Reply to Anonymous Referee #1

We thank the reviewer for the careful review and helpful comments. Our responses are detailed below (reviewer's comments marked in blue and our responses in black.

Comment: The major problem is that you should explain your results, not just describe the figures. How is the CRE effect influenced by LWP and CDNC? Why does the non-local effect exist? Especially, why the CRE maximum occurs over the Mexican gulf. These should be discussed and investigated.

Reply: Following the suggestion, the corresponding paragraph has been reorganized and additional description is added. We now explain how changes in cloud droplet number concentration (CDNC) and liquid water path (LWP) result in the negative SCRE in detail. The non-local effect, that is, the tendency of maximum SCRE to appear over the Gulf of Mexico is related to a more sensitive SCRE response to the larger relative change of CDNC and LWP over Gulf of Mexico compared to the land region. As shown in Fig.8 in the original manuscript, changes in both CDNC and LWP are of comparable magnitudes between Gulf of Mexico and the land region. However, given the smaller background CDNC and LWP over Gulf of Mexico, SCRE is more sensitive to changes in the two items over Gulf of Mexico than in the land region. In the revised paper, we have pointed out this phenomenon (Line 315-316) and provided an explanation (Line 337-341).

It now reads (Line 315-316):

"It's interesting to note that the maximum SCRE tends to center around adjacent Gulf of Mexico rather than the land region."

and (Line 320-348):

"To find out the causes of the fire aerosol SCRE, fire aerosol-induced changes in cloud properties are analyzed. Given the largely insignificant change in cloud fraction (Fig. 8), the negative fire aerosol SCRE in the selected regions is mainly associated with increases in cloud droplet number concentrations (CDNC) and liquid water path (LWP). The increased CDNC due to an increase of CCN from fire aerosols (Fig. 8) leads to smaller droplet sizes, which in turn increase cloud albedo

by enhancing backscattering (Twomey, 1977) and further affect LWP by decreasing precipitation efficiency and allowing more liquid water to accumulate (Albrecht, 1989; Ghan et al., 2012). These changes in warm cloud properties demonstrate important contributions of both aerosol first and second indirect effects to the negative SCRE. Over Southern Mexico, although changes of CDNC and LWP are of comparable magnitudes between Gulf of Mexico and the land region (Fig.8), relative changes of both items are much larger over Gulf of Mexico (Fig. S6) due to the smaller magnitudes of background CDNC and LWP here (Fig. S5), which tends to lead to a more sensitive response of SCRE. That's why the maximum SCRE over Southern Mexico is more centered around Gulf of Mexico. Changes in ice water path (IWP) and ice crystal number concentration (ICNC) can also significantly affect SCRE, but with an opposite sign and mostly in the central U.S. The decreased IWP and ICNC, which are possibly caused by fire aerosol-induced changes in the circulation (Ten Hoeve et al, 2012 and reduced coarse mode dust aerosol concentrations), are responsible for the positive SCRE in the north part of central U.S. In the south part of central U.S., the reduction of IWP and ICNC also results in a positive SCRE, which partly offsets the negative SCRE resulting from changes in warm cloud properties. This explains the weaker total negative SCRE in this region compared to the Southern Mexico region despite the more substantial increase in CDNC and LWP here. "

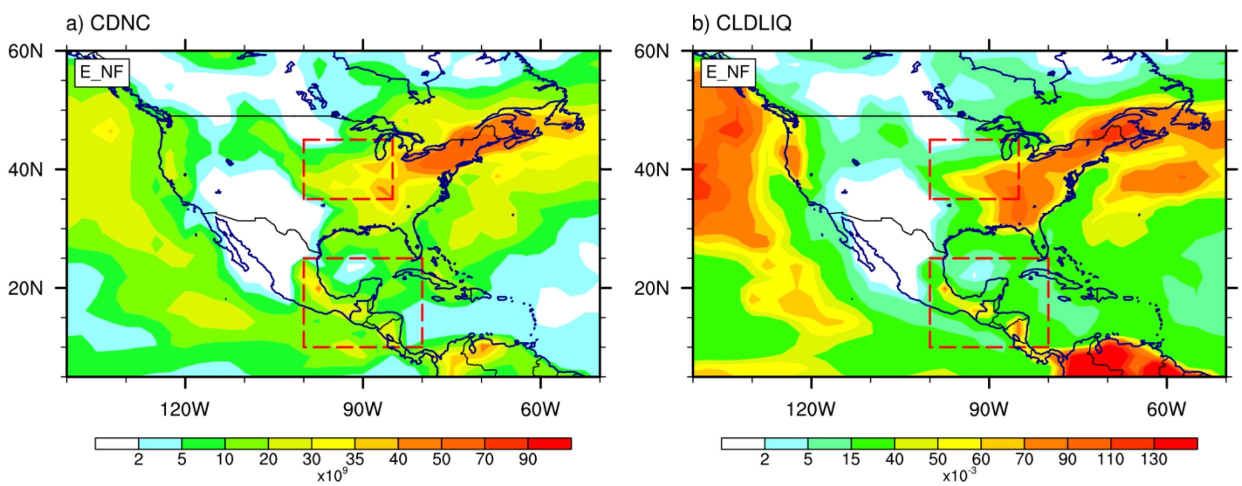

Figure S5. Spatial distributions of 10-day average (Apr. 1-10) ensemble mean a) column-integrated droplet number concentrations (m^{-2}) and b) liquid water path ($g\ m^{-2}$) in the E_NF simulations.

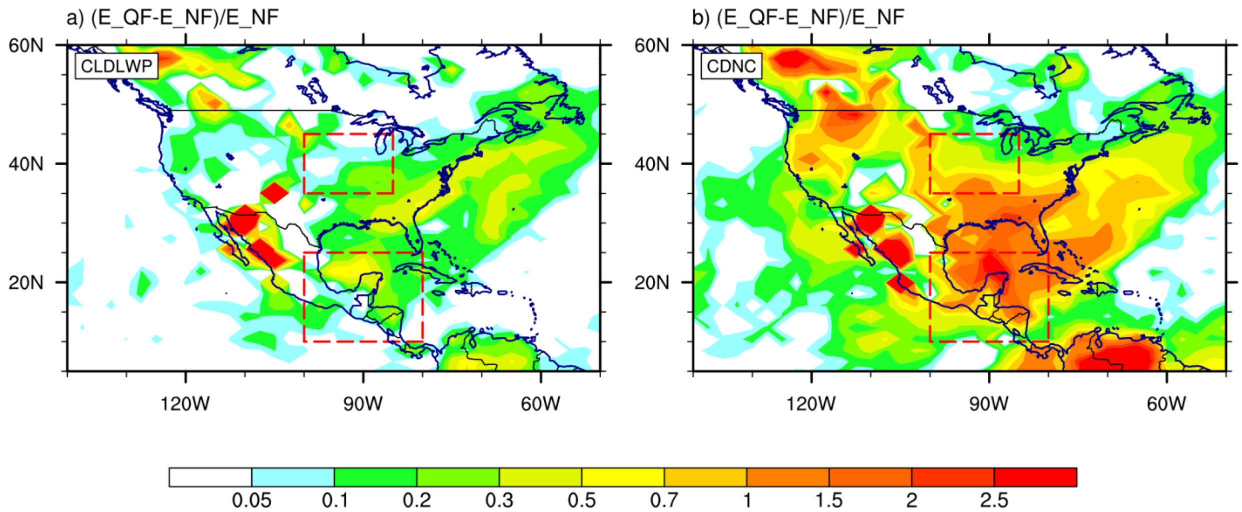

Figure S6. Relative changes of 10-day average ensemble mean cloud properties between the E_NF and E_QF simulations. a) cloud liquid water path, b) column-integrated droplet number concentration

Minor comments:

L60: studied->study

Reply: Done.

L370: Add "are" between "which" and "possibly";

Reply: Done.

L384: Same->The same;

Reply: Done.

L77-79: You should clarify why the indirect effect of fire aerosol deserves study.

Reply: Kaufman et al. (2005) and Zamora et al. (2006) show the short-term indirect effects of fire aerosols are strong based on satellite observations and aircraft measurements (Line 68-72 in the original manuscript). The fire aerosol indirect effect may significantly affect the cloud formation and radiative balance near wildfire burning region. We now explicitly mention the significant radiative effect of fire aerosol indirect effect in the previous paragraph (Line 65-66) to emphasize this as one motivation of our study. We further pointed out in this paragraph the current lack of model simulations of short-term fire aerosol indirect effects, which is another motivation of our work.

L101-103: What's the difference between nudging horizontal wind and temperature.

Reply: Nudging the horizontal winds will constrain the circulation towards reanalysis, but the thermodynamical features are not directly affected. If temperature is nudged strongly (i.e. use small relaxation time scale) too, the heating/cooling introduced by nudging may affect large scale vertical motion and the parameterized convection. In our study, horizontal wind nudging was applied to constrain the large scale circulations, thus a shorter relaxation time scale of 6 hour is adopted. On the other hand, we only used very weak temperature nudging (much longer relaxation time scale) and perturbed the nudging time scale gently to create ensembles. A much longer relaxation time scale of about 10 days is used. We have clarified this difference in the revised paper. Time scales of wind nudging and temperature nudging are now explicitly provided in the corresponding paragraph. The text reads (Line 92): "*Horizontal winds were nudged towards 6-hourly reanalysis to constrain the large-scale circulation*" and (Line 96): "*we also employed very weak temperature nudging (~10days) in combination with ensembles to quantify the uncertainty. More details of the nudging setup are described in section 2.3.*"

L297-503: How you can get the conclusion that at least 9 members are needed from Fig. 14. You need to quantify the results.

Reply: Thanks for the suggestions. The number 9 in the discussion paper was determined by simple visual comparison. As shown in Fig.14b, discrepancies in the ensemble mean fire aerosol SCRE are substantial when the number of ensemble members (N) is smaller than 8. We agree it is better to determine the minimum required ensemble number in a quantitative way. We now use results from the 20-member ensemble simulations as a reference to evaluate the results from ensemble simulations with varying N. For a specific N, the root mean square error (RMSE) of the ensemble mean SCRE during April 1-10 is chosen to quantify the deviation of the simulated ensemble mean from the reference value. It is calculated as the standard deviation of the differences between the daily ensemble mean SCRE in the N-member simulation and the 20-

member simulation. To get robust results, for each N, we randomly sample N members from the 20 members for 1000 times and evaluated the performance of the 1000 groups (each group has N members) to avoid the influence of limited sampling. Figure 15 shows that both the RMSE of ensemble mean SCRE and the difference of RMSE between the 1000 groups of simulations (for each N) decrease with increasing N. The minimum number of N required is determined when the 90th percentile of RMSE is smaller than a threshold RMSE. Without a good reference, we set the threshold RMSE to 20% (0.566W m^{-2}) of the reference 10-day mean SCRE (-2.83Wm^{-2}). As shown in Fig.15, at least 11 members are needed to meet this criterion. We've refined the conclusion regarding the total number of ensembles needed in the revised paper. The corresponding paragraph now reads (Line 395-408):

"However, discrepancies in the ensemble mean fire aerosol SCRE (Fig. 14b) are substantial when the number of ensemble members is small. The same is true for the ensemble spread of fire aerosol SCRE (Fig.S8).In order to quantify the discrepancies of the simulated SCRE, we chose the ensemble mean SCRE in the 20-member simulation as a reference and use the root mean square errors (RMSE) of the ensemble mean SCRE in the N-member simulation to quantify the deviation of the simulated SCRE from the reference value. It is calculated as the standard deviation of the differences between the daily ensemble mean SCRE in the N-member simulation and the 20-member simulation. For each N, we randomly sampled 1000 times from the 20 members to help reduce the influence from limited sampling. Figure 15 shows that both the RMSE of ensemble mean SCRE and the difference of RMSE between the 1000 groups of simulations (for each N) decrease with increasing N. The minimum number of N required is determined when the 90th percentile of RMSE is smaller than a threshold RMSE. Without a good reference, we set the threshold RMSE to 20% (0.566 $\mathrm{W}\ m^{-2}$*) of the reference 10-day mean SCRE (-2.83* $\mathrm{W}\ m^{-2}$*). As shown in Fig.15, at least 11 members are needed to meet this criterion."*

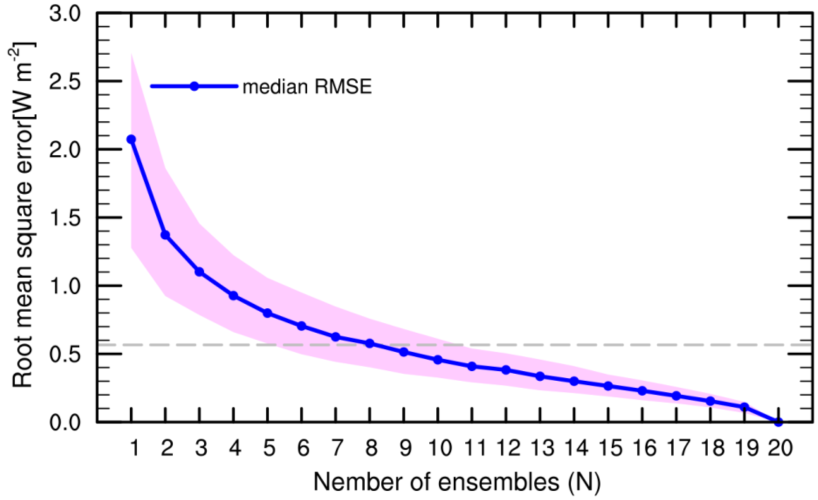

Figure 15 Root mean square errors (RMSE) of the ensemble mean of the regional mean fire aerosol SCRE during April 1-10 over Southern Mexico in simulations with different total number of ensemble members (N). The blue line represents the median RMSE of the 1000 groups (each group has N members/simulations). The grey line represents the threshold RMSE. Shaded area denotes the range between the 10^{th} and 90^{th} percentiles.