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Aerosol Indirect Effect on Warm Clouds over Eastern China Using Combined CALIOP and MODIS Observations

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Aerosol, one of key components of the climate system, is highly variable, both temporally and spatially. It often exerts great influences on the cloud-precipitation chain processes by serving as CCN/IN, altering cloud microphysics and its life cycle. Yet, the aerosol indirect effect on clouds remains largely unknown, because the initial changes in clouds due to aerosols may be enhanced or dampened by such feedback processes as modified cloud dynamics, or evaporation of the smaller droplets due to the competition for water vapor. In this study, we attempted to quantify the aerosol effects on warm cloud over eastern China, based on near-simultaneous retrievals from MODIS/AQUA, CALIOP/CALIPSO and CPR/CLOUDSAT during the period 2006 to 2010. The seasonality of aerosol from ground-based PM10 is quite different from that estimated from MODIS AOD. This result is corroborated by lower level profile of aerosol occurrence frequency from CALIOP, indicating the significant role CALIOP could play in aerosol-cloud interaction.

The combined use of CALIOP and CPR facilitate the process to exactly determine the (vertical) position of warm cloud relative to aerosol, out of six scenarios in terms of aerosol-cloud mixing status in terms of aerosol-cloud mixing status, which shows as follows: AO (Aerosol only), CO (Cloud only), SASC (Single aerosol-single cloud), SADC (single aerosol-double cloud), DASC (double aerosol-single cloud), and others. Results shows that about 54We categorize dataset into warm-season and cold-season subsets to figure out how the boomerang shape varies with season. For moderate aerosol loading (AOD<0.4), the effect on the droplet size for the "Mixed" cases is greater during cold season (denoted by a large slope), as compared with that during warm season. It is likely associated with an increase in the emission of light absorbing aerosol like smoke (black carbon), mainly caused by coal-fired heating during the cold season in China. As expected, the sensitivity of CDR to AOD is much weaker for "Separated" cases, irrespective of warm or cold seasons, indicating no real aerosol indirect effect occurring in this case. In contrast, for heavy aerosol loading (AOD>0.4), an increasing CDR with AOD can be seen in "Mixed" scenario during the warm season. Conversely, a closer look at the responses of CDR during the cold season shows that CDR decreases with AOD, although the strength is not much large. Therefore, we argue that cloud droplet size decreases with aerosol loading during cold season, irrespective of moderate or heavy atmospheric pollution.

Finally, we discuss the possible factors that may influence the aerosol indirect effects on warm clouds investigated here. For instance, aerosol-cloud interaction conundrum might be affected by aerosol humidification, which is the case for MODIS AOD during warm seasons. But this issue can be partly overcome by categorizing dataset into warm-season and cold-season subsets, representing different ambient humidity condition in the atmosphere. The different boomerang shapes observed during various seasons, particularly after transition zone due to droplet saturation effect, have great implications for climate forcing by aerosol in eastern China.