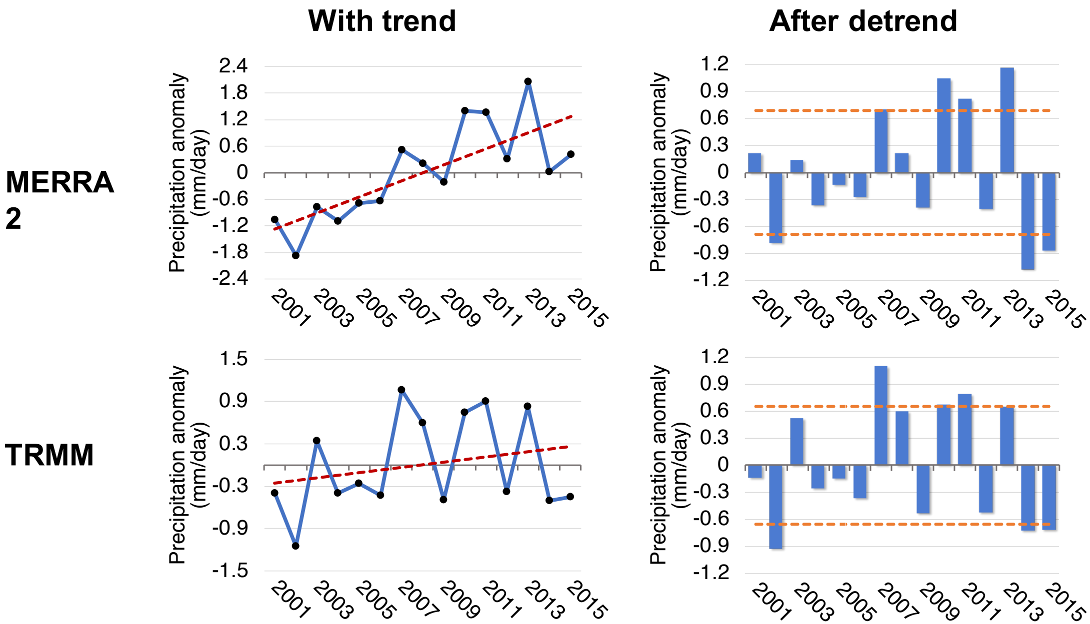

Fig. 1. Comparison of trend of precipitation from MERRA2 and TRMM

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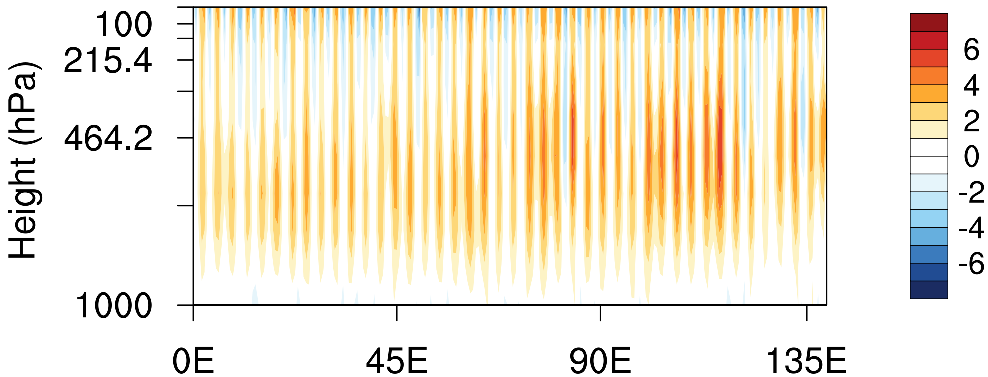

Fig. 2. Zonal cross-section of MLS_CO between 25 N and 35 N

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