Conv-741003--9

PRECIPITATION SCAVENGING IN A SQUALL LINE:
NUMERICAL EXPERIMENTATION

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As a part of the on-going research effort in precipitation scavenging by the Atmospheric Sciences Department, a numerical model of squall line convection has been utilized to obtain estimates of internal cloud circulation patterns. This information is being used to study incorporation of pollutants into such clouds at various locations relative to the cloud. In addition, various environmental profiles of pollutant concentration are being assumed in order to include the possible range of natural occurrences. The initial effort is directed toward investigation of the redistribution of such pollutants by the cloud-air motions with no interaction considered among pollutant, rain, and cloudwater. A second step is directed toward studying the interaction of pollutant and rainwater and the resulting distribution of pollutant concentrations in the atmosphere and in the fallen rainwater. A third step will involve the inclusion of pollutant in the cloudwater in the form of condensation nuclei.

The model used to calculate air motions and other cloud properties is a two-dimensional time-dependent squall line thunderstorm model. The model will not be described in depth here; model equations and other details may be found in an earlier paper (Hane, 1973). The model variables are the two components of air motion in the plane of propagation of the storm, the air temperature, and the mixing ratios of water vapor, cloudwater, and rainwater. Integrations are carried out over a rectangular grid with total dimensions of 25.6 km in the horizontal and 12.8 km in the vertical with 400 m grid intervals in both the horizontal and the vertical. The general procedure followed in running the model is to begin the calculations with no cloud present, superimposing a perturbation in the motion field upon the observed environmental

winds for the case in question. The observed vertical distributions of temperature and moisture for the case in question are applied to the entire horizontal extent of the grid in the initialization. Important boundary conditions include no vertical motion through the upper or lower boundary and time invariant vertical distributions of horizontal motion along the lateral boundaries. The calculations are done in a relative horizontal wind field; i.e., the motion of the storm is subtracted from the total motion field.

The squall line thunderstorm model has been applied using the environmental conditions existing in the St. Louis area on August 21, 1972. The storm which occurred on that day possessed several squall line characteristics. The rainfall pattern is shown in Figure 1 as measured by the raingage network operated by the Illinois State Water Survey. Amounts in excess of three inches were measured in southeast St. Louis and directly across the Mississippi River in Illinois. The elongated rainfall maximum in the northern section of the area resulted from the movement of a separate cell toward the east-northeast. The rainfall pattern in the south part of the city represents the movement of individual cells in an easterly direction, but with development of new cells quasi-continuously on the right flank. The result of this was a propagation toward the southeast.

The wind, temperature, and moisture profiles were measured at approximately 1400 CST, a few hours prior to the storm's occurrence. The winds which were used in the two-dimensional model calculation were the components of the wind in the direction of storm motion (taken to be from the northwest (315°)). The resulting wind profile is shown in Fig. 2. Actually two wind profiles were used in the model calculations, one profile to the left and one profile to the right of the storm, so as to produce low level convergence and upward motion.

FIGURE 1. Rainfall (inches) for 21 August 1972 storm. The heavy lines show the positions of rain sampling arcs employed for precipitation scavenging measurements.

FIGURE 2. Component of the wind in the plane of motion of the storm as a function of height for the 21 August 1972 storm.

The profile shown in Fig. 2 is actually the mean of these two profiles. The temperature, water vapor mixing ratio, pressure, and air density as shown as functions of height in 400 m increments in Table 1.

The model calculations were initiated by allowing the area of upward motion to produce a convective cloud. The evolution of the cloud is represented by the time variations of several parameters shown in Fig. 3. The model was run for about 60 minutes until a fairly regular oscillatory time evolution of the cloud circulation was obtained. A time was chosen (about 55 minutes) when a typical cloud circulation was occurring. The motion field, rainwater mixing ratio distribution and cloudwater distribution were then assumed to be fixed in time for purposes of experimentation with pollutant inclusion into the storm. The streamfunction representing the motion field is shown in Fig. 4. A pollutant distribution was then introduced in the lower 2 km of the atmosphere upwind from the storm. The pollutant was then allowed to travel with the air motion (motion field is that relative to the moving storm, translational speed has been removed) and not allowed to interact with the rain or cloud. The distribution was allowed to enter through the right boundary for a limited amount of time corresponding to the finite width of a pollutant over an urban area.

The resulting redistribution of the pollutant by the storm circulation is shown in Fig. 5 at four different times. It can be seen that most of the pollutant is transported to the upper atmosphere while another significant part is retransported to lower levels in the storm downdraft. This portion which is transported to the lower levels would have ample opportunity to be scavenged by cloud and rain since it traverses both the updraft and downdraft. The portion of the pollutant which remains in the upper levels might not be scavenged so effectively. An examination of the circulation pattern within the storm reveals that the air which comprises the downdraft originates in the

Table I. Variables of state and water vapor mixing ratio as a function of height used as environmental conditions for model calculations. Based upon observations taken at Lambert Field, St. Louis, Missouri on 21 August 1972 at 1417 CST.

Ht. (km)	P (mb)	T (°C)	q _v (g/kg)	ρ (kg/m ³)
0.0	990.	35.2	15.542	1.1082
0.4	947.	30.4	14.526	1.0775
0.8	905.	26.0	13.305	1.0458
1.2	865.	21.6	12.193	1.0147
1.6	826.	17.5	11.503	.9828
2.0	788.	14.0	11.216	.9492
2.4	751.	11.8	8.691	.9134
2.8	716.	8.7	6.264	.8812
3.2	682.	5.7	4.429	.8492
3.6	649.	4.2	4.238	.8130
4.0	618.	2.7	3.825	.7782
4.4	588.	1.1	3.317	.7450
4.8	559.	-1.1	2.707	.7146
5.2	532.	-3.6	2.182	.6861
5.6	505.	-6.9	1.844	.6600
6.0	480.	-9.8	1.511	.6339
6.4	455.	-12.3	1.187	.6075
6.8	432.	-14.6	.896	.5816
7.2	409.	-16.7	.664	.5559
7.6	388.	-18.7	.448	.5312
8.0	368.	-21.1	.377	.5080
8.4	348.	-23.5	.307	.4857
8.8	329.	-25.9	.251	.4641
9.2	312.	-28.3	.207	.4433
9.6	295.	-30.7	.163	.4233
10.0	278.	-33.5	.131	.4045
10.4	263.	-36.3	.104	.3865
10.8	248.	-39.1	.077	.3690
11.2	234.	-42.2	.057	.3525
11.6	220.	-45.4	.045	.3368
12.0	207.	-48.7	.033	.3216
12.4	195.	-52.0	.021	.3069
12.8	183.	-54.2	.015	.2914

FIGURE 3: Time evolution of maximum upward motion (m/sec), maximum downward motion (m/sec), and maximum rainwater mixing ratio for the model storm.

FIGURE 4.

FIGURE 5.

lowest levels prior to its incorporation into the storm. Therefore, if it is true that pollutant traversing both the updraft and downdraft is scavenged most effectively, the fraction of pollutant which is ultimately scavenged depends to a very large extent upon the vertical distribution of pollutant prior to its entry into the storm.

A next step in this ongoing research will be to determine the extent to which the pollutant traversing various parts of the storm will be scavenged by cloud and rain. This will involve invoking realistic assumptions regarding the interaction of the pollutant with falling rain, and finally assumptions regarding the interaction of pollutant (either as a condensation nucleus or as a dissolved gas) with the cloud droplets. Regarding the latter interaction, the pollutant may have to be considered in a less passive manner in its effect upon the evolution of the storm.

FIGURE CAPTIONS

Figure 1 Rainfall (inches) for 21 August 1972 storm. The heavy lines show the positions of rain sampling arcs employed for precipitation scavenging measurements.

Figure 2 Component of the wind in the plane of motion of the storm as a function of height for the 21 August 1972 storm.

Figure 3 Time evolution of maximum upward motion (m/sec), maximum downward motion (m/sec), and maximum rainwater mixing ratio for the model storm.

Figure 4 The motion field within the model storm as represented by the streamfunction (kg/m-sec).

Figure 5 The pollutant distribution at four different times following its insertion into the storm environment: upper left, time = 0; upper right, time = 30 min; lower left time = 50 min; and lower right, time = 70 min.

Table 1 Variables of state and water vapor mixing ratio as a function of height used as environmental conditions for model calculations.
Based upon observations taken at Lambert Field, St. Louis, Missouri on 21 August 1972 at 1417 CST.

REFERENCE

Hane, C. E., 1973: The Squall Line Thunderstorm: Numerical Experimentation, J. of Atmos. Sci., 30, pp. 1672-1690.