Response to comments #1

Response: Thanks for your helpful and constructive comments. We have made several modifications and implemented the suggestions as described below. We describe a few major changes first, followed by our response to individual comments.

i) Response of cloud liquid water is added.

ii) Response of lower tropospheric stability is added.

iii) SWCRE response for individual models is added to the supporting material.

iv) Replace Fig. 7 with SWCRE response.

This paper investigates the response of shortwave cloud radiative effect and daily maximum temperature to greenhouse gases and aerosols (BC and sulfate). It is found that BC results in a stronger positive SWCRE change than CO2 when normalized by effective radiative forcing, but sulfate does not have much effect on SWCRE. It is also shown that the increase in SWCRE resulting from CO2 and BC leads to an increase in daily maximum temperature during the summer. The results are interesting and have some important implications, however a number of things need to be addressed before recommendation for publication.

Major

1. Most of the results are normalized by effective radiative forcing. What are the surface temperature responses to CO2 and BC, respectively? Could the difference in SWCRE be partly due to the difference in the temperature change (i.e., the efficacy of BC)?
Response: the multi-model mean temperature changes for CO_2 and BC experiments are 2.5K and 0.7K respectively. The ratio of 2.5/0.7=3.6 is slightly larger than the ERF ratio (3.65/1.16=3.15), which means if SWCRE changes were normalized by dT, the difference of between CO_2 and BC would be slightly larger. As the results would not change much, however, the efficacy of BC will not significantly influence our results in the bar plot (Fig. 3).

2. The SWCRE change is attributed to the change in cloud cover. I would be interested to see some discussion in the change in cloud liquid water content or liquid water path, which also plays an important role in determining SWCRE.

Response: added in Fig. 4 and section 3.2. We added the following discussion after line 172:

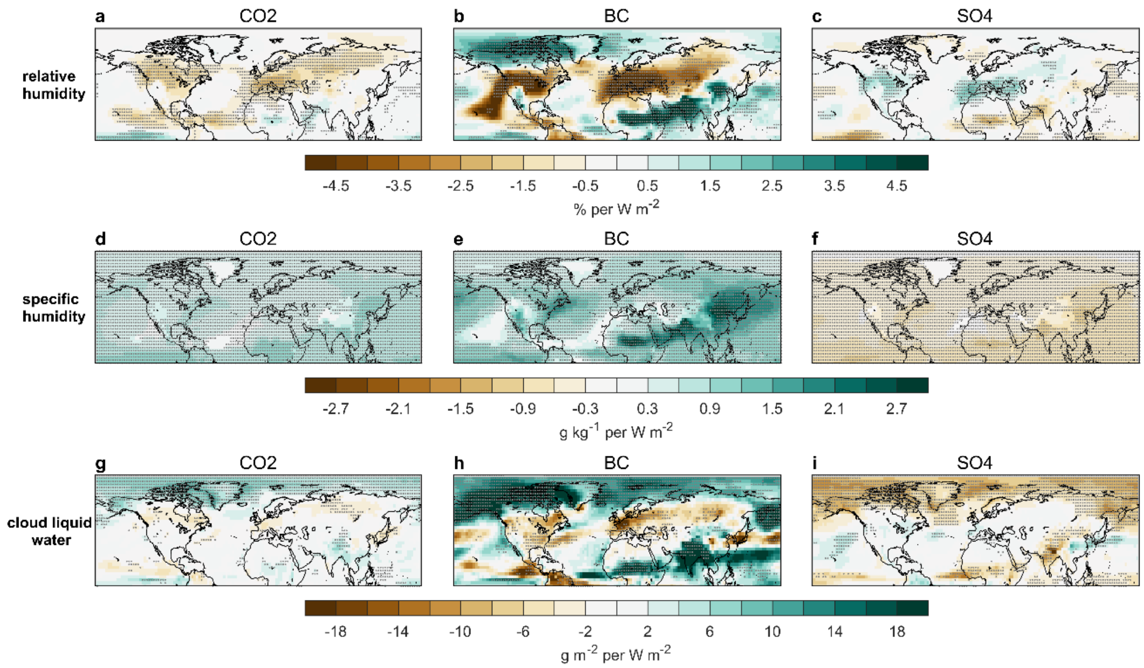

Figure 1: Same as Figure 2, but for humidity at 850 hPa.

"The response of cloud liquid water in the BC experiment could further support this conclusion (Fig. 4h). Liquid water decreases (increases) in regions with decreasing (increasing) cloud cover, following the pattern of RH. As cloud water content directly impacts cloud optical thickness and albedo, such a response may further impact SWCRE (i.e., enhance reflectance in regions showing increasing liquid water and enhance transmittance in regions with decreasing liquid water). However, the liquid water responses under CO2 and sulfate aerosols are much weaker, only significant in part of Asia and tropical Africa (Fig. 4g and i)."

3. The change in cloud cover is explained by the change in RH. However, there are a lot of other factors affecting clouds (radiation, dynamics, thermodynamics, etc., see Bretherton (2015) and references therein), and I think a more detailed discussion would be helpful. The authors look at vertical velocity and suggest that the change in stability plays less of a role, but it is not clear to me how the conclusion is reached. The estimated inversion strength or lower troposphere stability may be a better predictor for stability.

Response: accepted. We added lower troposphere stability in Fig. 6 and also kept the vertical velocity, as this is reported by some previous studies saying that subsidence could impact cloud cover (e.g., Myers and Norris, 2013). Thus, for the cloud cover changes, on top of humidity, we also discussed liquid water, moisture flux, dynamics and stability. Some discussions are also included and we also acknowledged that it is impossible to examine all the factors in the current study due to limited output.

We added the following discussion after line 192:
"Another mechanism that has been reported to influence cloud cover is LTS, in which a stable boundary layer could trap more moisture, thereby permitting more low-level clouds (Wood & Bretherton, 2006; Bretherton, 2015). In order to investigate this mechanism, we further analyzed LTS, defined as the difference of potential temperature between 700 hPa and surface (Fig. 6g-i), in which positive anomalies indicate a stronger inversion or weaker lapse rate. The LTS response is again strongest in response to BC forcing (Fig. 6h), with a widespread increase in stability. A previously reported positive correlation between LTS and low-level cloud cover is, nonetheless, only observed in BC source regions (tropical Africa and India) and part of the central US (Fig. 6h). The LTS responses over land are much weaker in response to CO2 and SO4 forcing, with some responses in Africa and India in response to sulfate aerosols (weaker inversion and less cloud). Some other factors have also been suggested to play a role in modifying low-level clouds, such as the diurnal cycle (Caldwell & Bretherton, 2009) and radiative effects of cirrus clouds (Christensen et al., 2013). Due to the limited model output, however, we acknowledge that it is impossible to examine these factors in the current study and it is beyond the scope of our study to probe all possible factors driving the cloud changes. In summary, the above analyses illustrate that the cloud cover changes we see can be primarily explained by RH changes and, to a lesser extent, changes of liquid water content, circulation, dynamics, and stability."

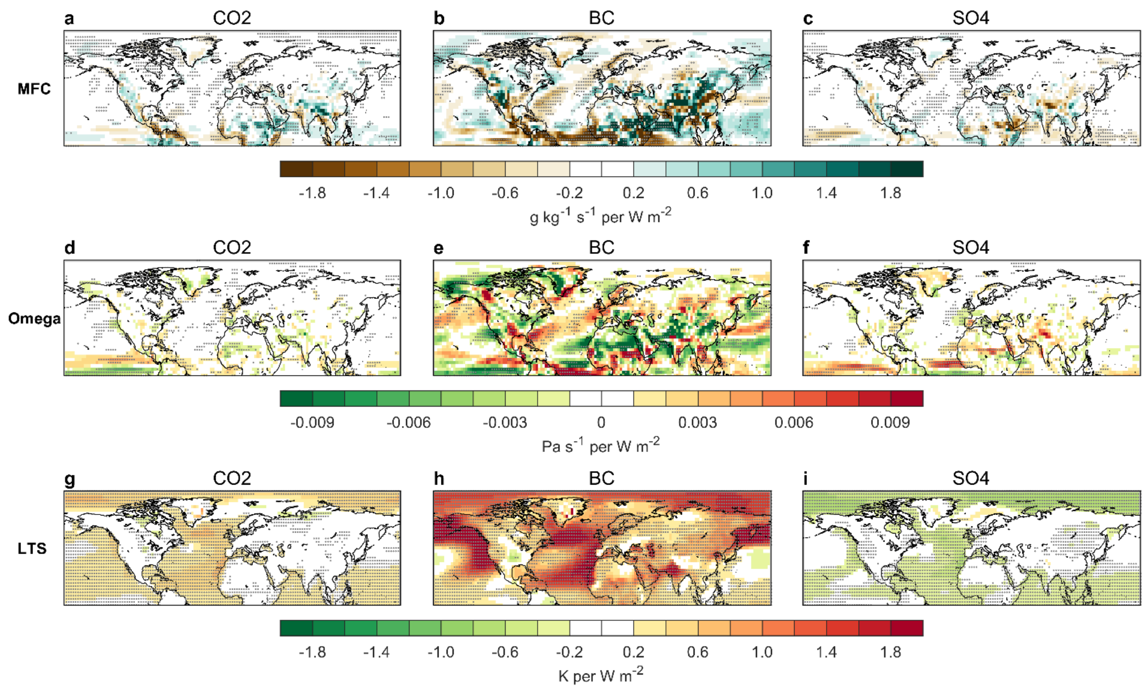

Figure 2: Same as Fig. 2, but for changes of moisture flux convergence (MFC, a-c), vertical velocity (omega, d-f) and lower tropospheric stability (LTS, g-i) per unit forcing. For vertical velocity (omega), positive anomalies indicate the air is less convective. LTS is calculated as the difference of potential temperature between 700 hPa and the surface. Positive LTS anomalies in g-i indicate stronger inversion or weaker lapse rate.

4. I have some conservation about including downward LW in the multilinear regression model. It is possible that downward LW change is a result rather than a cause of Tmax change (Tmax change results in changes in boundary layer temperature and moisture, and thus downward LW). In fact, consider the approximation $LW \sim \sigma T^4$, $dLW \sim 4\sigma T^3 dT$, with T=300 K, $dT/dLW \sim 1/(4\sigma T^3) \sim 0.16$, which is very close to the coefficients derived from the regression.

Response: thanks for your demonstration. For the multilinear linear regression, we still prefer to keep the LW component, as dT is directly related with incoming radiation. The aim of the linear regression is to attribute the contribution of those radiation components to Tmax changes and whether the radiative component is forcing or feedback is not important. In fact, the SWCRE we discussed in this study is mainly a feedback process, which is also included in the regression model. Your demonstration here further lends confidence to our regression results.

5. In PDRMIP BC and sulfate are increased by a factor of 10 and 5, respectively. It may be helpful to comment on whether the response is linear for such a large change. The small SWCRE response to sulfate is interesting and somewhat surprising. Given that aerosol direct effect is probably more linear than aerosol

indirect effect, would the authors expect different SWCRE response to historical change in sulfate?

Response: Previous studies show that most aspects of the climate change linearly with climate forcing, including BC. Thus, the large perturbation is unlikely to substantially impact the results and conclusions. We added a sentence in section 2.2 after line 116.

"Previous studies demonstrated that climate changes linearly with climate forcing for various forcing agents, including BC (Hansen et al., 2005; Mahajan et al., 2013)."

For SWCRE response to sulfate change, we do not have a definitive answer to the question of why these are so small or how linear they might be. Based on Fig. 8, the SWCRE change at the surface is not sensitive to cloud cover changes under sulfate aerosol forcing, as both aerosols and clouds scatter solar radiation. Thus, we cannot rule out the possibility that the historical changes are similar to our results.

Minor:

1. Please clarify that the paper analyzes SWCRE at the surface in the abstract, the main text, and the figures. It is somewhat confusing because I think SWCRE is more commonly referred to as TOA radiative forcing, and the first paragraph in the introduction describes SWCRE at the TOA.

Response: accepted and clarified where necessary.

2. Eq.(1): What is the time frequency of q and V for calculating the moisture flux?

Response: The time frequency of q and V is monthly, and we added this in the methods section, line 131:

"In Eq (1), q is specific humidity in g kg^{-1}, and V is horizontal wind including both zonal and meridional components. All variables have a monthly temporal resolution."

3. Figure 7: Maybe show the fast and slow responses of SWCRE instead of cloud cover, as the paper focuses on SWCRE.

Response: accepted and changed. Here is the new Fig. 7.

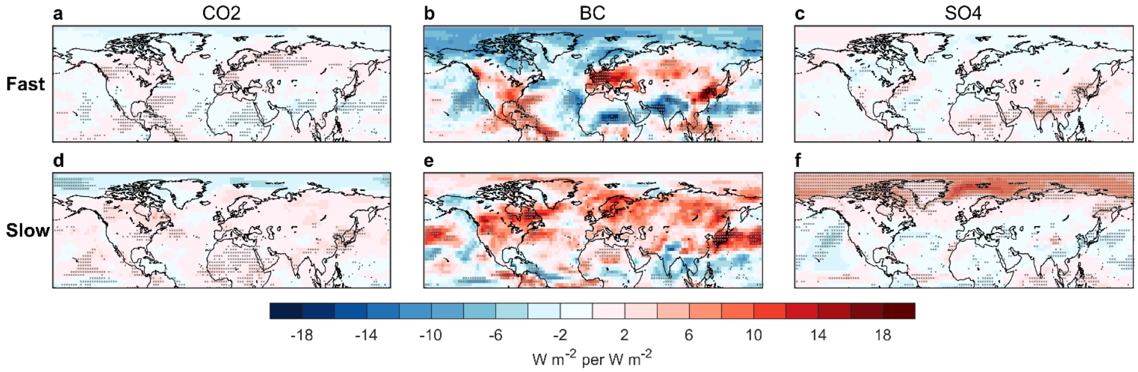

Figure 3: Same as Figure 2 (d-f), but for fast (a-c) and slow responses (d-f) of SWCRE changes per unit forcing.