Effect of Aerosols on the Onset of Precipitation: AMF Deployment in Shouxian, China

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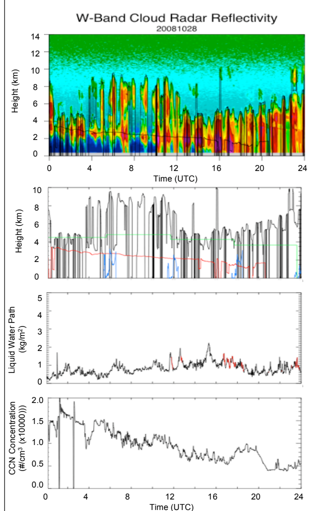
Motivation

Theories of indirect effects of aerosols and recent satellite observations have revealed evidence for the suppression of precipitation in warm clouds in aerosol rich environments, such as are prevalent in eastern China. The observational studies of this project use data from the AMF deployment in Shouxian, China to explore these theories. Modeling Studies are also carried out to determine how aerosols can affect the microphysical processes and cloud properties to help understand and compare with observational results.

Observational Studies

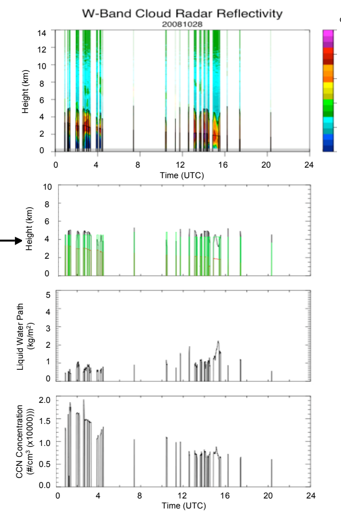
Objective To use data from AMF deployment in Shouxian, China to determine the relative importance of aerosols and atmospheric stability on cloud properties such as thickness, liquid water content, drop sizes and ultimately surface rain. Unfortunately, in gathering this data, it became evident that the W-band cloud radar was operational for only 2 months of the AMF deployment (10/15-12/15/2008) and that during this time the radiometer was inoperative for 35 days, leaving few cases for analysis. Therefore, data from the permanent ARM facility in Oklahoma has been included to increase the robustness of the results (warm rain cases only), and to provide more dynamical situations in which to examine the aerosol effect. Future work will incorporate data from more ARM sites, including those from the Tropical Western Pacific (Darwin and Nauru) and Niamey.

Shouxian, China 10/28/2008



Subset Data:

- Warm rain cases (cloud top [-30dBZ] below 1km above freezing level)
- Maximum reflectivity greater than -15dBZ in cloud (drizzle threshold)
- No rain at surface (radar and radiometer data unreliable once the instrument is wet, used radiometer wet flag and surface reflectivity threshold of -5dBZ)



Figures 1 and 2

(Row 1) Radar reflectivity, cloud base height from ceilometer and cloud top height determined using reflectivity threshold of -30dBZ
(Row 2) Cloud top height (black), cloud base height (red), freezing level (green) and LCL (blue); FL and LCL calculated from sounding data (4 times per day)
(Row 3) Total liquid water path from radiometer, red marks when the radiometer reported it was wet
(Row 4) CCN concentration from AOS

Figure 3

- China (green) is generally much more polluted than Oklahoma (black); CCN concentrations don't tend to overlap
- Range of relative humidities in the two regions are equivalent.
- Linear fits show no trend in cloud thickness with increasing CCN; outliers may be skewing the results
- No significant relationship between cloud thickness and RH or LWP and RH
- Slight increase in total LWP with increase in CCN
- Very slight decrease in drop size diameter with increasing CCN and RH, but no significant trend

Future work will include data from other sites as well as examination of seasonal cycles in the trends (e.g. to account for difference in relative humidities in Oklahoma). Other proxies for stability may be used to test the robustness of the effect of dynamical processes. Also, microphysical processes will be examined further through retrieval of a rain drop size distribution at cloud base.

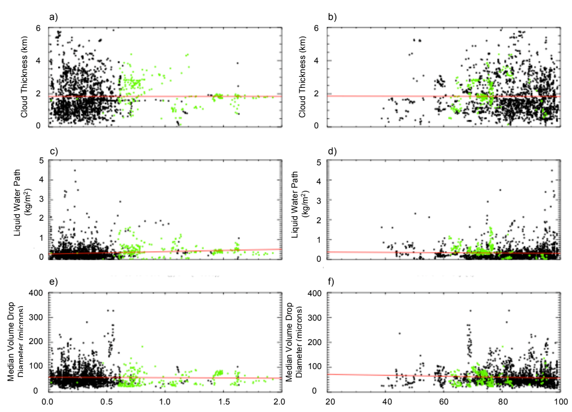


Figure 3 Scatterplots of data from cases determined through subset criteria. Black dots denote cases from SGP (Southern Great Plains or Oklahoma) and green dots represent cases from Shouxian, China. a) Cloud thickness vs CCN concentration. b) Cloud thickness vs relative humidity, which is used here as a proxy for stability (measures lower tropospheric moisture). c) Total liquid water path vs CCN concentration. d) Total liquid water path vs relative humidity. e) DSD proxy/median drop diameter (explained below) vs CCN concentration. f) Medican drop diameter vs relative humidity. Future work will include more analysis on dynamical effects, including accounting for seasonal variability of relative humidity and other proxies of stability.

DSD proxy/median drop diameter

- From D. Atlas (1954)
- Median volume diameter: $d_0 = \sqrt{\frac{\pi Z}{6W(1.35)}} \times 10^6$
- Where Z is reflectivity in mm^6/m^3 and W is liquid water content in g/m^3, determined from liquid water path and cloud thickness

Modeling Studies

Objective To improve our understanding of how aerosols modify cloud properties over the East China Sea, using cloud resolving model simulations. The focus is on warm rain cases that have exhibited dramatic differences in retrieved rainfall rates from active and passive satellite sensors.

Selected CRM Simulation Cases

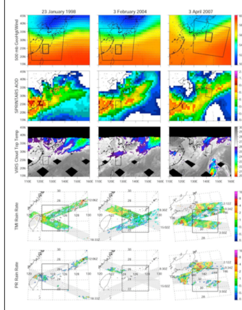


Figure 4 (Row 1) Geopotential height contours (m) and wind (m/s) and placement of model grids for the three events of 1998 Jan 23, 2004 Feb 3, and 2007 Apr 2, (Row 2) SPRINTARS model AOD, (Row 3) VIRS cloud top temperature (K), (Row 4) TMI rainfall rate (mm/hr), and (Row 5) PR rainfall rate (mm/hr).

The Regional Atmospheric Modeling System (RAMS) at Colorado State University was used to simulate aerosol effects on rainfall using sulfate aerosol concentrations from the SPRINTARS aerosol transport model as input for cloud condensation nuclei (CCN). Three different case studies were performed from 23 January 1998, 2 February 2004, and 3 April 2007. These cases were selected based on dramatic differences between rainfall estimates from the active (precipitation radar) and passive (microwave imager) sensors on board the Tropical Rainfall Measuring Mission spacecraft. The rainfall estimates are shown in the figure on the left along with geopotential height and winds from ECMWF, SPRINTARS aerosol optical depth, and IR cloud-top temperature.

For each case a total of four simulations was run using the SPRINTARS CCN in the control run and then varying the amount of aerosol by 1/4X, 1/2X, and 2X. The figure on the left shows the resulting time-averaged rainfall for each aerosol simulation for each of the three cases. Although the overall patterns change slightly, even dramatic changes in the aerosol amount used to initialize the model have a relatively small impact on the total rainfall.

Rainfall as a Function of Aerosol Concentration

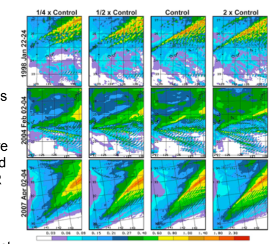


Figure 5 Averaged precipitation rate (mm/hr) (from left to right) for the ¼ x Control, ½ x Control, Control, and 2 x Control simulations (labeled on top) for the simulated events from 1998 Jan 22-24 (top row), 2004 Feb 02-04 (middle row), and 2007 Apr 02-04 (bottom row). Here Control represents use of the SPRINTARS derived CCN concentration and, for example, 2 x Control uses a CCN concentration field that is twice the Control concentration.

Cloud Properties as a Function of Aerosol Concentration

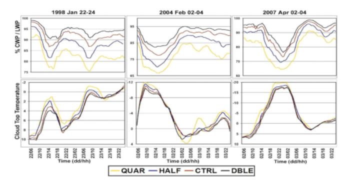


Figure 6 Time series of cloud area averaged values of the ratio percentage of cloud water path (CWP) to total liquid water path (LWP) (top row) and cloud top temperature (deg C) (bottom row) for the simulated events of 1998 Jan 22-24 (left), 2004 Feb 02-04 (middle), and 2007 Apr 02-04 (right). The color legend displays which color line matches the appropriate simulation, whereby, QUAR = ¼ x Control, HALF = ½ x Control, CTRL = Control, and DBLE = 2 x Control.

Rain Water Properties as a Function of Aerosol Concentration

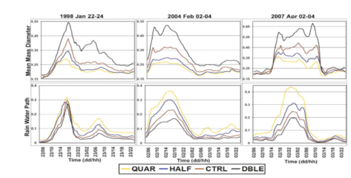


Figure 7 Time series of cloud area averaged rainndrop mean mass diameter (μm) (top row), and rain water path (mm) (bottom row) for the simulated events of 1998 Jan 22-24 (left), 2004 Feb 02-04 (middle), and 2007 Apr 02-04 (right). The color legend displays which color line matches the appropriate simulation, whereby, QUAR = ¼ x Control, HALF = ½ x Control, CTRL = Control, and DBLE = 2 x Control.

Cloud Water Properties as a Function of Aerosol Concentration

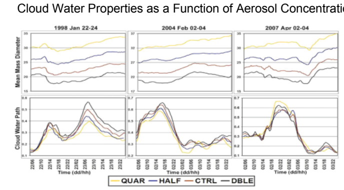


Figure 8 Time series of cloud area averaged cloud droplet mean mass diameter (μm) (top row), and cloud water path (mm) (bottom row) for the simulated events of 1998 Jan 22-24 (left), 2004 Feb 02-04 (middle), and 2007 Apr 02-04 (right). The color legend displays which color line matches the appropriate simulation, whereby, QUAR = ¼ x Control, HALF = ½ x Control, CTRL = Control, and DBLE = 2 x Control.

Profiles of Rain Mixing Ratio as a Function of Aerosol Concentration

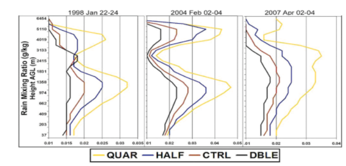


Figure 9 Horizontally averaged vertical profiles of rain mixing ratio (g kg^{-1}) for the simulated events of 1998 Jan 22-24 (left), 2004 Feb 02-04 (middle), and 2007 Apr 02-04 (right). The color legend displays which color line matches the appropriate simulation, whereby, QUAR = ¼ x Control, HALF = ½ x Control, CTRL = Control, and DBLE = 2 x Control.

Summary of Results

1. The model simulations show that increasing aerosols leads to smaller droplet size. The observations, however, (figure 3e) show virtually no trend in drop size with increasing CCN. DSD retrieval methods and additional sites will be used to test this result more thoroughly.
2. Reduced droplet autoconversion in the high aerosol simulations leads to formation of fewer rain drops, however, these drops are able to grow to appreciably larger sizes, resulting in larger rain drop fall speeds and sedimentation. Observational data cannot validate this result, as they currently do not contain separate data on cloud and rain drops. New retrieval techniques will be developed to extract additional DSD information from the coincident radar and radiometer observations
3. The simulations indicate a slight increase in the cloud-top temperature (or decrease in cloud top height) with aerosol, which appears counter to observational results (figure 3a shows no trend in cloud thickness with increased CCN). This could be due to the type of cloud in the studies, as the observed clouds tend to be more cumuliform. This question will be examined further in the final year.
4. Profiles of rain mixing ratio in the simulations indicate substantial evaporation for the low aerosol simulations due to smaller drops, resulting in minimal differences in surface rainfall even though there is more rain water aloft. Again, this is currently difficult to examine with observations (because cases with rain at the surface are not included and vertical profiles of aerosol and cloud properties are not available), but it is hoped that better retrievals of rain DSD, cloud liquid water and sub-cloud relative humidities will allow for testing of these results.

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