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 #2:

1. I have pointed out that "No long-term observations of DSR and aerosol data support the long-term variations of DSR and anthropogenic aerosol developed in this study", and the authors chose 5 sites from GEBA to support their main conclusion. But it should be noted that the 5 sites from GEBA is also from the observations of Chinese Meteorological Administration. This contradicts with your statement that "We didn't include ground observations from Chinese Meteorological Administration stations due to data discontinuity and large uncertainty". The obvious low values between 1980 and 1990 is the questionable observations, and this sites cannot be used to validate the long-term variations of your fused dataset (see Shi et al., 2008).

Thanks for the valuable comment. We've corrected this mistake. In the revised version, we employed CMA rather than GEBA data. Only observations before 1980 are used in order to avoid the data discontinuity issue after 1980. The revised results show that surface DSR observations can reflect TP dimming since 1958 with large uncertainty [SFig. 2(a), SFig mark means the figure is shown in the supplementary material and directly used here.]

SFig. 2(a). Surface DSR temporal variation of (a) 5 CMA sites mean, (b-f) individual sites. Temporal variations were averaged by the 5-year moving window in order to remove the impact of annual variability.

We still use surface radiation measurement as a reference. 130 CMA radiation sites over China were collected and 12 sites are located in the TP. For detecting the long-term DSR variation, the sites starting to operate after 1970 were not used, so 7 sites left (Figure r1, following figures marked by ‘r’ are only shown in the response file).

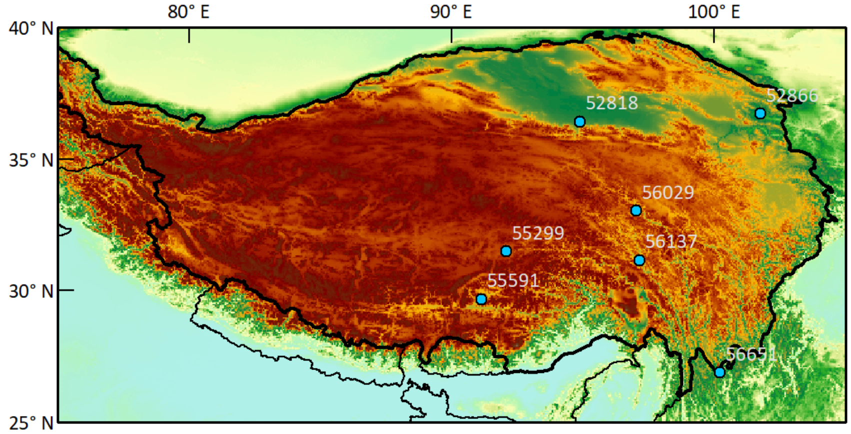

Figure r1. 7 CMA sites distribution.

We drew the averaged DSR temporal variation at 7 sites, and corresponding site numbers at each year is shown by red bars.

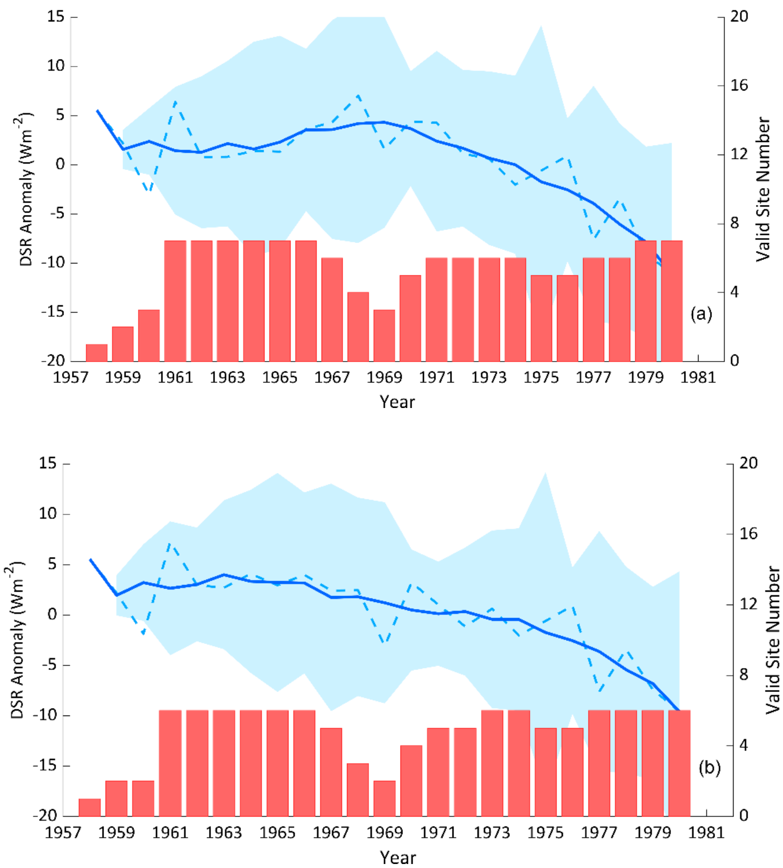

Figure r2. DSR temporal variation at (a) 7 sites, (b) 6 sites without site 56029.

In Figure r2, the dimming time of 7 sites started in 1967, which is different from our study, and the unstable annual anomalies in 1958-1960 and 1968-1970 are mainly caused by missing measurements in some sites in these years. However, sites 56029 and 55299 had continuously missing measurements for more than 5 years. Therefore, considering the data continuity and location sampling (site 56029 is near site 56137, and site 55299 is near site 55591 compared with other sites), we abandoned these two sites in SFig. 2, and the left 5 sites are scattered in TP.

In the SFig. 2, the dimming time started in 1958, and only site 55591 has a different starting time. Sites [56651 and 52866, SFig. 2(c, f)] located in eastern region show clear DSR decreases from 1958, and the other 2 sites have an overall slight decrease with oscillation from 1958. It is consistent with our result (Figure 4a) that TP dimming is more significant in the southeastern region.

We also checked the dimming time change in site averaged results. We found that once site 56029 was removed in the analysis, the starting time would be changed to 1958 [Figure r2 (b)]. It illustrated that the site number and location did considerably affect the starting time. Our data covered the whole TP and caught the solar decrease especially at southeast TP.

In all, both site observations and our results can prove that the TP has undergone dimming since the 1950s. The large uncertainty of site observations and larger dimming trend may be caused by measurement drifts explained by He *et al.* (2018) who used sunshine duration derived DSR showing a smaller dimming magnitude compared with observed DSR at global scale.

2. how did you reach that “estimated DSR driven by sunshine duration was not calculated either because the method accuracy may be not high enough to capture the influence of aerosols at low-level magnitude.”? In my opinion, the accuracy of DSR driven by sunshine duration is generally higher than those of satellite-based DSR and CMIP5. At least, the accuracy of DSR driven by sunshine duration is also higher than that fused by yours.

We speculated that Sunshine Duration (SunDu) derived DSR in TP cannot capture the trend at the decadal scale and SunDu may not represent DSR to show TP dimming especially for the early period at the TP based on the results in He *et al.* (2018). In their study, He et al. estimated DSR from SunDu from globally distributed site observation pairs based on a widely used method (Kun Yang *et al.*, 2006), and observed DSR is considered as reference and the estimation accuracy is satisfactory at the global scale.

However, we found that the SunDu derived DSR has an opposite trend with observed DSR in TP [Figure r3, also Figure 3 in (He *et al.*, 2018)].

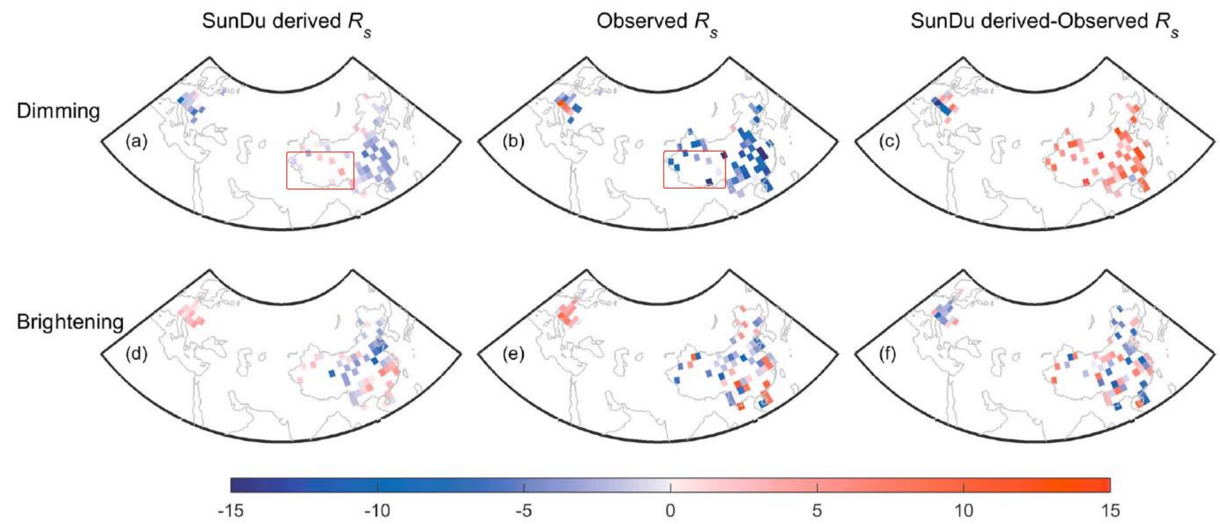

Figure r3. Maps of the decadal trends (units: W/m2 per decade) in 2.5° × 2.5° grids of sunshine duration (SunDu)-derived Rs (a and d), the observed Rs (b and e), and differences between the two data sets (c and f) over China and Europe during two periods of dimming and brightening. "Dimming" denotes the periods of 1959–1989 in China and 1961–1980 in Europe. "Brightening" denotes the periods of 1994–2010 in China and 1980–2009 in Europe.

In Figure r3, the dimming trend from SunDu-derived DSR matched with observed DSR except over the TP region. The paper didn't provide more explanations about the mismatch. However, when they applied this method in more than 2000 sites over china, we found that their SunDu-derived DSR over the TP has no dimming at all time periods (Figure r4, also Figure 4 in (He *et al.*, 2018)).

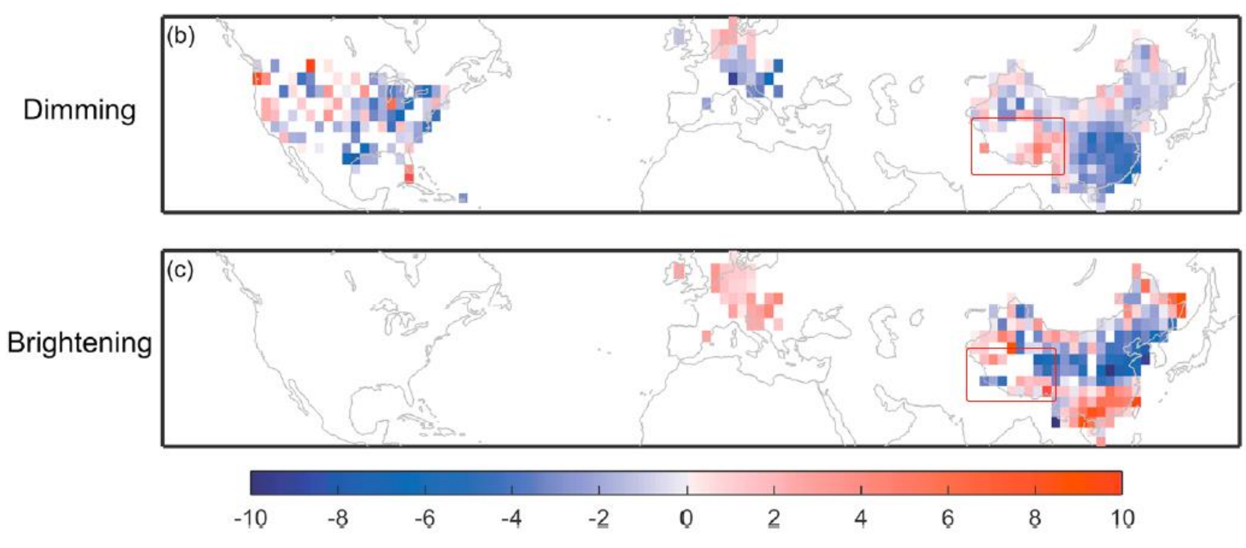

Figure r4. Maps of the decadal trends (units: W/m2 per decade) of all reliable SunDu-derived Rs stations over China, Europe, and the United States in 2.5° × 2.5° grids during three periods. "dimming" denotes the periods of 1959–1989, 1950–1980, and 1952–1980 in China, Europe, and the United States, respectively. "Brightening" denotes the periods of 1994–2010 in China and 1980–2009 in Europe.

They didn't focus on TP so there is no specific explanation of it, but the result is contradictory with our result and all former studies based on direct observations, model simulations, reanalysis, and satellite observations (Kuang and Jiao, 2016; Shi and Liang, 2013; K. Yang *et al.*, 2012; K. Yang *et al.*, 2014; You *et al.*, 2010).

We also contacted with the co-author Martin Wild who is in charge of GEBA network and he also expects that the sign of DSR derived from SunDu is same as the DSR observations.

Dear Aolin Jia,

Thanks for you mail. The Chinese data in GEBA have not been changed with respect to the CMA original data.
There are problems in the Chinese radiation data quality as you are sure aware, and as documented in many papers.
I had a visitor from CMA (Yang Su) visiting me for a year and working with me on the improvement of the quality of the dataset. I attach 2 related papers recently published in J. Climate.
Unfortunely those data are not public due to the Chinese data policy.
As for the Sunshine duration trends, I also expect them to be of the same sign as the radiation data. You may contact the Beijing group for more details on their analysis.

Kind regards
Martin

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Figure r5. Email from Martin Wild

Besides, we discussed this issue with the first author of the paper, who provided some valuable details about the estimated DSR over the TP. They explained that studying different time periods may result in different trends, it's true but unfortunately it cannot explain that why the overall trend at two time period is brightening especially at southeastern TP [Figure r6 (b), site 56651 is at the southeastern TP while the trend is overall negative]. The sites [Figure r6 (a)] they provided showed that these sites have dimming trend that matched former results, while the whole trend shown in Figure r4 is still brightening at dimming period (1952 - 1989), which is different from the DSR observations [SFig. 2 (a)]. We infer that even for the SunDu sites, the dimming time varied at different locations that matched what we found using DSR observations.

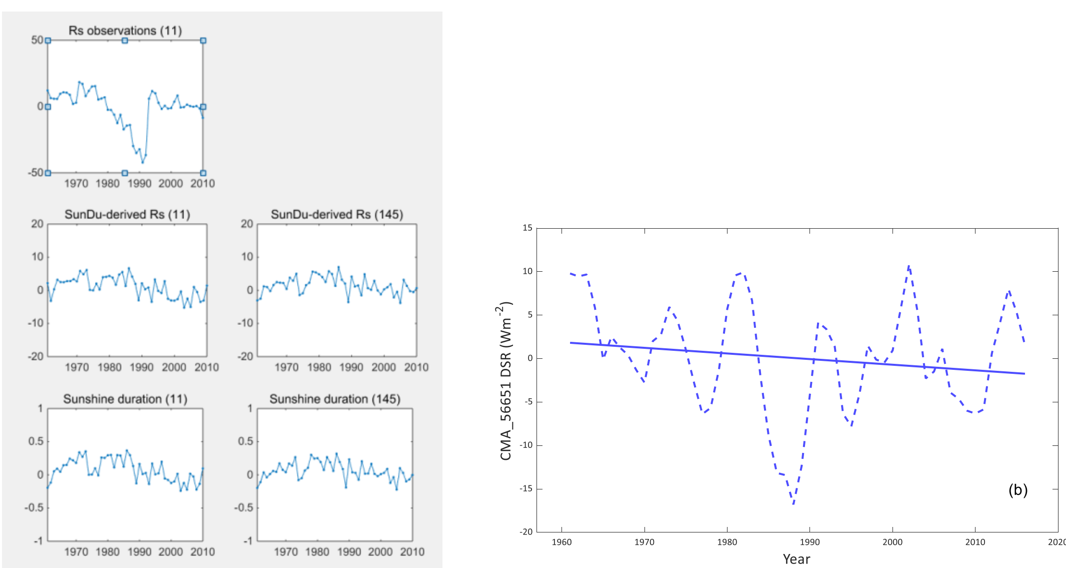


Figure r6. (a) Site samples the author provided for us; (b) DSR temporal variation of CMA 56651. Temporal variations were averaged by the 5-year moving window in order to remove the impact of annual variability.

Therefore, we speculated that SunDu-derived DSR couldn't be able to capture the observed DSR temporal variation in TP and SunDu may not represent DSR to show the dimming at the TP. According to Manara *et al.* (2017), SunDu has a different sensitivity to atmospheric turbidity changes that is estimated by aerosol optical depth (AOD). SunDu may lose its representability at low AOD level. We infer that this is the reason why this method didn't capture the dimming trend in the TP and SunDu may not represent DSR in the TP at low AOD level.

Additionally, the accuracy (standard deviation of bias, STD) of SunDu-derived DSR over China is about 19.32 Wm^{-2} (He *et al.*, 2018), and our validation showed that the standard deviation of the calibrated data bias is 20.64 Wm^{-2}. Considering that the validation of gridded data has scale mismatch effect while their validation results are observation pairs, we think our result is comparable to theirs. Besides, their validation sampling is over China while our validation samples are only limited in TP, where DSR is large and the bias and STD could be larger, let alone the measurement environment in TP is not as good as other regions and might introduce large uncertainty.

More discussions of physical relationship between DSR and SunDu and the estimation algorithm suitability are beyond the scope of this study, therefore, we didn't include more experiments assessing the estimation algorithm and directly used DSR observations as the references.

3. As you also known that TP is one of the cleanest areas in the world, and compared to other factors, such as cloud and water vapor, it's effect on the DSR over the TP may be ignorable. Thus, it can not cause the phenomenon of solar dimming over the TP.

Thanks! When we estimate instantaneous DSR at all-sky conditions, it's reasonable to ignore the influence of AOD because its influence is small compared to the DSR absolute value. However, when we analyze the impact at the decadal scale, any contributing factor that has a directional decrease or increase trend will affect the DSR trend accordingly. We also calculated the radiative effect of aerosols in Figure 6 (a), ~5 Wm^{-2} difference of decadal variation between the clean and aerosol case simulations cannot be ignored.

Besides, we also calculated the increased aerosol radiative forcing caused by AOD increase since 1998 based on K. Yang *et al.* (2012). The increased radiative forcing is about 1.97 Wm^{-2}, which can also prove that it is not ignorable.

As we explained in the last reply, it's true that TP is one of the cleanest areas in the world and the corresponding aerosol climatology is low. However, when we talk about solar dimming over the TP, we mainly focus on the DSR decreasing phenomenon over there, which is characterized by the variation of DSR decadal anomalies rather than the absolute magnitude. Besides, it's necessary to point out that when aerosol loadings in the atmosphere are at a low magnitude, direct radiative effects (scattering and absorption effect) play a dominant role in the interaction between aerosols and the atmosphere (Li *et al.*, 2017). Therefore, even TP has a clean condition, it is easily affected by aerosols increase.

4. You did not answer my question fully: "Why did you use the CERES EBAF DSR to calibrate the CMIP5 DSR data since the satellite radiation products generally can not capture the long-term DSR variations. Or you can demonstrate that the CERES EBAF DSR can reflect the long-term variations of DSR?". Even if the CERES EBAF DSR can capture long-term variations of DSR over the other regions, it not necessarily can capture long-term variations of DSR over the TP.

Thanks for your comment. We understand your concern.

First we've proved in the previous reply (Figure r7) that CERSE EBAF 4.0 can capture the absolute value variation over the CAMP network in the TP even there is a systematic bias at some sites.

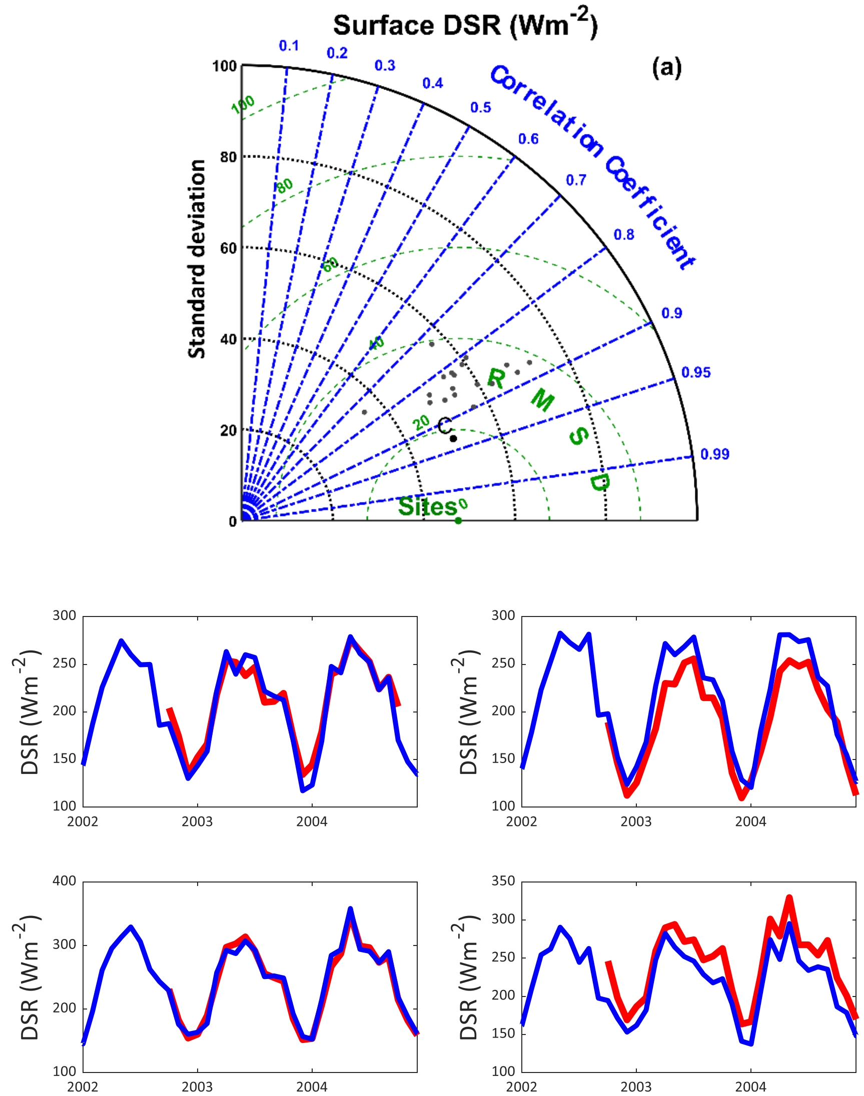
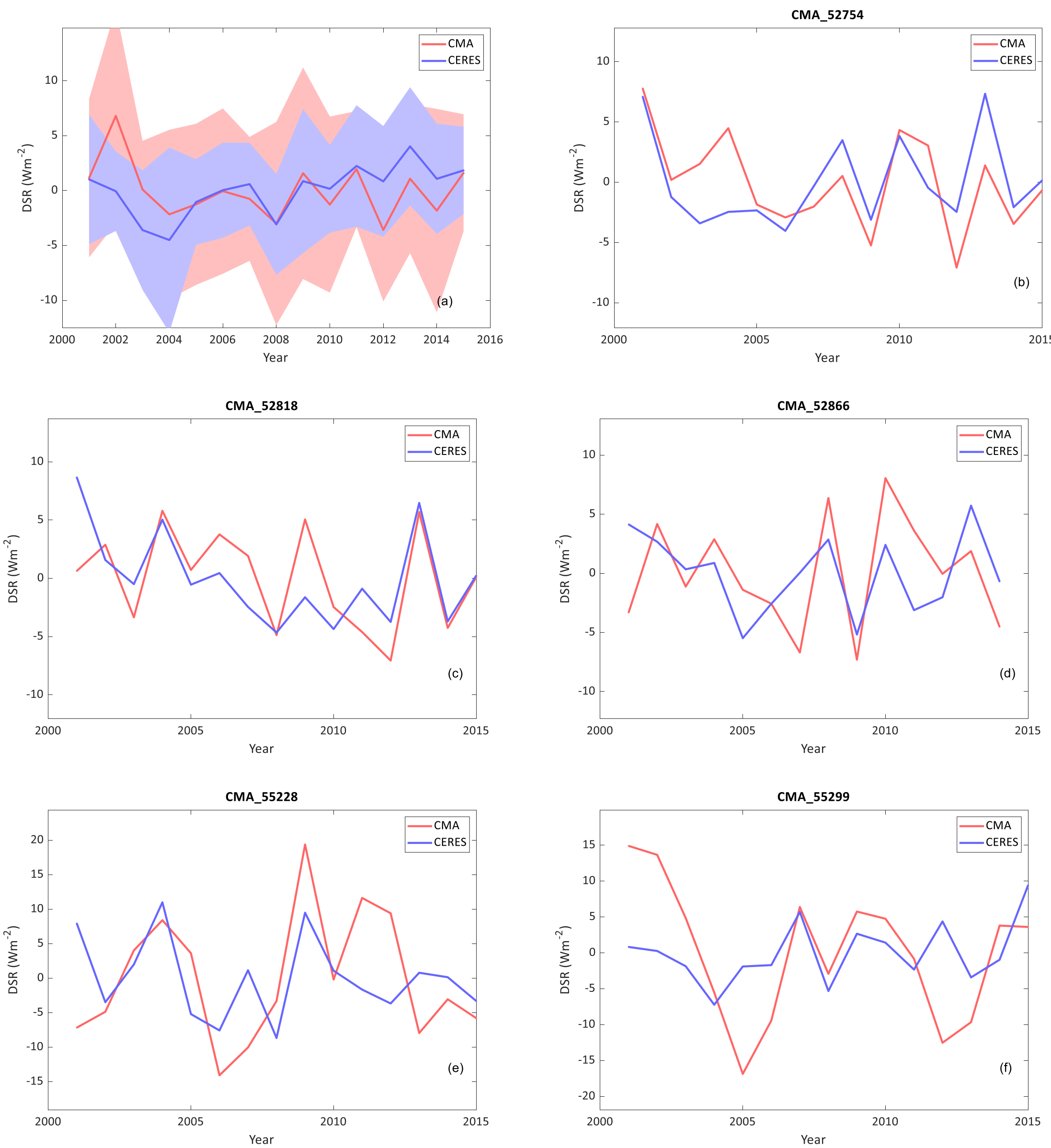


Figure r7. (a) Taylor diagram of solar validation of CERES EBAF (**black dot C**) and 18 CMIP5 models (**grey dots**). (b) Monthly variation of CERES EBAF (**blue line**) and site observations (**red line**). Only sites that were run more than 2 years long were shown here.

Then we used 11 CMA sites located in TP (deleted one that missed continuous measurement for 3 years) to prove that CERES EBAF 4.0 DSR can capture the overall temporal annual anomaly variation observed by CMA since 2001 over the TP (SFig. 1). Therefore, we can choose CERES as the reference at each pixel to calibrate the model simulation results. We added the CERES analysis into the supplementary as SFig. 1. Thanks for reminding us.


CMA
CERES
DSR (Wm-2)
Year
(a)
CMA_52754
(b)
CMA_52818
(c)
CMA_52866
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CMA_55228
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CMA_55299
(f)

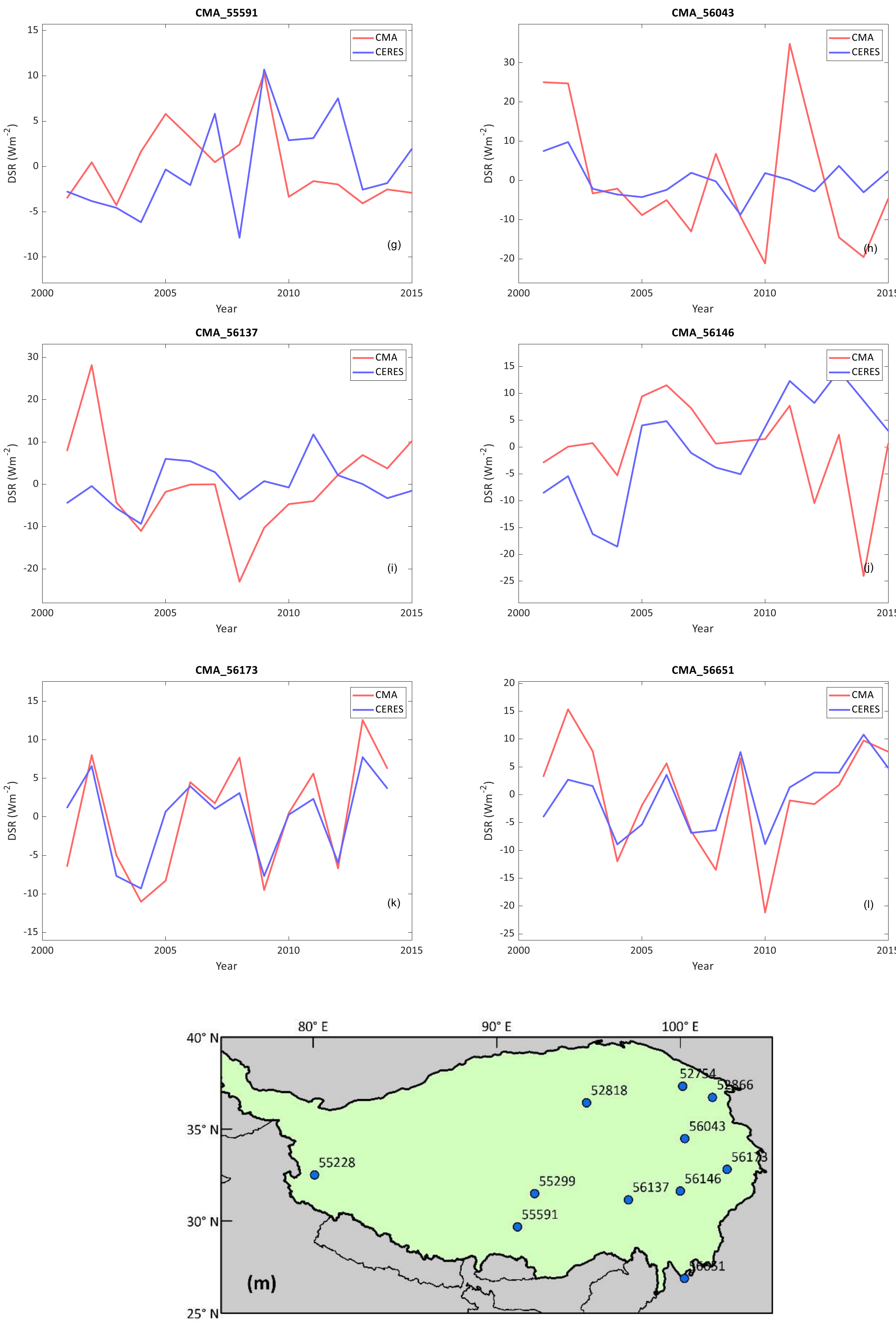
CMA_55591
CMA
CERES
DSR (Wm^-2)
Year
(g)
CMA_56043
(h)
CMA_56137
(i)
CMA_56146
(j)
CMA_56173
(k)
CMA_56651
(l)
80° E
90° E
100° E
40° N
35° N
30° N
25° N
52754
52866
52818
56043
55228
56173
55299
56146
56137
55591
56651
(m)

Fig. S1: Surface DSR temporal variation of CERES and all CMA radiation sites at TP (a) 11 CMA sites mean, (b-l) individual sites, and (m) 11 sites distribution

5. Because the 5 sites from the GEBA is measured by the Chinese Meteorological Administration and is the same as the observations of CMA. Thus, the question "The DSR over the Tibetan Plateau is decreased since 1950, which was different with the points derived based on the observations or based on the sunshine based DSR" should be re-answered.

Thanks very much for providing this valuable suggestion.

Base on the analysis in Q2, we suggested that the different start time of TP dimming from the previous study based on SunDu and our result is caused limited representability of SunDu to DSR at the TP. Therefore, we still selected DSR measurement as ground reference data. By analyzing DSR measurements, we concluded that sites at different locations show various dimming start time. Our data can cover the whole TP area especially the southeastern TP. Thus they may have a different start time.

References

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