Dear Editor and referees,

We would like to thank you for your valuable comments and suggestions. In this version, we have undertaken several major changes.

First, we clarified the research objectives and expanded the literature review about the aerosol's impacts on temperature based on referee #1's suggestions.

Second, ERA5 and additional surface albedo products have been included in the study according to the suggestion of referee #1.

Third, more discussions were provided about the aerosol depressing effects.

We also replaced GEBA observations by measurements at the CMA sites in the supplementary material, and more explanations were given to address referee #2's concerns about the observation uncertainty, aerosol effects. CERES assessment for capturing the temporal variation has been included in the supplementary suggested from referee #2.

Minor revisions about the grammar and expressions have been done.

The revised manuscript isn't uploaded during the open discussion section based on the journal requirement. Thanks very much for your time and efforts in reviewing the manuscript.

Best,

Aolin Jia and co-authors

Referee #1:

This is a good job. I recommend this article to be published in ACP after addressing the following issues.

We appreciate your encouragement and we've given a point-by-point response to the comments as follows.

Major comments:

1, The Tibetan Plateau (TP) area in your analysis should be defined clearly when you present Fig. 1.

Thank you for reminding us. We added the definition of the Tibetan Plateau used in this study at **Line 207-209 (new version)**.

> "The Tibetan Plateau region is defined as the Chinese Qinghai-Tibet Plateau in this paper, covering most of the Tibet Autonomous Region and Qinghai in western China (Wang *et al.*, 2016)."

2, The objectives of this paper need to be more clearly stated in the introduction part. Maybe the author needs more references reading.

Thanks for your suggestions. We clarified our research objectives at **Line 68-70**.

> "In this study, we aim to analyze the long-term spatiotemporal variation of surface radiation over the TP by generating a long-term surface radiation datasets from satellite products and model simulations. Solar dimming is to be attributed by analyzing multiple data sources. The depressing effect of aerosols on climate warming needs to be quantified in the end."

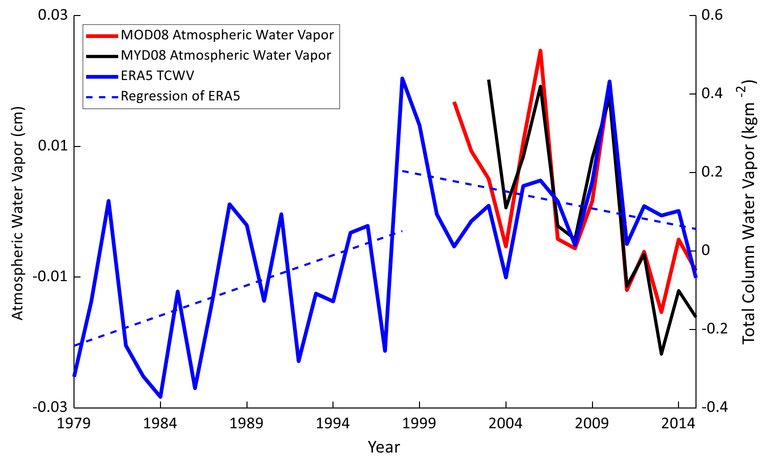
Besides, more literature reviews about the impacts of aerosols on temperatures at different spatial scales were summarized in the introduction (**Line 53-58**) and we point out that currently there is no conclusive answer and is still under discussion.

> "Aerosols have a net cooling effect on the global temperature with higher uncertainty from Intergovernmental Panel on Climate Change (IPCC) report (Stocker et al., 2013), whereas Andreae et al. (2005) has suggested that current aerosol loading may cause a hot future. Even Gettelman et al. (2015) contended that the net effect of aerosols on surface temperature can be neglected, Samset et al. (2018) pointed out that aerosol depressed surface temperature by 0.5-1.1 K globally. By contrast, one recent study (Feng and Zou, 2019) argued that aerosols contributed $+ 0.005 \pm 0.237$ K on global surface temperature change after 2000. Therefore, the aerosol effect on climate warming is still under discussion."

3, To perform more solid results, some data sets need to be analyzed:

3.1, Please add ERA5 reanalysis data into your analysis. ERA5 can be found at https://cds.climate.copernicus.eu/#!/search?text=ERA5&type=dataset

Thanks for your comment. To take advantage of reanalysis datasets for characterizing atmospheric profiles, we've employed ERA5 into our analysis. First, we replaced the ERA-Interim by ERA5 (the newest version) for detecting the temporal variation of column water vapor over the TP since 1979. The results showed that the variation of ERA5 can match with MODIS atmospheric products very well (SFig. 4, note: we added new results as SFig 1, so this figure number is changed from 3 to 4. SFig figures in the response file are directly used from Supplementary materials).



SFig. 4. Temporal annual variation of the atmospheric water vapor from MODIS atmospheric products and ERA5. ERA5 shows a considerable turning point in 1998 and the decreasing trend matches with satellite products very well.

The results demonstrated that the column water vapor trend undergoes considerable changes around 1998 and before this year, it had slightly increased and then it decreased significantly. However, solar radiation didn't respond to this variation based on former studies and our results. The overall variation of the column water vapor was not significant in recent 37 years. Therefore, the influence of the column water vapor can be ignored.

We also included the ERA5 in the cloud fraction analysis to prove that cloud coverage over the TP is decreasing (Figure 5c).

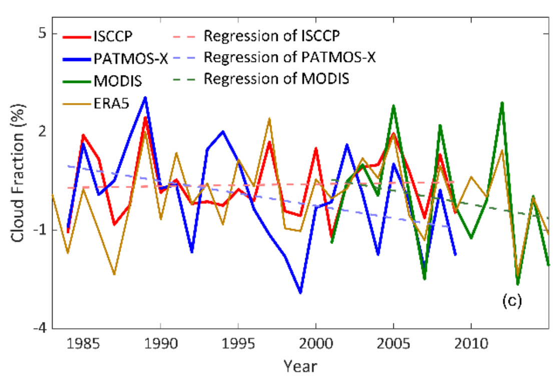


Figure 5(c). Temporal variation in detected factors from remote sensing products over the Tibetan Plateau (TP): (c) cloud fraction.

3.2, Please use more albedo data such as GlobAlbedo, CLARA-SAL, MODIS… (see He et al., 2014). He, T., S. Liang, and D.-X. Song (2014), Analysis of global land surface albedo climatology and spatial-temporal variation during 1981– 2010 from multiple satellite products, J. Geophys. Res. atmos.,119,10,281–10,298, doi:10.1002/2014JD021667.

Thanks! We included four surface albedo products (GLASS, CLARA, CERES, GlobAlbedo) to calculate the albedo climatology of the TP. These albedo products cover different satellite observation sources.

First, we generated the monthly climatological albedo of each satellite product, and we computed all standard deviations of any possible three climatological albedo combinations at each pixel. Then for each pixel, we chose the product combination that has the lowest standard deviation and calculated the mean value to represent the ground truth. The final result changed little in the graph especially when it shows the regional averaged depressing impact (Figure 8) because the albedo products have close climatology estimation at mid-latitude as the former study suggested (He *et al.*, 2014). We've added more data description and methodology explanation in the manuscript (**Line 165-183**).

> "According to He *et al.* (2014), the fine-resolution (0.05°) climatological surface albedo products retrieved from satellite observations agree well with each other for all the land cover types in middle to low latitudes. Therefore, we selected four commonly used satellite surface albedo products for calculating the surface albedo climatology over the TP, including the CERES EBAF, the Global LAnd Surface Satellite (GLASS), the Clouds, Albedo, and Radiation-Surface Albedo (CLARA-SAL), and the GlobAlbedo. First, we generated the monthly climatological albedo of each satellite product, and we computed all standard deviations of any possible three product climatology combinations at each pixel. Then for each pixel, we chose the product combination that has the lowest standard deviation and calculated the mean value to represent the ground truth climatology.
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> …
>
> The CLARA-SAL product is inversed from advanced very high resolution radiometer (AVHRR) observations (Riihelä *et al.*, 2013). Atmospheric correction was done by assuming AOD and ozone is constant. Sensor calibration and orbital drift have been dealt with and the uncertainty of monthly albedo estimation is about 11%. The GlobAlbedo product uses an optimal estimation approach European satellites, including Advanced Along-Track Scanning Radiometer (AATSR), SPOT4-VEGETATION, SPOT5-VEGETATION2, and Medium-Resolution Imaging Spectrometer (MERIS) (Lewis *et al.*, 2013). MODIS surface anisotropy information was used for gap-filling. More detailed algorithm introductions and comparison can be found in (He *et al.*, 2014)."

4, the conclusions need to be deepened. Whether other effects also can slow down surface warming over the TP? Could you conclude that aerosols increase is the major contribution to surface warming mitigation over the TP? Maybe the author needs to add more evidence.

Thanks for your suggestion. We've added more discussions about the depressing effect of aerosols and other factors in terms of water vapor (**Line 431-539**).

> "The attribution of solar dimming over the TP and corresponding aerosol effect quantification revealed that anthropogenic aerosols dominate the solar radiation decrease and depress the climate warming in recent decades. Aerosols are cloud condensation nuclei (CCN) and more CCN may depress the cloud formation and precipitation. Thus future studies need to analyze the indirect effect of aerosol loading (Qian *et al.*, 2015) over there. However, it should be noticed that we don't conclude that TP undergoes warming mitigation. In fact, TP has a rapid warming rate than global warming (Yao *et al.*, 2018) and other varying factors also affect the warming

> rate, in terms of the water vapor variation around 1998 (Supplementary Fig. S3). Water vapor is a weak DSR-absorbing factor but a major greenhouse gas emitting downward longwave radiation, so its decrease might slow down the local warming rate. However, the impact of water vapor variation after 1998 is at an annual scale that cannot match the analysis in this study, thus more further researches may focus on it."

We would like to point out that the TP didn't undergo temperature mitigation. For water vapors, we tried to conduct depressing analysis but there are some limitations. Reanalysis datasets start from 1980 while our depressing analysis focused on decade scales (Figure 8). Besides, CMIP5 didn't release any column water vapor variables or provide some HistoricalMisc experiments designed for water vapors' influences, which means it's hard to conduct related attribution analysis and depressing quantification based on CMIP5 experiments at decadal scales. Therefore, in this study, we only focus on aerosol impacts on climate warming.

We mentioned in the discussion that varying column water vapor trends in 1998 (SFig. 4) could cause some impacts on local warming because it is a weak shortwave absorber but an important greenhouse gas emitting longwave radiation. The decreasing water vapor may depress the local warming and the follow-up researches can work on it at annual scale. In this study, we mainly focus on the impact of aerosols on the long-term temporal scale.

Minor comments:

1, Why the first author is not the corresponding author?

Prof. Liang is the advisor of the first author Aolin Jia who is currently a Ph.D student.

2, In the abstract, the time range needs to be specified for the contribution of 48.6%.

Corrected. Thanks!

3, Please use the orange to replace the yellow color in Fig. 7.

Corrected. Thanks!

4, Please add more words in the caption of Fig. S3.

Corrected. Thanks!

5, There is a good review paper including discussions of aerosol effects over the TP (Qian et al., 2015). Qian, Y., et al.: Light-absorbing particles in snow and ice: Measurement and modeling of climatic and hydrological impact, Adv. Atmos. Sci., 32, 64-91, 2015.

We included it, thanks for your help!

References

Andreae, M. O., C. D. Jones, and P. M. Cox (2005), Strong present-day aerosol cooling implies a hot future, Nature, 435(7046), 1187.

Feng, H., and B. Zou (2019), Satellite-based estimation of the aerosol forcing contribution to the global land surface temperature in the recent decade, Remote Sensing of Environment, 232, 111299.

Gettelman, A., D. Shindell, and J.-F. Lamarque (2015), Impact of aerosol radiative effects on 2000–2010 surface temperatures, Climate dynamics, 45(7-8), 2165-2179.

He, T., S. Liang, and D. X. Song (2014), Analysis of global land surface albedo climatology and spatial‐temporal variation during 1981‐2010 from multiple satellite products, Journal of Geophysical Research: Atmospheres, 119(17), 10,281-210,298.

Lewis, P., C. Brockmann, and J. Muller (2013), GlobAlbedo: Algorithm theoretical basis document V4-12, in Technical Report, edited.

Qian, Y., T. J. Yasunari, S. J. Doherty, M. G. Flanner, W. K. Lau, J. Ming, H. Wang, M. Wang, S. G. Warren, and R. Zhang (2015), Light-absorbing particles in snow and ice: Measurement and modeling of climatic and hydrological impact, Advances in Atmospheric Sciences, 32(1), 64-91.

Riihelä, A., T. Manninen, V. Laine, K. Andersson, and F. Kaspar (2013), CLARA-SAL: a global 28 yr timeseries of Earth's black-sky surface albedo, Atmospheric Chemistry and Physics, 13(7), 3743-3762.

Samset, B., M. Sand, C. Smith, S. Bauer, P. Forster, J. Fuglestvedt, S. Osprey, and C. F. Schleussner (2018), Climate impacts from a removal of anthropogenic aerosol emissions, Geophysical Research Letters, 45(2), 1020-1029.

Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley (2013), Climate change 2013: The physical science basis, edited, Cambridge University Press Cambridge.

Wang, Z., Z. Li, M. Xu, and G. Yu (2016), River morphodynamics and stream ecology of the Qinghai-Tibet Plateau, CRC Press.

Yao, T., Y. Xue, D. Chen, F. Chen, L. Thompson, P. Cui, T. Koike, W. K.-M. Lau, D. Lettenmaier, and V. Mosbrugger (2018), Recent Third Pole's rapid warming accompanies cryospheric melt and water cycle intensification and interactions between monsoon and environment: multi-disciplinary approach with observation, modeling and analysis, Bulletin of the American Meteorological Society(2018).