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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Effects of wintertime polluted aerosol on cloud over the Yangtze River Delta: case study" *by* Chen Xu et al.

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Dear editors:

The authors thank referee #2 for the comments (RC2). There is a response to RC2 review of our manuscript "Effects of wintertime polluted aerosol on cloud over the Yangtze River Delta: case study" (ACP-2016-968). According to the reviewer's suggestions, we make revision to the manuscript in detail, all of revision have been marked in red in the new manuscript (Supplement). The following is a response to comments one by one.

Question1: A comprehensive investigation about the aerosol-cloud interaction has been performed by Myhre et al. (2007, ACP) using the aerosol and cloud measurements from MODIS satellite data. They have found an enhancement in the cloud cover with increasing aerosol optical depth, which is most likely attributable to the aerosol-

cloud interaction and a prolonged cloud lifetime. What is new in the present study compared to Myhre et al. (2007)?

Answer 1: The comprehensive investigation paper by Myhre et al. (2007) used satellite data (only MODIS) and two global aerosol models for studying aerosol-cloud interaction in large scale. The method of Myhre et al. (2007) is to compare the results from satellite observed to the model simulations. In our present study, we chose one typical period with heavy pollution and focus on a region, considering satellite data and local observations. What we wanted to find is the effect of aerosol on cloud during the polluted winter time for distinct regions of the YRD (that have different surface characteristics, geographies). The new part added to our present study is that we took more meteorological, terrain conditions and multifarious data into account. For instance, in section 3.2.3, we added parameter, AOD/LWP, helping to analyse the relationship between AOD and CDR. When analysing the general relationship between AOD and cloud parameters, we divided clouds into four groups and AOD into two levels (see Supplement1). We found that aerosol plays an important role in cloud evolution for the low layers of troposphere (below 5km) in case of the stable atmosphere in wintertime. Moreover, the non-monotonic responses of cloud properties to aerosol perturbations exposed the inhibited property of aerosol. In addition, we have a case study (section 3.3), which covers both the growth and decrease of one pollution event. In this case study, we examined the change of cloud according to aerosol. We identified the vertical distribution of aerosol and cloud. Combined with sea level pressure, surface lifted index and PM2.5 concentrations, we identify occurrence of air mass updrafts for supporting the source of acting aerosols. Furthermore, with the help of NOAA's HYSPLIT model, we identify more clearly whether the development of cloud is because of air mass transportation or aerosol effect.

Question 2: Does the high AOD correspond to high aerosol concentrations in the atmosphere? In addition, if assuming that AOD is well related to aerosol concentrations, can the observed aerosols by satellites be the same source with those influencing clouds?

Answer 2: Satellite measurements of aerosols, called aerosol optical thickness, are based on the fact that the particles change the way the atmosphere reflects and absorbs visible and infrared light. The hygroscopic property of aerosol will change the values of AODs for the same concentration of aerosols. For example, a higher relative humidity increases the AOD due to more water uptake by the particles. Many studies have worked on the relationship between AOD and aerosol concentration. For instance, G. Myhre et al. (2007) point out that the increase in AOD is not a major result of the hygroscopic growth, as the Angstrom exponent increases in many areas with AOD from MODIS results. Aerosol and cloud will transport with the moving air mass. It is difficult to analyse whether the observed aerosols by satellite are the same source influencing clouds on a large scale. Therefore we added a four-days case study that investigates in more detail and considers the air mass transport. In section 3.3, it showed air mass updrafts and horizontal transmission by meteorological conditions and trajectories from HYSPLIT model.

Question3: Three-month analyses of satellite measurements are not sufficiently long to establish the relationship between aerosols and clouds. The region division is somewhat confusing because the 3-month mean AOD difference among the four regions is not significant.

Answer 3: We agree that three-month analyses of satellite measurements is short for a general study on the relationship between aerosols and clouds. But our work we chose these three months as a special case study when there was a heavy pollution period in the region in order to try to understand how amounts of aerosols affect clouds. So, this manuscript is a case study. In response to the reviews we tried to analyse more details within our case study to better understand the relationship between aerosol and cloud. The region division is chosen not only according to the AOD difference but also with terrain characteristics that can influence the probable sources of aerosols in the regions. We explained this in section 3.1.

Question 4: How does IN affect clouds?

Answer 4: Our study focuses mostly on lower level clouds (< 5 km) that can be strongly influenced by CCN but for which IN are less important. 1. IN play an essential role in the physical processes of the ice cloud via its direct effect on size and number concentration of ice particles and indirect effect on the formation of precipitation and lifetime of clouds, which in turn modulate processes of the atmospheric radiation and thus climate. 2. The formation of ice in clouds can occur through primary processes (nucleation of ice from liquid water or vapor phases, either homogeneously or heterogeneously), or through secondary processes (fragmentation of large drops during freezing, ice splinter formation during riming, crystal fragmentation). 3. The IN effect originates with the coexistence of ice crystals and supercooled droplets in mixed-phase clouds. Since the saturation water vapor pressure over water is higher than that over ice, ice crystals gain mass by vapor deposition at the expense of the supercooled droplets that lose mass by evaporation. Owing to the relatively low ice crystal number concentration but high droplet concentration in clouds, many droplets surround each ice crystal. As a result, the droplets evaporate with the resulting water vapor being deposited onto crystals to form precipitating particles. All in all, most ice particles in the atmosphere appear to form by homogeneous freezing at temperatures near or below -37 °C, followed by ice multiplication. There is, however, a small but cloud microphysically very important fraction of ice particles that are initiated at warmer temperatures by the action of insoluble solid particles with favourable surface properties, the ice nuclei. Mineral dust, primary biogenic particles, and some industrial/combustion-derived anthropogenic particles are the most common IN.

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Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/acp-2016-968/acp-2016-968-AC2-supplement.pdf

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