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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Wet scavenging limits the detection of aerosol–cloud–precipitation interactions" *by* E. Gryspeerdt et al.

Anonymous Referee #3

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OVERVIEW

This manuscript examines the relationship between AOD and precipitation in GCMs and satellite retrievals. Satellite retrievals show a positive correlation between clear sky AOD and adjacent precipitation in most tropical and subtropical locations, but AOD and precipitation retrievals are non-coincident. In GCMs, AOD is an "all sky" variable rather than a "clear sky" variable, and the AOD-precipitation relationship is different than in satellite retrievals. With the aid of a 3-week mesoscale simulation of deep convective systems in the Congo, the authors show that this is a result of wet scavenging of aerosols. The aerosols ingested into the deep convective updrafts come from non-scavenged regions, which supports the use of satellite clear sky retrievals of AOD in inflow regions adjacent to convective clouds and precipitation. Further support comes

from the lack of a positive AOD-precipitation relationship in a high CF thick mid-level cloud regime when the MACC reanalysis AOD is used instead of MODIS AOD.

The strongest part of the paper is the demonstration of wet scavenging producing different AOD-precipitation relationships in GCMs and satellite retrievals. The weakest is the hand wavy discussion of "invigoration" in shallow cumulus and thick mid-level cloud regimes, as discussed more in comments below. Overall, this is a manuscript on the important but complicated topic of aerosol impacts on precipitation, and it is worthy of publication in ACP, but only following revisions.

MAJOR COMMENTS

1. Sections 2.3 and 3.2 are confusing, and there needs to be better transitions from and connections to the simulation result sections (e.g., Sections 2.2 and 3.1). Here are a couple examples from the observations results that did not make sense to me:
a. You ensure that high and low AOD quartiles have the same distributions of CF and meteorology at T+0 for different cloud regimes and claim that changes in precipitation before and after T+0 are the result of aerosol interactions. Why can't meteorology or CF change before or after T+0 and be responsible for differences in precipitation rather than aerosols?

b. Controlling for 850 hPa relative humidity, 500 hPa pressure vertical velocity, 10 m/s wind speed, and LTSS (from Gryspeerdt et al. 2014) does not control for all meteorological factors that impact precipitation. What about variables that directly impact rainfall such as precipitable water or variables that directly impact convection such as CAPE and vertical wind shear? Without controlling for these variables, the claim that an aerosol invigoration effect is occurring is unsubstantiated.

c. If there were an aerosol invigoration effect, you'd expect to see it in the deep convective regime where updrafts are strong enough to loft liquid into the mixed phase zone so that freezing can be enhanced. An increase in aerosols should reduce the probability of warm rain precipitation in shallow cumulus (since they don't contain ice) because increased CCN reduces cloud droplet size, so aerosol invigoration of precipitation doesn't make sense for these clouds. Thick mid-level clouds are presumably stratiform rainfall in mesoscale convective systems and frontal type systems. Again, little cloud water is lofted in this cloud type, so how does aerosol invigoration operate?

d. To examine large deep convective systems in the Congo with a simulation and then global shallow cumulus and thick mid-level clouds regimes with observations is part of what contributes to the confusion when transitioning between sections of the paper. Since most of the precipitation in the tropics is from deep convection, and this is the regime where one would theoretically most expect an aerosol invigoration effect, why not include this regime in the observational analysis?

2. Can you clarify what you mean by an invigoration-like effect? I'm assuming that you are referring to the dynamical invigoration of convection by increased lofting and freezing of cloud water (as hypothesized by Rosenfeld), but there are a lot of steps missing between what you have shown and concluding that this type of an effect is increasing precipitation. You can certainly hypothesize reasons for increased precipitation with increased clear sky AOD, but you shouldn't be so conclusive without more evidence shown, and you should more clearly lay out what invigoration means and how it might lead to more precipitation. In my mind, I don't see why meteorological conditions that you did not control for at T+0 (see 1b) can't be correlated with AOD and lead to increased precipitation just as easily as the aerosols themselves.

3. Convective downdrafts bring down cleaner air from mid levels into the boundary layer. Can you show that this effect is small relative to wet scavenging in your WRF simulation? Also, although not an issue over the rainforest in the Congo, convective system outflow in arid regions (e.g., the Sahel) often generates large amounts of dust that can increase AOD (e.g., Flamant et al. 2007 (http://onlinelibrary.wiley.com/doi/10.1002/qj.97/abstract)), so the simulation in the Congo region may not be universally representative.

MINOR COMMENTS

1. This is not a major gripe, but I don't think the title of the paper fits the results you show. First, wet scavenging is an aerosol-cloud-precipitation interaction. Second, you are not examining all aerosol-cloud-precipitation interactions. You are primarily concerned with aerosol-precipitation interactions. Third, these interactions are not being detected by satellite. Correlations are being detected. And lastly, detection isn't limited in satellite retrievals. It is limited in GCMs. A more specific title would be something like "Wet scavenging limits the detection of aerosol effects on precipitation in GCMs" or "Wet scavenging produces different relationships between AOD and precipitation in satellite retrievals and GCMs".

2. You mention the uncertainty associated with modes of convection that are different than your composite mode from the WRF simulation, but what about uncertainty in the scavenging of aerosols that contribute to AOD that are not present in the Congo? Is scavenging of biomass burning aerosols representative of scavenging of other aerosols such as dust? Is scavenging of boundary layer aerosols representative of scavenging of free tropospheric aerosols plumes?

3. Does your WRF simulation reintroduce aerosols into the atmosphere when cloud and rain droplets evaporate? If not, removal of aerosol could be overestimated.

4. Do you have a citation for the last sentence of the second paragraph in Section 4 (stating that aerosol hygroscopic growth generates much of the positive correlation between clear sky AOD and precipitation)?

5. It seems strange to have a Section 4 (Discussion) and Section 4.1 (Comparison to GCM processes) without a 4.2. Maybe change Section 4.1 to Section 5 or have the first part of Section 4 as Section 4.1 with the comparison to GCM processes as Section 4.2.

6. Can you explain what you mean by relative frequency of occurrence (RFO)?

7. At the beginning of Section 4.1, you should change “air is drawn into convective updraughts from non-precipitating regions” to “air is usually drawn into convective updraughts from non-precipitating regions”.

8. Can you provide a citation for the last sentence in the second paragraph of the conclusions (aerosol hygroscopic growth primarily causes the increased in AOD with increasing precipitation in scenes with low precipitation)?

Interactive comment on Atmos. Chem. Phys. Discuss., 15, 6851, 2015.