Response to Referee #2

This study investigates the impact of aerosol-cloud interactions (ACI) and aerosol radiation interactions (ARI) on fog formation. The important roles of changing of advection and PBL dynamics in fog formations are revealed. It highlights the role of BC in the formation and maintenance of fog. In general, the manuscript is well organized. Thus, I suggest a minor revision before publication. The suggestions and comments are lists as following:

Response:

We appreciated the referee to offer us these insightful suggestions. We will revise this article accordingly.

1. Introductions, Line 30, Page 2: I think it is not appropriated to claims "the impact of BC on fog has been rarely investigated by existing studies" after listing two references of "the impact of absorbing aerosols on fog formations". Since BC is one of the most important absorbing aerosols.

Response:

Accepted. We will revise "rarely investigated" to "not fully understood" in the introduction.

2. Could you describe whether nudging is employed and the detailed method of nudging? Because nudging can affect the estimation of ARI.

Response:

The application of nudging can affect the feedback from chemistry module to the meteorology. So we did not apply any nudging while simulating of ARI or ACI. We will clearly demonstrate this in the revision.

3. As mentioned in Aerosol-Radiation-Microphysics Interactions (https://ruc.noaa.gov/wrf/wrf-chem/wrf_tutor ial_2018/AerosolInteractions.pdf, page 42), "Comparing runs with chem_opt = 8 (without cloud-borne aerosols) with chem_opt = 10 (with cloud-borne aerosols) for MOSAIC coupled to Lin microphysics does not quantify the indirect effect, since the autoconversion scheme used in the Lin microphysics scheme will be different". I'm not sure if it is the same for Morrison module? Could you describe the prescribed aerosol used in EXP_NOAER scenario?

Response:

In all experiments, the cloud water mixing ratio is predicted by the Morrison schemes. In EXP_NOAER, model simulated aerosol has no impact on the cloud/fog droplet. Instead, a constant value of cloud droplet number (250 cm^{-3}) is used, which is a default treatment in the WRF model. In other experiments (EXP_CTL, EXP_NORAD and EXP_NOBC), the prognostic cloud droplet number is applied. The purpose of the autoconversion is to convert cloud droplet or ice (mass and number) into snow or rain due to collision–coalescence between cloud droplets. The Lin scheme would have a different autoconversion parameterization when switching from constant value to prognostic droplet number, which is why it's not qualified for estimating the indirect effect. But in the Morrison scheme, the same autoconversion parameterization is implemented for either constant or prognostic droplet number (Yang et al., 2011). Moreover, in our result, the episode of fog-haze event is neither affected by precipitation during the early December 2013, nor the fog process are largely influenced by the autoconversion in the microphysics schemes since very little fog is predicted in the YRD region on 7 December in EXP_NOAER scenario.

4. Mentioned in Line 15, page 11, "Comparison between ARI and ACI shows that the effect of ARI was dominant over the effect of ACI. The reason may be that during this haze pollution episode there was little cloud and ACI was very weak." However, the role of ACI is not limited as the change of solar radiation and PBL dynamics. One of the most important ways is acting as CCN during fog formations. I'm curious if the number and radius of fog droplet are changed. Could you show some results?

Response:

The ARI took a dominate role in both affecting the meteorological condition and inducing the fog occurrence. If without the enhanced moisture advection induced by the ARI, the moisture level in the YRD region would be relatively unfavorable for the formation of fog, and the ACI effect of aerosols acting as the fog nuclei can be limited (under low relative humidity). As a result, the ACI has a very small impact on the liquid water content in the near surface (LWCns) of the YRD region at 10 LST on 7 December in Figure S3b (which is provided in the supplemental information of the article). Figure R1 shows the time series of the ARI, ACI and aerosols' total impact on the water vapor mixing ratio (Qns) and LWC in the near surface of the YRD region. It also suggests that during the fog episode of 7 December, the ARI took a dominate role in both introducing the Qns and LWCns. There is only a small contribution from ACI (less than 0.05 g m^{-3}) on enhancing the LWCns. The effect of ACI is calculated as the difference between EXP_NORAD and EXP_NOAER. In EXP_NORAD, which remove only ARI, both of the cloud water mixing ratio and number concentration is predicted. In EXP_NOAER, which remove both ARI and ACI, the cloud water mixing ratio is predicted but the number concentration is fixed to 250 cm^{-3}. Figure R2-R4 shows the liquid water content (LWC), number concentration and the effective radius of cloud droplet at LST 7:00 7 December 2013 in EXP_NORAD and EXP_NOAER. A small enhancement of LWCns can be seen in the northern part of the YRD region due to ACI (Figure R2). Accordingly, in EXP_NORAD, the number concentration is above 350 cm^{-3} which is above the constant value of 250 cm^{-3} in EXP_NOAER (Figure R3), and the effective radius of the droplet is mildly decreased (Figure R4) from EXP_NORAD to EXP_NOAER.

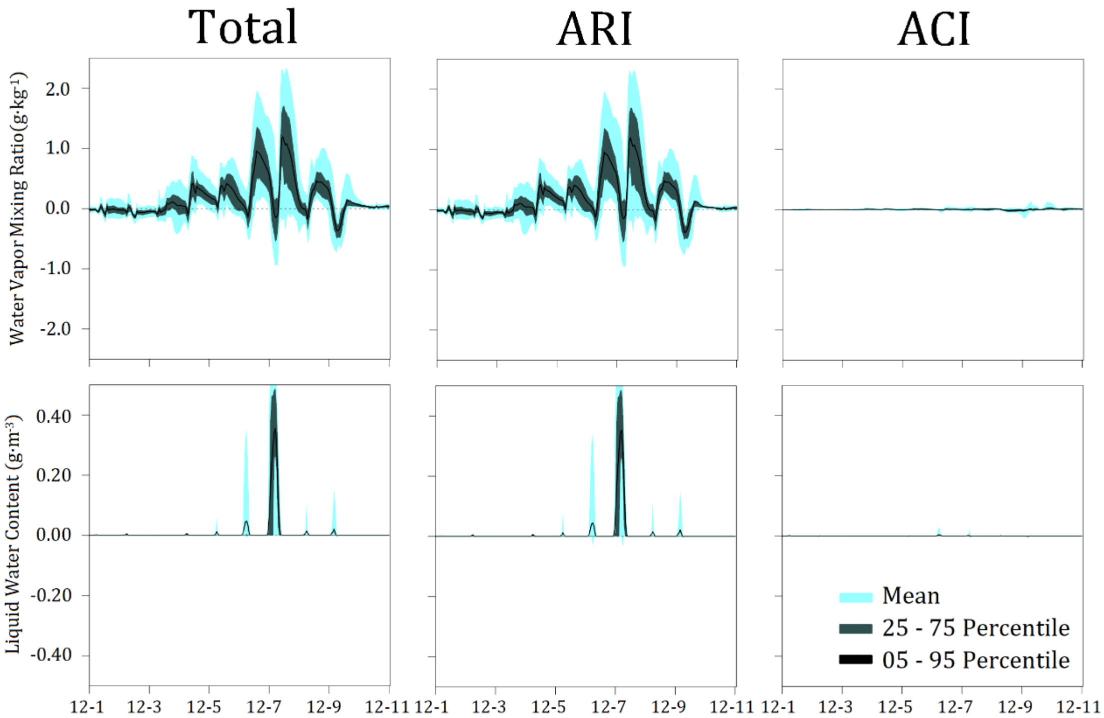

Figure R1. The ARI, ACI and aerosols' total impact on the near surface water vapor mixing ratio and liquid water content during 1-10 December 2013 in the YRD region.

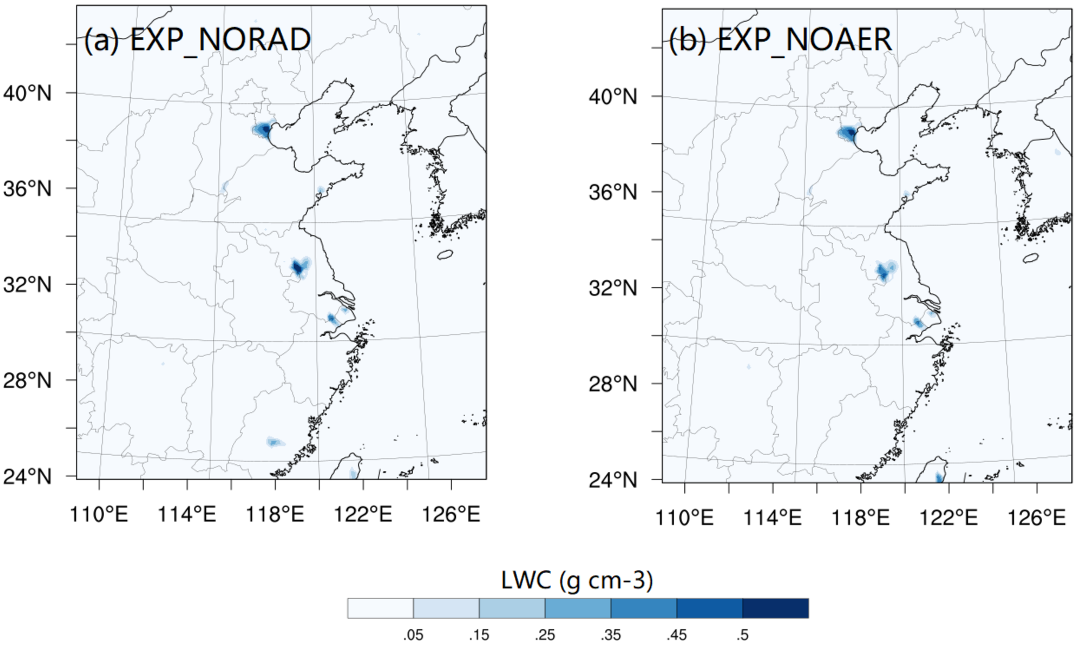

Figure R2. Liquid water content in the near surface over the eastern China, LST 7:00 December 2013, from (a) EXP_NORAD and (b) EXP_NOAER.

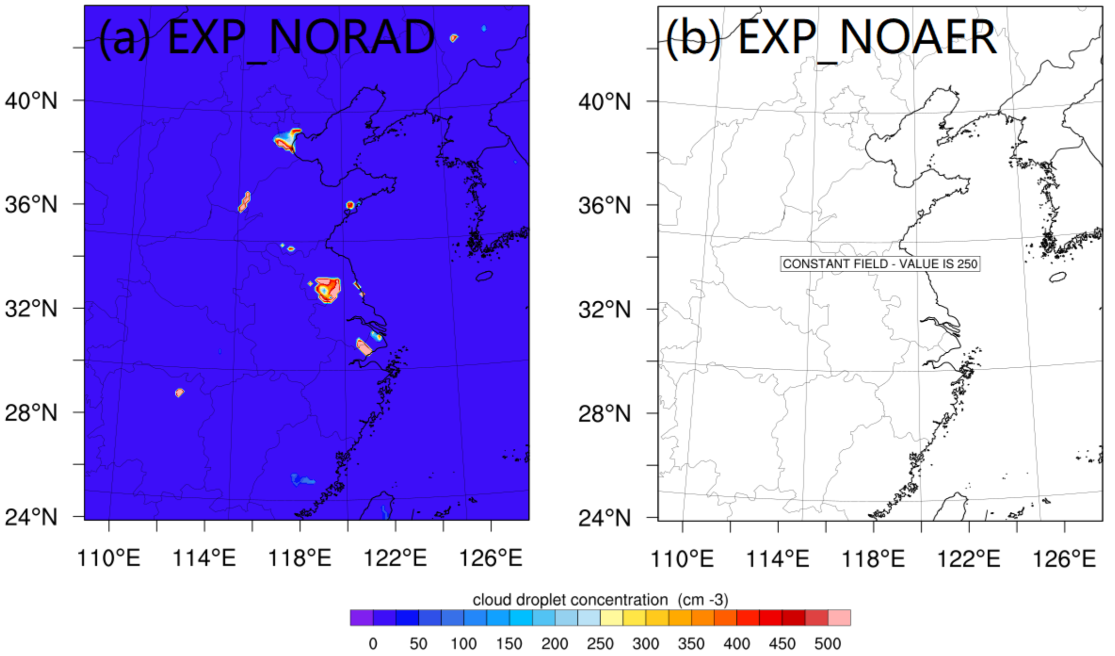

Figure R3. Number concentration of cloud droplet in the near surface over the eastern China, LST 7:00 December 2013, from (a) EXP_NORAD and (b) EXP_NOAER.

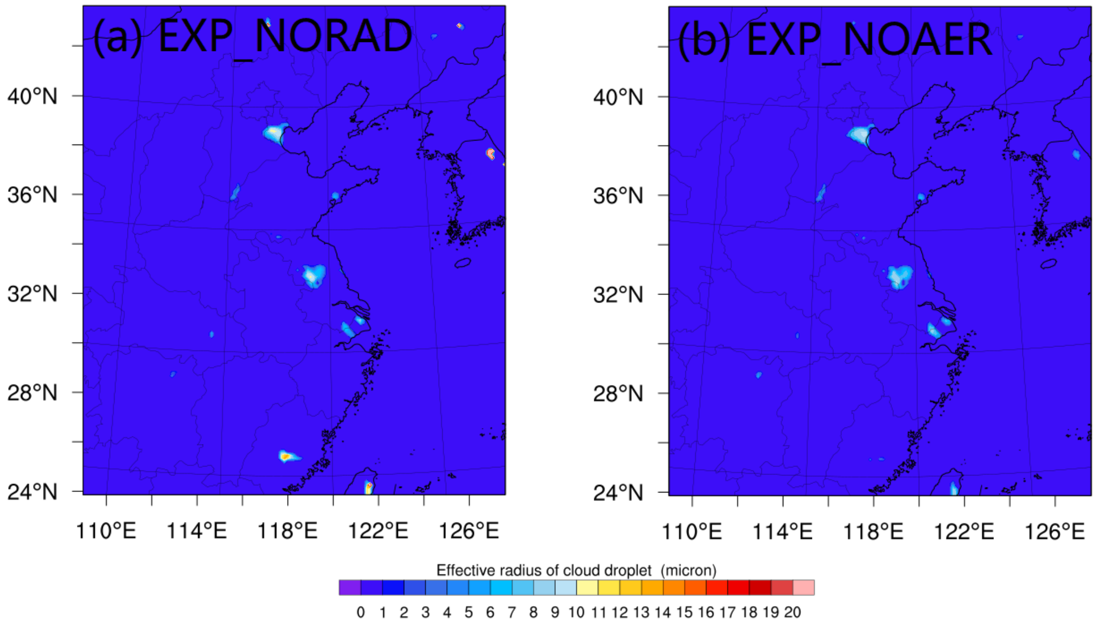

Figure R4. Effect radius of droplet in the near surface over the eastern China, LST 7:00 December 2013, from (a) EXP_NORAD and (b) EXP_NOAER.

5. I think some statements in abstract and conclusion are too strong as a case study, like "We find that the ARI dominates this fog-haze episode while the effects of ACI are negligible." It would be more appropriate if the statement could be limited as for specific scenarios. Further, it would be interesting to investigate under which conditions ARI is more important and under which conditions, ACI is more important in future studies. Maybe it is beyond the scope of this study.

Response:

Accepted and thanks for the suggestions. Some modifications will be applied to avoid strong statements about the experiment result. We are also interested in the question about under which condition the ARI/ACI is more effective in affect fog formation. Although it is not easy to answer this question from one single case study, we will include this suggestion in our future work.

6. *I'm not sure whether the sharp decrease of PM2.5 and BC on Dec 7 in Figure 4 is due to wet removal or not. I guess the sharp decrease and rapid increase may be caused by the activation of the interstitial aerosol to the cloud-borne aerosol, and resuspension from the cloud-borne aerosol to the interstitial aerosol. And cloud-borne aerosol is not counted in CTL_EXP scenario. If so, could you check if the cloud-borne aerosol is calculated in the optical module and discuss whether ARI is underestimated during fog episode?*

Response:

Accepted. The $PM_{2.5}$ and BC that measured in our observation is dehumidified particle which include both interstitial and cloud-borne aerosols. However, the $PM_{2.5}$ and BC provide by the simulation result is the dry mass from only interstitial aerosol. The cloud-borne aerosol is processed in the CTL_EXP separately as aerosols-in-cloud-water type variables, which is not included in the Figure 4. So, we will revise the explanation for the underestimation of the $PM_{2.5}$ and BC on Dec 7 accordingly. Also, the optical effects from the cloud-borne aerosol are not directly estimated, in the optical module from the WRF-Chem that we used (version 3.8.1). In fact, many climate models tend to omit the treatment of optical effect from cloud-borne aerosol as well, because the scattering of the sunlight can be less efficient once the aerosol particle attached to the droplet (Ghan and Easter, 2006). However, Bond et al. (2013) pointed out the absorption of the BC can be increased when it is coated with non-absorbing material include water, and the neglect of this effect can influence the general estimation of the radiative forcing in global scale. However, in this study, the cloud cover is low during the fog-haze event. So, the neglect of the optical effect from the cloud-borne aerosol did not have much influence on the radiation flux or other meteorological fields. And it would not affect the fog formation since it mostly took place during nighttime. Only after the sunrise, when the fog top is heated by the solar radiation, the cloud-borne BC can absorb more sunlight, warm the ambient atmosphere and speed up the evaporation of the droplets at the top fog layer. The absence of the optical effect from cloud-borne aerosol may, to some extent, slow down the dissipation of fog. From another perspective, under the heavy fog condition, the reduction of the incoming solar radiation mostly resulted from the light extinction of fog droplets, which can overwhelm the direct ARI from cloud-borne aerosol particle.

References :

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