Responses to referee #1:

General comments: In the manuscript 'Understanding Climate-Fire-Ecosystem Inter- actions Using CESM-RESFire and Implications for Decadal Climate Variability', Zou et al. explored complex interactions between climate change, fire, and ecosystem using a global Earth System Model equipped with a coupled fire module. They estimated the global net radiative effects and NEE changes due to fire aerosols and fire-induced land cover changes under present-day and future scenarios. The topic is interesting and relevant to the scope of ACP. Overall, this is a nicely written manuscript with a clear description of data, model design and results. I recommend it to be published after some minor modifications suggested below.

Response: Thank you for your recommendation and constructive comments. We revised the manuscript accordingly to improve the presentation quality. Please see below the point-by-point responses and corresponding revisions in the manuscript.

Specific comments: My only major concern is the present manuscript lacks a detailed discussion about the uncertainty of the simulations and calculations. Specifically, although most current state-of-art fire models (including RESFire used in this study) may be able to reproduce the main spatial variability of fire emissions (and fire pollutants) under current climate condition, their ability to simulate temporal variability, as well as the changes under a changing climate has not been validated. As mentioned by the authors, some important processes (such as the lightning changes in the warming future) are also ignored in this study. It will be interesting to know how does it lead to changes in the simulated fire impacts in the future scenario. I believe this paper will be benefited from adding some discussions on this topic.

Response: Thank you for the helpful suggestion. We agree with you that uncertainty is still a challenging issue for the current state-of-art fire models. The same statement also applies to global lightning projections under climate change scenarios. Before using the RESFire model for future projections, we comprehensively evaluated its modeling performance in terms of both spatial distributions and temporal variations for global burned area and fire emissions in our previously published model development paper in the Journal of Advances in Modeling Earth Systems (JAMES, Zou et al., 2019). As shown in the following figures (Figs. R1 and R2) reproduced from Figs. 9 and 10 of Zou et al. (2019), the RESFire model captures the burning patterns and fire seasonality in different regions driven by either reanalysis-based atmospheric data (RESFire_CRUNCEP) or online simulated atmospheric data (RESFire_CAM5). It can also reproduce the observed decadal trends driven by different forcing factors such as decadal climate variability as well as demographic and socioeconomic changes as shown in Andela and van der Werf (2014) and Andela et al. (2017). However, since climate-fire-ecosystem interactions are of interest in this work, we fixed the socioeconomic factors such as population density and GDP in the RESFire simulations to eliminate the uncertainties associated with future population and socioeconomic projections. Lightning was also fixed in the future projections due to large uncertainty in its parameterization and future projections (Tost et al., 2007; Clark et al., 2017). There are other considerable uncertainty factors remaining in the projections, including fire emission estimation, fire radiative forcing related with aerosol-cloud interactions, fire induced land cover change and biogeochemical/biophysical effects, etc. We added a new section 3.4 to discuss the relevant uncertainties you suggested.

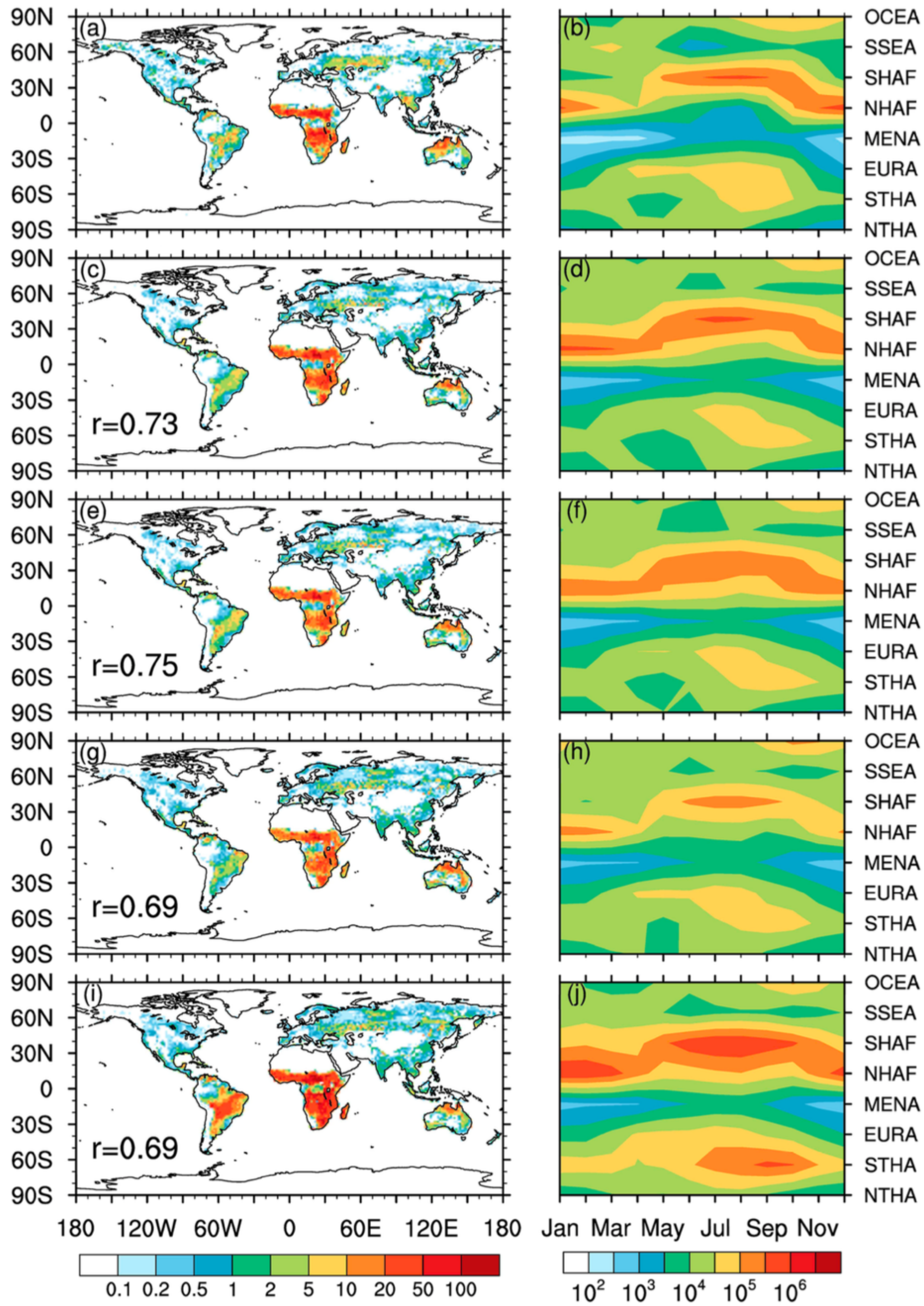

Figure R1 Comparisons of spatial distributions and seasonal variations of burned area in the observations and simulations. (a) GFED4.1s burned area fractions (%) averaged from 1997 to 2010; (b) seasonal variations of averaged GFED4.1s burned areas (km^2) in the eight subregions; (c, d) same as (a, b) but from RESFire_CRUNCEPa driven by the CRUNCEP reanalysis-based atmospheric data and varying population density; (e, f) same as (a, b) but from RESFire_CRUNCEPb driven by the CRUNCEP reanalysis-based atmospheric data and fixed population density; (g, h) same as (a, b) but from RESFire_CAM5a driven by online bias corrected CAM5 atmosphere simulations and fixed population density; (i, j) same as (a, b) but from RESFire_CAM5b driven by online CAM5 atmosphere simulations without bias correction and fixed population density. The spatial correlation coefficients between simulated global burned area fractions and the GFED4.1s data are shown on the bottom left corners of (c), (e), (g), and (i). RESFire = REgion-Specific ecosystem feedback Fire; GFED = Global Fire Emissions Database; CRUNCEP = Climatic Research Unit and National Centers for Environmental Prediction; CAM5 = Community Atmosphere Model version 5. (reproduced from Fig. 9 in Zou et al., 2019)

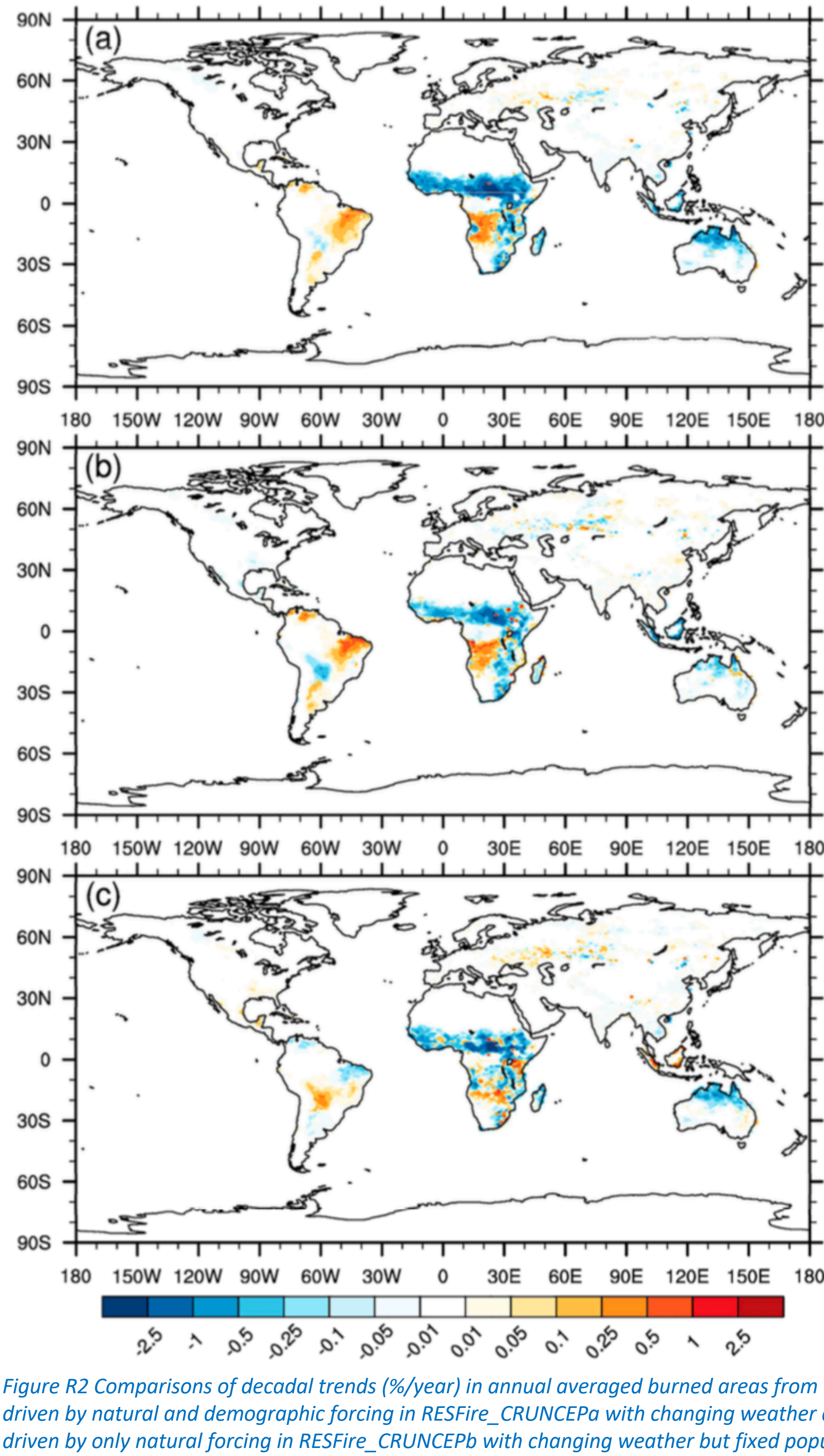

Figure R2 Comparisons of decadal trends (%/year) in annual averaged burned areas from 1991 to 2010. (a) Burned area trends driven by natural and demographic forcing in RESFire_CRUNCEPa with changing weather and population; (b) burned area trends driven by only natural forcing in RESFire_CRUNCEPb with changing weather but fixed population density; (c) burned area trends driven by demographic changes only. RESFire = REgion- Specific ecosystem feedback Fire; CRUNCEP = Climatic Research Unit and National Centers for Environmental Prediction. (reproduced from Fig. 10 in Zou et al., 2019)

Minor and technical comments:

Page 1, Line 17: "The complex climate-fire-ecosystem interactions were not included in previous climate model studies". I suggest softening the tune here. Some components of the interactions between climate, fire, and ecosystem have been considered in previous studies (although they were not necessarily incorporated into, or might not be represented thoroughly in a fully coupled online model).

Response: Thank you for the suggestion. We revised the narrative here to "The complex climate-fire-ecosystem interactions were not fully integrated in previous climate model studies".

Page 2, Line 58: "These processes were not included in previous climate model studies". Similar to the above, this sentence is way too assertive.

Response: Thank you. We revised it to "These processes were not fully included in previous climate model studies".

Page 3, Line 102-103: Since the new scheme is not implemented in this study (and the readers don't know the strength of the new approach), you don't have to mention it here. Removing this sentence won't affect the integrity of this paper.

Response: Thank you. The fire plume parameterization paper has been submitted to the Journal of Advances in Modeling Earth Systems and is under review now.

Page 7, Line 218-220: In addition to biogenic organic aerosols, can an underestimation of fire emissions be another reason for low simulated aerosols?

Response: You are right. We added this possible cause of underestimated fire emissions in line 231-232 of the revised manuscript as follows:

"Another possible cause for the underestimation problem is underrepresented burning activity due to deforestation and forest degradation and consequently underestimated fire aerosols emissions in these regions".

More detailed discussion is given in the next paragraph based on Fig. 2.

Page 7, Line 246-247: Any physical explanation for the differences between the signs of aerosol-cloud interactions and aerosol-radiation interactions?

Response: As explained in line 252-256, the land-sea contrast warming and cooling effects by aerosol-radiation interactions over Africa and South America (Fig. 3a) result from strong light absorption of fire aerosols enhanced by increased low-level cloud reflection over the downwind ocean areas. Fig. R3 shows the changes in low-level cloud fractions induced by fire aerosols in the present-day simulation (CTRL1-SENS1A). It demonstrates decreased low-level clouds over the African land region where biomass burning occurs and increased low-level clouds over the downwind Atlantic Ocean region. Therefore, opposite land-sea contrast signs occur due to distinct aerosol-cloud and aerosol-radiation interactions with positive aerosol-cloud radiative forcing over the land region and negative aerosol-cloud radiative forcing over the ocean area (Fig. 3b).

We added Fig. R3 in the supplement and more detailed explanation in line 259-265:

"The land-sea contrast of radiative effects emerges again in the vicinity of Africa and South America, but the signs of the contrasting effect related with aerosol-cloud interactions are opposite to these from aerosol-radiation interactions. The large amounts of fire aerosols suppress low-level clouds over the African land region by stabilizing the lower atmosphere through reduction of radiative heating of the surface. However, fire aerosols increase cloud cover and brightness in the downwind Atlantic Ocean areas because they increase the number of cloud condensation nuclei and the larger cloud droplet number density reduce cloud droplet sizes (Lu et al., 2018; Rosenfeld et al., 2019; Fig. S1 in the Supplement)".

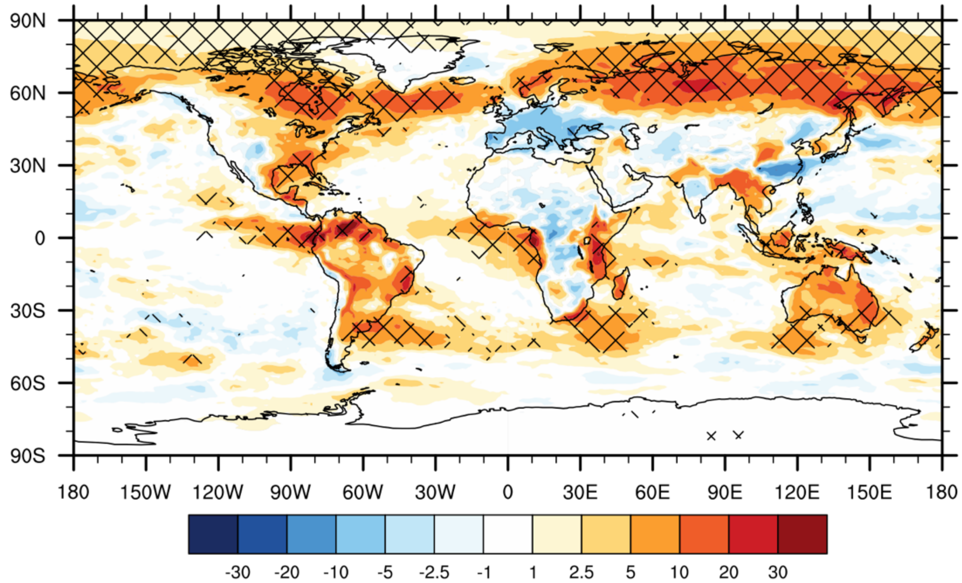

Figure R3 Fire aerosol induced low-level cloud fraction change (unit: %) in the CESM-RESFire present-day simulation (CTRL1-SENS1A).

Page 8, Line 279: It would be good to briefly introduce this plume rise parameterization (e.g., based on what measurements? Global universal or regional-based?)

Response: Thank you for the suggestion. The Sofiev et al. (2012) plume rise parameterization is globally universal and is based on atmospheric boundary layer height, fire radiative power, and Brunt-Väisälä frequency in the free troposphere. We added relevant description in line 299-302 as follows:

"In our simulations, we used a simplified plume rise parameterization (Sofiev et al., 2012) based on online calculated fire burning intensity (FRP) and atmospheric stability conditions (PBLH and Brunt-Väisälä frequency) in CESM-RESFire and applied vertical profiles with diurnal cycles to the vertical distribution of fire emissions".

Page 11, Line 376-379: The terms 'fire combustion factors', 'fire spread distribution', and 'fire spread factors' are probably not familiar to many readers. Please consider a short explanation on these parameters (i.e., what do they mean physically).

Response: Thanks. Fire combustion factors (FCF) are based on 10-day running mean of surface temperature, 10-day running mean of total precipitation, and soil water fraction for top 0.05 m layers as a surrogate for fuel combustibility (see Table 3 of Zou et al. (2019)), while fire spread factors (FSF) include surface air temperature, relative humidity, surface soil wetness, and fractions of wet canopy as listed in Table 4 of Zou et al. (2019). We added the explanation for these terms in line 396-397 and line 400-401 of the revised manuscript.

Page 11, Line 388-389: I don't quite understand the causal relationship stated in this sentence. The changes in wind speed are higher over the ocean than that over land, but this could be

simply due to the larger magnitude of wind speed over the ocean. Relatively smaller changes in land wind speed could still have large impacts on fire spread and burned area.
Response: Thank you for the comment. We rewrote the analysis for climate-fire-ecosystem interactions in Sect. 3.3. Please see the revised manuscript for details.

Page 25, Figure 2: Please align tick label '0.1' with other tick labels in panels b, c, d.
Response: Thanks. The figure has been updated.

Page 27, Line 817: Should the unit of CDNUMC '10^9 # /m2' (as correctly shown in panel d)?
Response: That's correct. Thanks for the correction.

Page 30, Figure 7: The colors in panel c don't have enough separation. Please use another scale.
Response: Thank you. The scale in this figure has been updated for better color separation.

Page 32, Figure 9: If my understanding is correct, the data in this figure show the differences of fire modifications on weather variables between the future and present ((CTRL2-SENS2B)-(CTRL1-SENS1B)), not the differences of weather variables (in CTRL model) between the future and present (CTRL2-CTRL1). The current form of figure caption is a bit confusing.
Response: Thank you for the correction. Fig. 9 is used to explain the future changes in simulated global fire activity. Therefore, we compare the future and present-day fire weather conditions in CTRL2 and CTRL1 to understand these fire simulation results shown in Figs. 7 and 8. This figure has been updated with the corresponding sensitivities to surface temperature, precipitation, relative humidity, and surface wind speed between CTRL2 and CTRL1. The changes in fire feedback on these fire weather variables (i.e., (CTRL2-SENS2B)-(CTRL1-SENS1B)) are shown in Fig. 10 with corresponding discussion in Sect. 3.3 of the revised main text.

References

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