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IMPACT OF AEROSOL CONCENTRATION ON A TROPICAL MESOSCALE CONVECTIVE SYSTEM: MODEL STUDY

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1. INTRODUCTION

Impact of aerosol on precipitation dynamics is investigated by simulating a tropical mesoscale convective system using a cloud-resolving model. The 2-D Goddard Cumulus Ensemble (GCE) model coupled with the explicit bin mirophysical scheme in the Hebrew University Cloud Model (HUCM) is used to simulate February 22 case during TOGA COARE (1993) experiment. The model has 1026 horizontal grids and 33 vertical grids. Horizontal resolution is fixed at 750m at the center domain and is stretched towards lateral boundaries. The vertical coordinate was stretched with finest resolution near the ground. HUCM explicitly simulates microphysical processes of 7 hydrometeorite types: cloud/rain, 3 types of ice (plate, column and branch), snow, graupel, hail/frozen drops. Each hydrometeorite type, as well as atmospheric aerosol are represented by 33 mass-size bins. Unlike bulk microphysical scheme, bin scheme is capable of assessing cloud-aerosol interactions and its effect on tropical convective systems dynamics.

2. SIMULATIONS

Initial aerosol is specified in terms of Cloud Condensation Nuclei (CCN) concentration, which depends on super saturation S (%): $N_{CCN} = CS^k$. C (cm^{-3}) and k are parameters for different background aerosol concentrations. Three pairs of parameters C and k, i.e., (100, 0.42), (600, 0.42), and (2520, 0.308) are used in our simulations. C=100 corresponds to pristine ocean background, whereas C=2520 represents heavily polluted background.

Significant amount of surface rain accumulations occur for all three sensitivities runs during the 12-hour simulation period, as well as a comparison run using a bulk type microphysical scheme. In all simulations, warm rains dominate in the first 3-4 hours. Strong, deep convections with significant ice contents appear after the shallow convection stage. The intensity of deep convection tends to decrease with time. The systems tend to reach a semi-steady state after about 6 hours' simulation, with regenerating convections moving toward downwind. Structures of this semi-steady state vary significantly with initial CCN concentrations, as shown in figure 1.

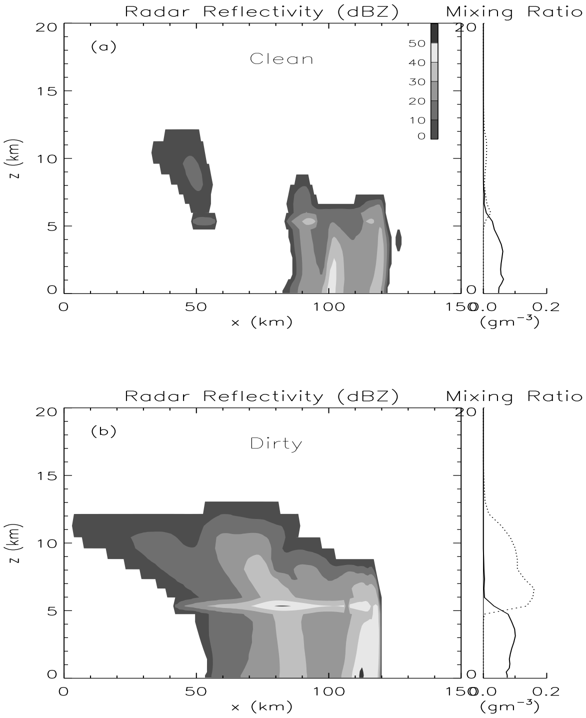

Fig.1: Radar reflectivity pattern (left panels) and domain average total water mixing ratio profile (solid line) and ice mixing ratio profile (dotted line) 8 hours into simulations: (a) Clean air with C=100 cm^{-3}, k=0.42; (b) Dirty air with C=2520 cm^{-3}, k=0.308.

Figure 1 illustrates differences of the semi-steady stage for low CCN (clean air in figure 1a) and high CCN (dirty air in figure 1b) cases. Simulated radar reflectivity (right panel) and domain averaged water/ice mixing ratio profile (left panel) at t=8 hours are plotted. Figure 1 is representative of the semi-steady state achieved for both cases after about 6 hours' into simulations. In clean air, surface precipitation is dominated by warm rain. Very little ice exists in this system except for 1-2 km above freezing level (~5 km). The small amount of

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ice well above 8 km shown in the right panel of figure 1a is remnant from previous strong convective stage. In dirty air, however, ice contributes significantly to surface rainfall, as shown in the right panel of figure 1b. The precipitation system is stronger and more widely spread, representing a well structured tropical mesoscale convective system. Convective cells are repeatedly generated at the leading edge of the system, trailed with a relatively homogeneous light stratiform rain. An obvious radar bright band exists at about 5 km in stratiform region. On the other hand, clean air simulation produces only regenerating and propagating cumulus congestus with cloud top at 6-8 km.

Table 1. Characteristic values of different cases.

Case	C=100	C=600	C=2520	Bulk
Rainrate (mm/hr)	17.2	23.0	27.3	24.7
T rain begin (min)	11	14	17	11
T echo reach 15 km (min)	260	210	180	100
w_{max} (t > 6hr) (m/s)	2.9	6.0	15.2	11.1
w_{min} (t > 6hr) (m/s)	-0.7	-1.8	-2.1	-3.7
Max echo top (t > 6 hr) (km)	6.6	9.6	9.6	10.4

In addition to different semi-steady state of the storm as illustrated in figure 1, other significant differences exist when changing initial CCN concentration in the cloud-resolving model. Table 1 listed some of the different characteristic values. Surface rainfall larger than 0.5mm/hr starts at 11 minutes for C=100 case, but is 6 minutes later for C=2520 case. After the first 2 to 3 hours' warm rain, strong convection starts much earlier in dirty air scenario. Zero dBZ cloud top reaches 15 km at 180 minutes in C=2520 case. But it is more than 1 hour later for C=100 case. The last 3 row of table 1 gives the maximum and minimum vertical air velocity and the maximum 30 dBZ radar echo top during the last 6 hours of simulation (semi-steady stage). It further shows that much stronger system develops in dirty air compared with clean air scenario.

3. DISCUSSION

It is shown through cloud model simulation that cloud-aerosol interaction may play a very crucial role in cloud dynamics and precipitation formation. With everything else being identical, change of initial CCN concentration results in dramatically different precipitation systems in a case study of a tropical precipitation system. Some of the model behavior can be readily explained by existing theories. For example, the delay of the initial rainfall in dirty air scenario is due to smaller drops formed in the presence of large quantities of CCN. It takes longer for these small cloud droplets to form large raindrops. Other differences, e.g., earlier onset of the deep convection, different storm intensity and structure at semi-steady stages of the simulations, have not been recognized before and requires detailed analysis of model microphsyics and dynamics feedback to explain. Both latent heat release from cloud/rain freezing and ice deposition, together with different strength of the downdraft and gust front generated by rain evaporation, may play crucial roles in shaping storm structures.

Observational evidence of storm enhancement due to polluted air over maritime environment may be inferred from Cerveny and Balling (1998) paper. Pollutants (CO + O_3) concentration is found to have a strong weekly cycle over the coastal area in northwest Atlantic ocean. There is a high pollution level during the late week days (Wed. through Sat.) and a low level during the early week, which is believed to be the result of the weekly human activity pattern. Rainfall amount over the same area shows the same trend as pollutant concentrations, indicating that dirty air may enhance precipitation. Our model simulations may offer a possible storm enhancement mechanism through cloud-aerosol interactions. Other mechanisms, e.g., different thermal structure of the polluted air, may also play important roles. More research is needed to quantify aerosol-cloud interaction and its role on affecting storm strength.

4. SUMMARY AND FUTURE WORK

A cloud-resolving model with explicit bin microphysical scheme is used to study the sensitivity of tropical storms on initial CCN concentrations. With identical initial condition and environment, rain starts to form earlier and reaches deep convection stage much later in clean background compared with dirty background. The most significant difference exists in the semi-steady stage achieved by model simulations. Precipitation in clean air scenario during the later half of the simulation is dominated by warm rain, with cloud top between 6-7 km. In dirty air, the cloud top reaches about 10 km, with significant amount of rain coming from ice phase. The maximum air velocity is 15 m/s in dirty air simulation, compared to only 3 m/s in clean air simulation. The stronger storm simulated in dirty air scenario generates large amount of small ice and forms extensive anvil clouds aloft, in contrary to very little ice in clean air simulation. Radiative cooling of these cirrus clouds may affect large-scale circulation. Research is underway to quantify aerosol impact on storm strength and radiative forcing.

REFERENCE

Cerveny, R. S., and R. C. Balling, Jr, 1998: Weekly cycles of air pollutants, precipitation and tropical cyclones in the coastal NW Atlantic region. *Nature,* **394,** 561-563.