Journal: Atmospheric Chemistry and Physics

Article title: In-situ observation of warm atmospheric layer and the heat contribution of suspended dust over the Tarim Basin

Manuscript number: acp-2021-892

Dear Editors and Reviewers:

Thank you for your letter and for the reviewers' comments concerning our manuscript entitled "In-situ observation of warm atmospheric layer and the heat contribution of suspended dust over the Tarim Basin (acp-2021-892)". These comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. We have studied comments carefully and have made correction which we hope meet with approval. Revised portion are marked in the document named "manuscript_revised". The point-to-point responses to reviewer #2's comments are as follows.

Reviewer #2:

This work combined the radiosonde observations, reanalysis data as well as satellite images to investigate the possible impact of dust on meteorology. The authors found that there might be an anomalous warm atmospheric layer caused by suspended dust over the Tarim Basin, with a maximum heating effect of approximately +0.45 K and +0.25 K in spring and summer, respectively. The research topic is of interest. However, the descriptions on the utilized dataset ought to be detailed and also its applicability needs to be justified. I have the following questions and suggestions to the authors.

1. My main concern is that the authors claimed that "the ERA-5 data are generated from an ECMWF IFS spectral model and do not yet assimilate the impact of aerosols on meteorology", but "the MERRA-2 data include the impact of dust on meteorology". Actually, both the two data are reanalysis, which means that they have assimilated tremendous atmospheric observations, including temperature measurements. Here is the detailed information on the data assimilation system for

ERA-5 and MERRA2. The fact is that since 1997, ECMWF operations have applied 4D-var assimilation system.

https://www.ecmwf.int/en/elibrary/20196-ifs-documentation-cy47r3-part-ii-data-assimilation.

https://journals.ametsoc.org/view/journals/clim/30/14/jcli-d-16-0758.1.xml

These data assimilation systems do constrain the forecast by using surface observations, balloon data, aircraft reports, buoy observations, radar and satellite observations. Once the temperature and other meteorological fields are assimilated, the impact of aerosols on meteorology is certainly included in the reanalysis data. Investigations on relevant literature are highly suggested, based on which I also suggest the authors to reconsider the method or the datasets used in this work.

Response: Thanks for your comments. We agree with your opinion. Yes, as you mentioned above, the reanalysis data assimilation systems do constrain the forecast by using surface observations, balloon data, aircraft reports, buoy observations, radar and satellite observations. Generally, once the temperature and other meteorological fields are assimilated, the impact of aerosols on meteorology is certainly included in the reanalysis data.

In our study, we focused on the Tarim Basin (TB) region, which covers an area of 5.3×10^5 km^2 and contains the Taklimakan Desert (TD). And the TD is one of the major dust sources in Asia (Gong et al., 2003; Wang et al., 2005). However, at present, there are only 30 ground observation stations and 6 radiosonde stations in TB participated in global sharing (National Meteorological Information Center http://data.cma.cn/). To some degree, the scarce observational data could limit the quality of assimilation in both ERA-5 and MERRA-2 reanalysis data.

According to your suggestion, we have investigated the relevant literature. ERA-5 data indeed have assimilated multiple measurements through a four-dimensional variational data assimilation system in 12-hourly analysis cycles (Thepaut et al., 1996). However, ERA-5 data are generated from a spectral model (ECMWF Integrated

Forecast System) and have not considered the impact of aerosols on meteorology yet (Simmons, 2006). From the perspective of assimilation, reanalysis filed error includes model error and observation error (https://www.ecmwf.int/node/19997). Previous studies indicated that there are more than 100 dusty days per year in the TB (Zhou et al., 2020), meanwhile, these dust aerosols can suspend at attitude of 3-5 km for a long time, which have obvious positive radiation forcing, and the short-wave heating rate is greater than 6K/d (Huang et al., 2009). Therefore, if the effects of aerosol are not considered in the reanalysis model, the model error will be underestimated, which could somehow reflect the error in reanalysis field induced by dust aerosols.

Compared with ERA-5, MERRA-2 data include the assimilation of aerosol observations, thereby it provides a multidecadal reanalysis in which aerosol and meteorological observations are jointly assimilated within a global data assimilation system (Gelaro et al., 2017). More importantly, the aerosols and their interactions with weather and climate have been considered in MREEA-2 (Randles et al., 2017). Therefore, there is an obvious difference between ERA-5 and MERRA-2. Figure R1 shows a comparison of MERRA-2 data with radiosonde observations in the TB region. A good agreement is found between MERRA-2 data and radiosonde observations. Hence, we used the MERRA-2 reanalysis data to supplement the observation data.

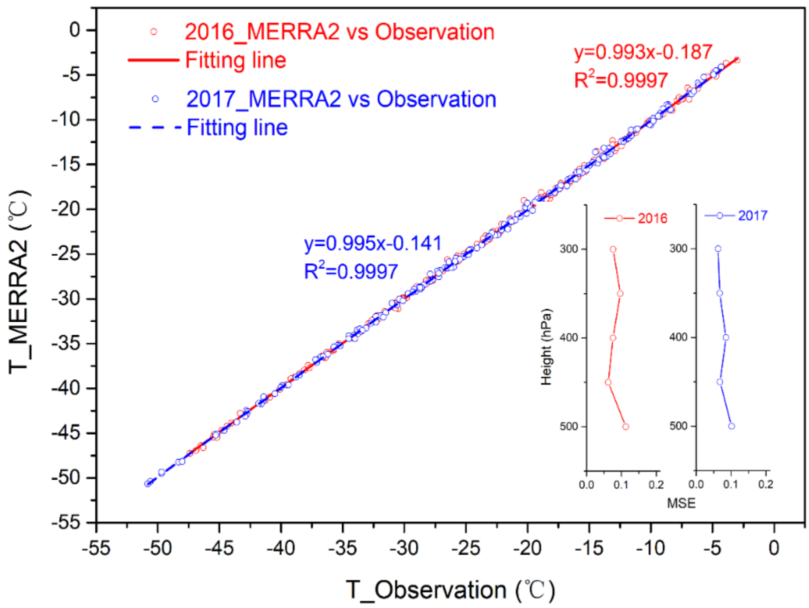

Fig. R1. Comparison between atmospheric radiosonde temperature observations and MERRA-2 reanalysis data at altitudes of 500-300 hPa in spring and summer during 2016-2017.

The OMR method is proposed by Ding et al. (2021). This method is based on the assumption that the difference between observations and reanalysis models reflects the impact of un-resolved processes (Huang and Ding, 2021; Huang et al., 2018; Kalnay and Cai, 2003; Wang et al., 2013; Zhao et al., 2014). It means that these real biases, which result from missing physical or chemical processes in the model, have been misinterpreted as observational errors and discarded during the data assimilation procedure for the reanalysis data (Huang and Ding, 2021; Huang et al., 2018). As illustrated above, ERA-5 data were generated from a spectral model (ECMWF Integrated Forecast System) and has not considered the impact of aerosols on meteorology yet (Simmons, 2006). Therefore, investigation of the difference between observation (radiosonde observation and MERRA-2 reanalysis data) and ERA-5 reanalysis data can provide an opportunity to study the heating effect of dust aerosols, especially in a region with dust aerosol pollution (Huang and Ding, 2021; Ding et al., 2013). This method has been tested by previous work and proved to be well suited to identify the effects from aerosol impacts on the air temperature (Huang and Ding, 2021; Ding et al., 2013; Huang et al., 2018; Kalnay and Cai, 2003; Wang et al., 2013; Zhao et al., 2014). We have supplemented the reanalysis data and method in the revised version (**Lines 101-103; Lines 139-143**).

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Zhou, C., Yang, F., Mamtimin, A., Huo, W., Liu, X., He, Q., Zhang, J., and Yang, X.: Wind erosion events at different wind speed levels in the Tarim Basin, Geomorphology., 107386, https://doi.org/10.1016/j.geomorph.2020.107386, 2020.

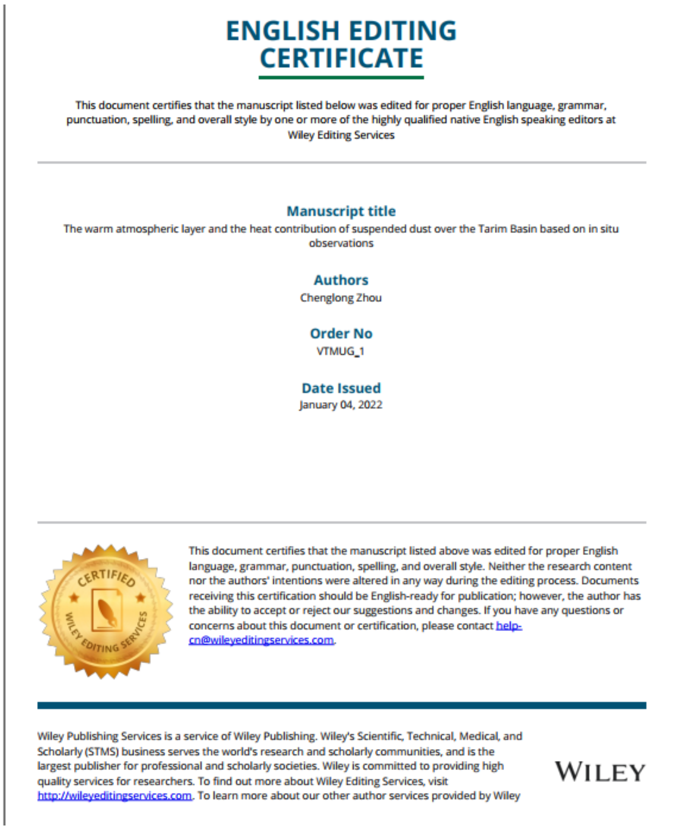
2. The northward extension of the Tibetan heat source proposed in 3.4 is somehow descriptive and hypothetical. I think in-depth data analysis and solid evidence should be provided while a scientific conclusion is drawn.

Response: Thank you for pointing it out. Yes, as you suggested, an in-depth data analysis and solid evidence are essential.

Gu et al. (2006, 2016) and Law et al. (2006) presented some numerical results to elucidate the dust’s impact on air temperature at upper layers. As an observational evidence, Huang et al. (2009) found the significant radiative forcing and heating effect due to dusts over the part of the TB using CALIPSO data. However, there is no direct evidence about the heating of dust aerosols in the upper-layer atmosphere. In our study, the results show that there is a suspend dust layer over the TB in spring and summer (Figs 4 and 5), heating the atmospheric layer between 300-500 hPa with a maximum of approximately +0.45 K in spring and with a maximum of approximately +0.25 K in summer, which almost covers the whole basin (Figs 7c and 7d). Topographically, the TB is adjacent to the Tibetan Plateau (TP), which acts as an elevated heat source in spring and summer. The warm atmospheric layer over the TB seems a northward extension of Tibet heat source. Therefore, the concept of the northward extension of Tibetan heat source is proposed. (**Lines 291-295**)

3. I also recommend language editing for improving the accuracy of language as well as overall readability.

Response: Thanks for your comments. We have proofed the language.



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Manuscript title
The warm atmospheric layer and the heat contribution of suspended dust over the Tarim Basin based on in situ observations

Authors
Chenglong Zhou

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Minor issues

1. Line 75: What is "ground-based radiosonde observations"? Do you mean ground-based and radiosonde observations?

Response: Thanks for your comments. We have added "and" before "radiosonde observations" **(Line 70)**.

2. Line 85-92 need to be rephrased.

Response: Thanks for your comments. We have rephrased it in the revised version as following:

We used radiosonde observations from six radiosonde stations situated in the TB for the spring and summer of 2016–2017 (Fig. 1), namely Kashi (KS), Akesu (AKS), Kuerle (KEL), Ruoqiang (RQ), Minfeng (MF), and Hetian (HT); from these data, we deduced the air-temperature profiles, which were measured twice per day (08:00 and 20:00 UTC+8). The observations were automatic and continuous, with 1 min temporal resolution, and the original data were processed into averages with 25 hPa interval. (**Lines 81-86**).

3. Line 104: correct reanalyzes to reanalysis

Response: Thanks for your comments. We have changed "reanalyzes" to "reanalysis" (**Line 97**).

4. Figure 3 is a little confusing and unclear since that it uses the size of markers to show the temperature difference. It might be more distinct while using gradient color.

Response: Thanks for your comments. We have modified Figure 3 as follows:

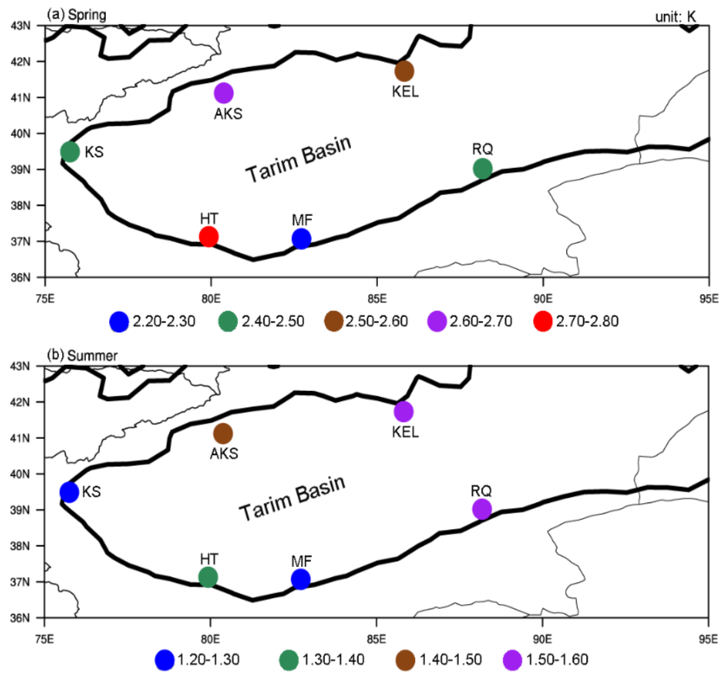

Fig. R3. Average ΔT between 500 and 300 hPa in (a) spring and (b) summer. Dots indicate the site locations, while different colors indicate different heating intensities

(**Page 31**).

5. The label in Figure 4 is too small to be clearly identified and needs to be improved. Figure 5 has the same problem.

Response: Thanks for your comments. We have modified Figures 4-5 as follows:

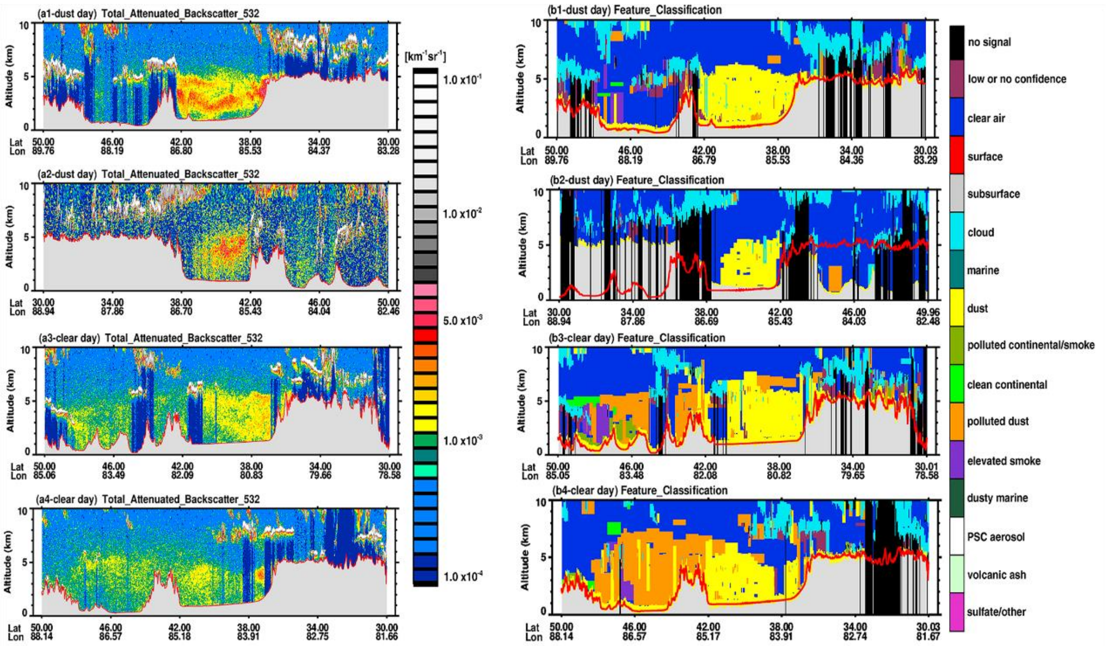

Fig. R4. The altitude–orbit cross-section of the 532-nm total attenuated backscattering intensity (left panels) and classified particles (right panels) on July (a1 and b1) 4, (a2 and b2) 5, (a3 and b3) 25, and (a4 and b4) 27, 2016, along the trajectory of the CALIPSO satellite over the Tibetan Plateau, as presented in Fig. 1. Gray shadings indicate the topography (**Page 32**).

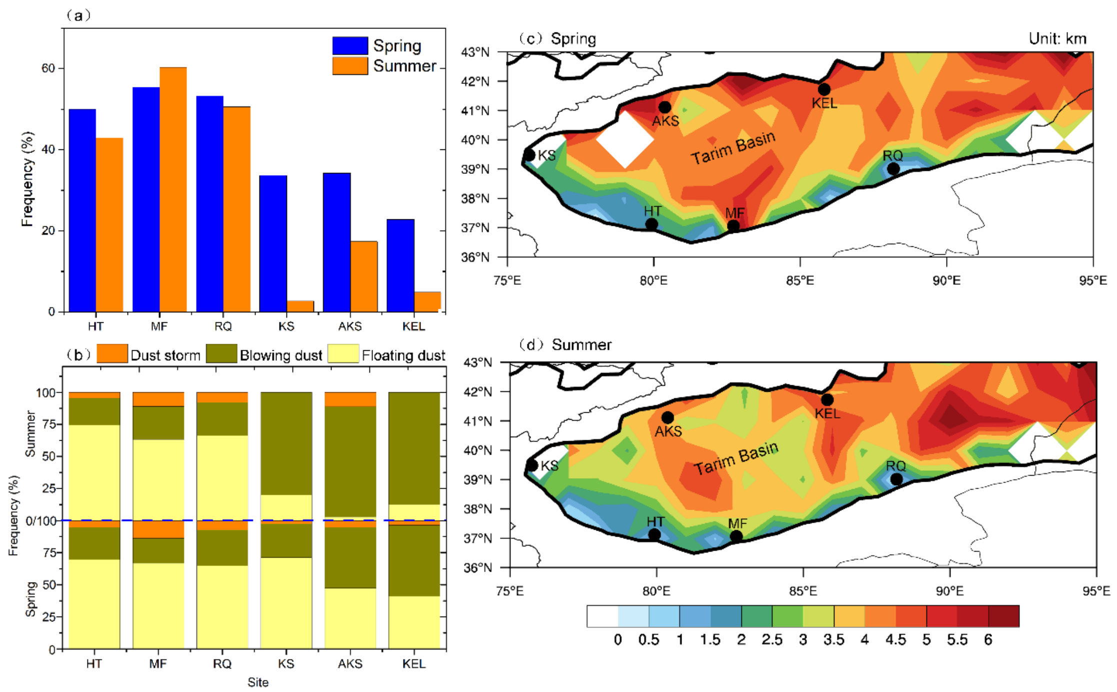

Fig. R5. Frequencies of (a) dust events and (b) dust events including dust storms and cases of blowing and floating dust at the (a) Kashi (KS), (b) Akesu (AKS), (c) Kuerle (KEL), (d) Hetian (HT), (e) Minfeng (MF), and (f) Ruoqiang (RQ) stations in the spring and summer of 2016–2017; the blue dashed line represents the boundary between spring and summer. Seasonal distribution of the dust-top height in km over the Tarim Basin in (c) spring and (d) summer, inferred from CALIPSO (**Page 33**).