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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Diurnal variation of heavy rainfall over the Beijing-Tianjin-Hebei region: Role of aerosol cloud effect and its sensitivity to moisture" *by* Siyuan Zhou et al.

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In this work, the authors look at how properties of gauge-measured rainfall is linked to satellite and reanalysis aerosol and cloud properties. They demonstrate that there are strong correlations between the satellite retrieved aerosol and cloud properties, similar to previous work. They also show a correlation between the timing of the precipitation and the retrieved aerosol. Using reanalysis meteorological and aerosol data, they demonstrate that these relationships between aerosol, cloud and precipitation vary as a function of large-scale humidity and aerosol type.

This work contains several interesting ideas, the use of the gauge precipitation data overcomes issues with the satellite retrieved datasets used in previous studies and the

authors have used their knowledge of the local meteorology to attempt to account for meteorological covariations. However, it is not clear that these covariations have actually been accounted for. Unfortunately, this means that many of the inferences in this work may be overstating the role of aerosols. The results in this paper are potentially interesting, but the authors either need to show more definitively that aerosols are driving these relationships or to tone down the assertions that aerosols are the controlling factor. As such, I would only recommend publication after major corrections.

1 Main points

1.1 The role of aerosols

Many previous studies have shown that aerosol optical depth (AOD) is not a good proxy for CCN (Stier, 2016) and is strongly correlated to humidity, which can generate correlations between AOD and cloud fraction (CF; Quaas et al., 2010), as well as other cloud properties (Christensen et al., 2017). It has been shown that using large scale humidity to account for this issue is insufficient (Boucher and Quaas, 2012).

This can even affect studies of cloud development similar to those in this study (e.g. Matsui et al., 2006; Meskhidze et al., 2009; Gryspeerdt et al., 2014). This is due to the AOD-CF relationship resulting in different initial cloud distributions for the high and low AOD populations. As cloud development is linked to this initial state, this leads to the AOD-CF relationship (known to be strongly controlled by relative humidity) generating a link between AOD and cloud (or precipitation) development.

As the authors note, it is not easy to isolate the impact of aerosols from that of meteorology in a purely observational study. By restricting the circulation patterns analysed, the authors have gone some way towards doing this, but subsetting by reanalysis humidity alone has been shown by previous studies to be unable to account for the impact of meteorology. This is a difficult task, one that may not be achievable with current data. However, in that case, the conclusions would have to be changed to reflect this.

1.2 Data choices

The MERRA data is not suitable for use as a cloud product, as it is not a measurement, but a model parametrisation. I am not clear to the extent which MERRA represents aerosol-cloud interactions, but if they are not included in the model, the relationship between MERRA clouds (depending only on meteorology) and observed aerosol would be indicative of a meteorological covariation (similar to the results presented in Boucher and Quaas (2012)).

The MODIS 1 by 1 degree CTP is an average of multiple retrievals. In cases with multiple layers of cloud in the same gridbox, the average CTP may be less than 600hPa despite the gridbox containing large amounts of low cloud. The histograms in the MODIS product could be used to better ensure a low contribution of low level cloud.

To account for the impact of humidity on the AOD retrieval, it may be possible to use reanalysis aerosol (McCoy et al., 2017). However, care should be taken in strongly precipitating environments, as this has a quite different spatial sampling compared to MODIS. Whilst MACC/MERRA reanalysis may be able to account for uncertainties in the retrieval, it has quite different relationships to precipitation which should be considered if it is used (Gryspeerdt et al., 2015).

1.3 Physical explanations

I found some of the explanations of the aerosol-cloud correlations confusing. In particular, the explanation for the moisture dependence of the correlation between AOD and CTP (L278) is very different from the process described in the references.

The standard impact of aerosol on collision-coalesence (C-C) is to reduce its efficiency (as smaller droplets have a reduced coalesence probability) suppressing precipitation (Albrecht, 1989). However, the explanation in section 4.3 seems to be suggesting that increased aerosol and droplet numbers enhance C-C, making precipitation more likely. This is not supported by the references (as far as I understand them).

There may also be similar explanations, for example - an increase in the low cloud fraction with increasing low level humidity could increase the gridbox mean CTP. The already high cloud fraction in the high AOD cases might limit the impact of this meteorological covariation to the low AOD cases only, explaining the different relationships of humidity, AOD and CTP observed in Fig. 3f.

This is not to say that the authors explanation is wrong, but it should be better supported by references, or with calculations or data if it is a new hypothesis.

2 Minor points

L61 - Qian et al. - not in references

L65 - complicacy - complicated nature?

L69 - The Twomey effect is only the change in droplet number resulting in a change in cloud albedo, not the collective result of all aerosol effects on liquid clouds.

L82 - Gryspeerdt et al. (2014) showed a link between aerosol and precipitation development with another attempt to account for meteorological covariations.

L83 - Similar to this study, these other studies have shown aerosol is correlated with a change in precipitation, not that it causes the change.

L110 - A map of the stations/region used would be useful here

L114 - AOD is not necessarily a good proxy for CCN (e.g. Stier et al, 2016)

L125 - 'we suppose' - could this be checked?

L133 - assimilation definitely reduces the shortcomings of model simulations, but it is not clear that it 'overcomes' them completely.

L146 - QA of marginal or higher. Marginal is the lowest retrieval confidence other than 'no confidence'. Why is this choice made - does using a higher confidence level strongly impact the results?

L159 - Why is a different reanalysis used for the clouds and the meteorology?

L167 - I am not clear why focusing on this time period better identifies the effect of aerosol

L174 - These are very high values of AOD. Brennan et al. (2005) suggested that at AOD>0.6, aerosol is likely to be misclassified as cloud. Might this affect the results here?

L190 - There also appears to be a later peak in the precipitation rate at high AOD. Is it clear whether the peak has move earlier or later.

L206 - Given that much of the paper is about the development of precipitation, it might be good to point out that the cloud properties are measured at the same time as the aerosol. This is stated in the methods section, but a small reminder would be useful.

L260 - It is not clear what 'nearly 350hPa' means. 340 or 360hPa?

L287 - Twomey not Towmey

L290 - via enhanced collision-coalesence - this is not the mechanism stated in Yuan et al. 2008, where the positive AOD-effective radius relationship is related to changes in aerosol properties.

L295 - The Wegner-Bergeron-Findeisen process can act whenever supercooled liquid

and ice crystals co-exist. As long as liquid droplets exist, it should not depend directly on the supersaturation over liquid, although if the region is supersaturated with respect to liquid, the liquid droplets can also continue to grow.

L319 - These changes would shift the PDF of CF, but I am not sure it can be said that BC 'corresponds to a slight decrease of CF when CF is more than 90%' as the CF in an aerosol-free atmosphere is not know. Instead, it would be more accurate to use phrases such as 'cloud fractions larger than 90% are less common in high BC environments'.

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