Understanding the Effects of Aerosols On Cloud Microphysics in Coastal Urban Environments

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Abstract

Several studies have found evidence of warm-season rainfall increases over and downwind of cities. This induced precipitation has been attributed mostly to induced updraft of warm air masses. Aerosols are abundant in urban environments and it has been hypothesized that they play a role in the water balance of cities. High concentrations of cloud condensation nuclei (CCN) may induce precipitation in humid urban environments. However, precipitation may be reduced due to excess CCNs or by large aerosols. The present research is directed to improve our understanding of the role of aerosols in cloud processes of complex coastal urban environments.

Background

Recent studies provide evidence that urban environments can modify or induce precipitation. Increases of 9%–17% have been found to occur over and downwind of major urban cities [1]. The frequency of intense rain showers has increased in recent decades in correlation with the population growth of Mexico City, Phoenix and Houston [2,3,4].

Convection

Cities motivate convective rain which occurs when the surface is locally overheated and the adjacent air expands and rises. During its ascent, the air mass remains warmer than the surrounding environmental air. Further cooling of the air causes the water vapor in the air to condense into water droplets. Heavy afternoon thunderstorms are likely to occur [5]. This intense rain usually lasts for a few minutes and it is localized.

Figure 1. Convective storm brewing.

Aerosols

Aerosols may play an important role in precipitation increase. Aerosols scatter and/or absorb solar and terrestrial radiation. Scattering and absorption levels depend on physical and chemical characteristics.

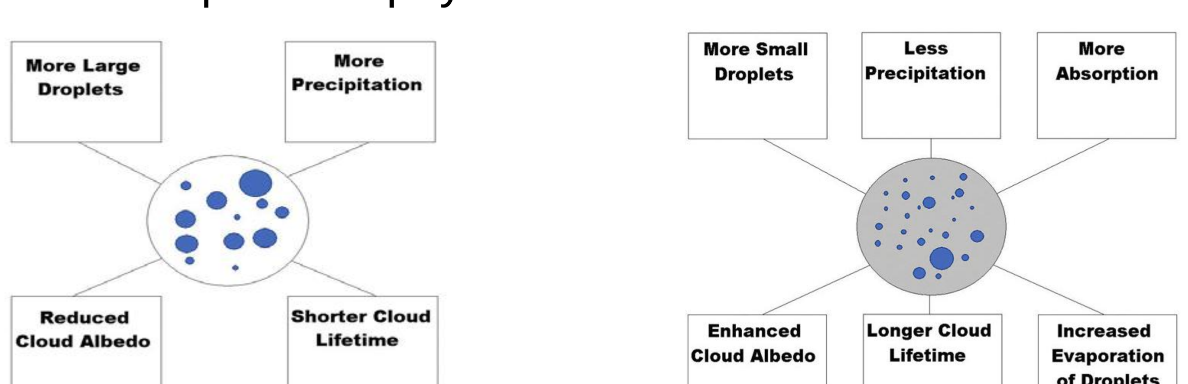

Figure 2. Aerosol effects on clouds.

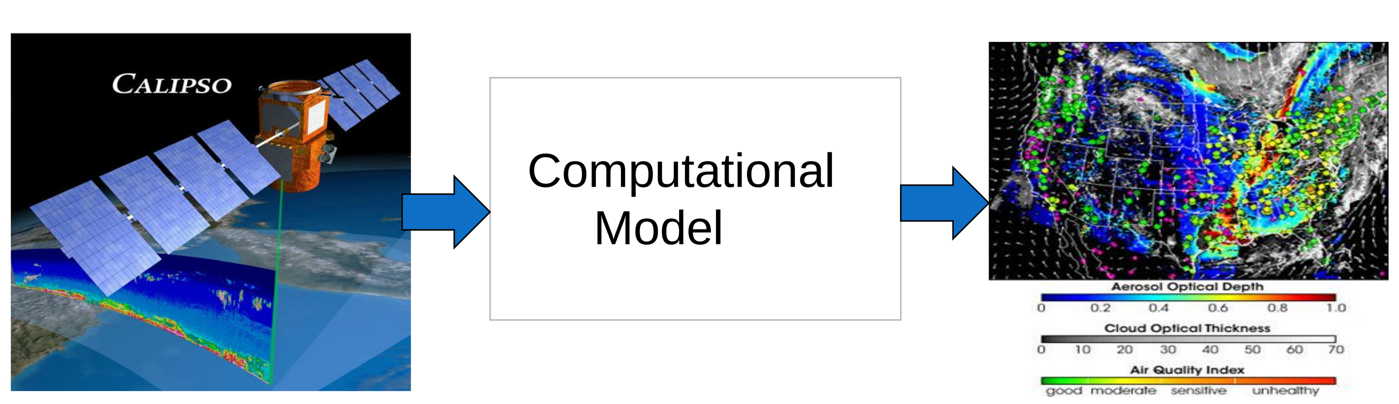

Figure 3. Data Acquisition, Ingestion, and Results. Data attainable from satellites (and from ground observations) include the information about radiation budget, clouds, aerosols, and tropospheric chemistry. Source: NASA.gov

Microphysics

Microphysical processes are cloud processes which take place on the scale of the individual aerosol. These processes include collision, coalescence, and droplet growth.

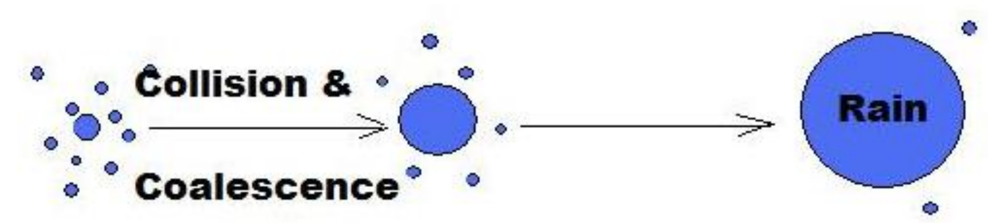

Figure 4. Microphysical Processes

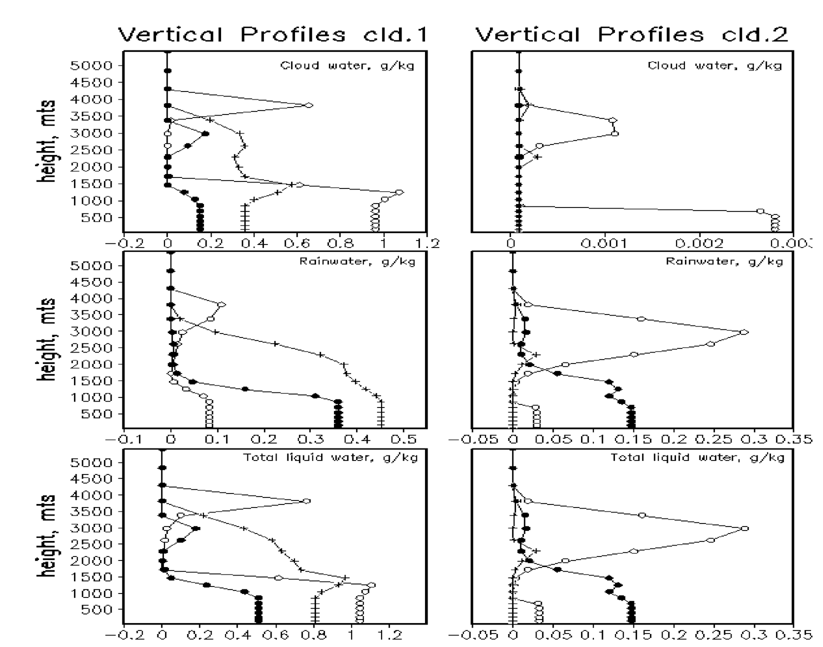

Figure 5. Simulation of precipitation in polluted (right) and non-polluted air (left). Rainwater in polluted air is less than a third of that in clear air [6].

Hypothesis

Based on analysis of background information, it is plausible that aerosols may enhance (as well as decrease) precipitation, and urban environments have been reported to influence precipitation. Thus, the research question is: How do aerosols and cloud microphysics contribute to precipitation in urban environments with and without added convection?

Observations

July 2007 is selected for case study in order to determine precipitation patterns in urban environments. This time period was chosen because a good amount of AERONET data is available .

Central Park	40.73 / −73.97
JFK Airport	40.63 / −73.77
LGA Airport	40.73 / −73.88
Harrison	40.75 / −74.15
Roosevelt Island	40.77 / −73.95
Saddle Brook	40.90 / −74.08
Jersey City	40.73 / −74.05

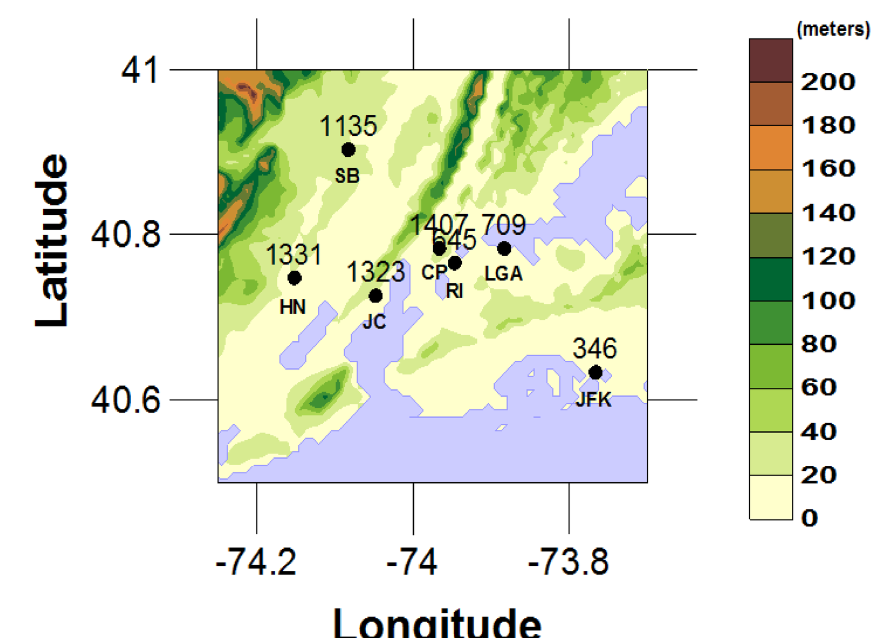

Figure 6. Total precipitation for given weather stations for the month of July 2007.

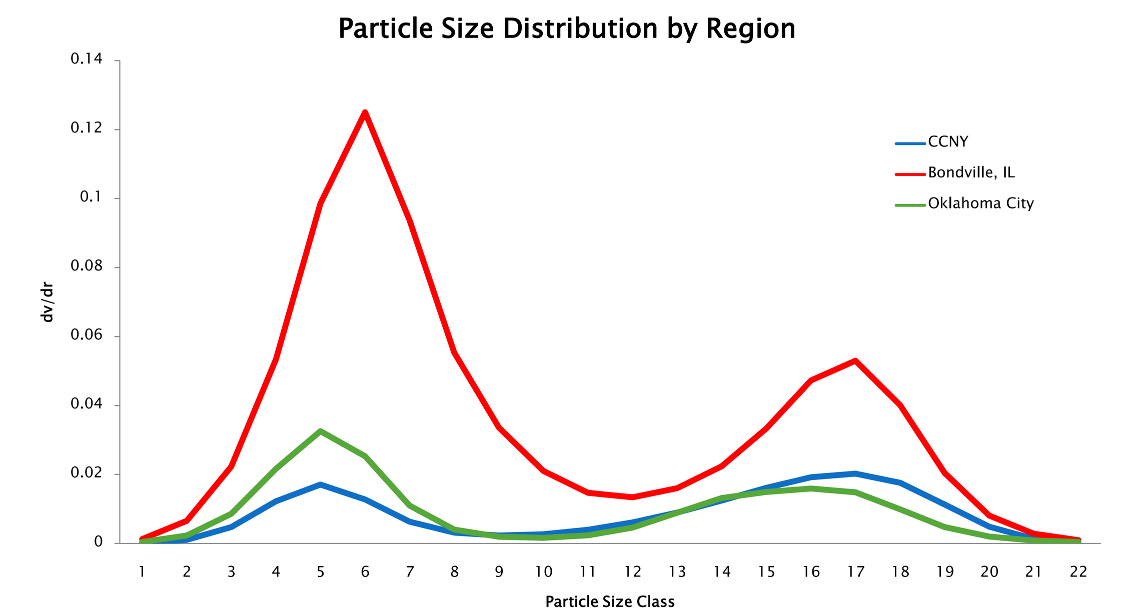

Figure 7. Variation of particle size distribution obtained from AERONET. How will altering the PSD change the droplet growth by diffusion?

Growth Equation (from [7]):

$$r_t \times \frac{dr_t}{dt} = \frac{\left(S_t - 1 - \frac{a}{r_t} + \frac{b}{r_t^3}\right)}{F_{kt} + F_{dt}}$$

Where :
- s is supersatuation
- a is droplet curvature effect
- b is droplet solution effect
- Fkt is a thermodynamic term
- Fdt is a vapor diffusion term

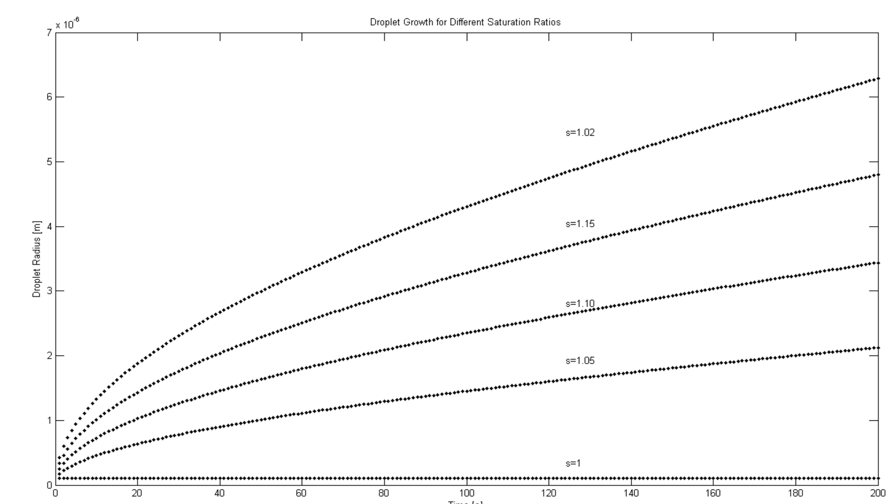

Figure 8. Growth of single droplets by diffusion. The higher the supersaturation (s), the larger the growth rate.

Growth Equation (from [7]):

$$\frac{dR_t}{dt} = \frac{\overline{E} \times M}{4 \times \rho_l} \times u_T$$

Where :
- E is collection efficiency
- M is cloud water content
- ρ is density of water
- u_T= terminal drop velocity

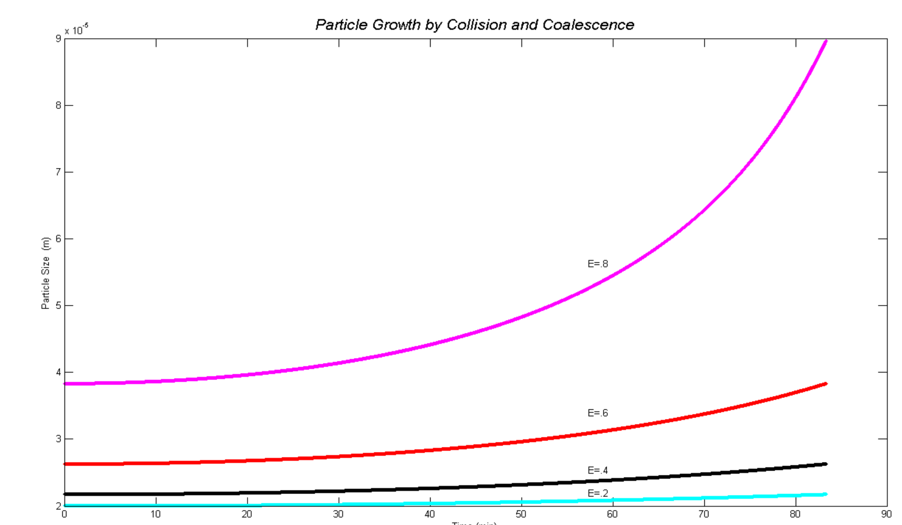

Figure 9. Growth of droplets by collision and coalescence. The higher the collection efficiency (E), the quicker the growth rate.

Future Work

Future work will include running mesoscale models with PSD data ingested to in order to explain observations. This will help to complete the picture of cloud microphysical and aerosol effect in urban environments.

References

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