Cloud Nuclei Spectra and Updrafts beneath Convective Cloud Bases in the High Plains

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ABSTRACT

Air samples and updraft speeds were obtained simultaneously beneath the bases of convective clouds in northeastern Colorado and in South Dakota. Air samples were examined on the ground in a thermal diffusion nuclei chamber in the supersaturation range of 0.1–0.3% and the nuclei spectra determined. Using Twomey's technique, the maximum supersaturation was estimated, thereby estimating the number of cloud nuclei activated.

The updraft speeds were plotted against the concentration of activated cloud nuclei for varying storm intensities. The results indicate the dominate variable, in identifying storm intensity, is updraft strength, with 4–5 m sec⁻¹ being the cutoff point between thunderstorm and hailstorms. The data gave no clear indication that cloud nuclei concentrations played a significant role in identifying storm intensity. Since $N \propto V^{3k/(2k+4)}$, where V is updraft strength, N number of activated nuclei and the values of k obtained from the analyzed air samples ranged from 0.4 to 2.9, it was determined that in the case of High Plains convection the resulting relation between activated nuclei and updraft strength is $N \propto V^{0.25}$ to $V^{0.89}$.

1. Introduction

Twomey (1959) derived an equation relating the cloud nuclei spectrum and the updraft velocity to the probable range of maximum supersaturation in the cloud base, and hence, the number of droplets formed when condensation occurs on nuclei entering at cloud base. The accuracy of the maximum supersaturation is better than 30%. The number of droplets, being proportional to the maximum supersaturation to power k , is given by the relation

$$N = cS^k = c^{2/(k+2)} \times \left[\frac{1.63 \times 10^{-3} V^{3/2} \Gamma(\frac{3}{2} + k/2)}{k \Gamma(\frac{3}{2}) \Gamma(k/2)} \right]^{k/(k+2)},$$

where

N = the number of nuclei activated at the maximum supersaturation² S (°C),

c = the nuclei spectrum distribution constant,

k = the slope of the nuclei-supersaturation distribution,

V = the updraft velocity (cm sec⁻¹) measured beneath the cloud, and

Γ = the gamma function.

Squires and Twomey (1960) made observations of cloud nuclei spectra below cloud base and cloud droplets just above cloud base. They assumed updraft values of 1 and 10 m sec⁻¹ at cloud base. Their results indicated that cloud droplet concentrations were primarily a function of the nuclei spectra, with $N \propto V^{0.14}$ to $V^{0.25}$; hence, their assumed range of updrafts did not affect their results. Since these results are the only known experiments relating updrafts and cloud nuclei spectra to cloud droplet concentrations, one may thus conclude that Twomey's derived equation has not been thoroughly tested, especially for values of $k > 1$, although it certainly must be correct in principle.

The strongest updraft velocities at cloud base occur along the leading edge of cumulus and cumulonimbus clouds (Ludlam, 1961; Newton, 1963; Browning, 1964; Auer and Sand, 1966). The Thunderstorm Project observed updraft speeds of 5–10 m sec⁻¹ with a maximum of 25 m sec⁻¹ at 25,000-ft MSL penetrations (Byers and Braham, 1949). Flight experience around cumulonimbi in Germany showed that the updraft speed averaged 4.5 m sec⁻¹ at cloud base (Ludlam, 1963). The Russian Bibilashvili (Battan, 1963) obtained values of 5–7 m sec⁻¹ at the base of the cloud by tracking objects through thunderstorms with radar. Auer and Sand (1966) found average values of updrafts of 6 m sec⁻¹ beneath the cloud bases at the leading edge of heavily precipitating thunderstorms in northeast Colorado.

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² Elsewhere in the text and in Table 1 we have expressed S in as a percentage since it is a more readily understood unit. The relation between S (°C) and S (%) for 10°C is S (°C) = 0.145 S (%).

TABLE 1. Data on updrafts, nuclei spectra, maximum supersaturation and number of activated cloud nuclei for classes of convection (TRWA=hailstorms, TRW=thunderstorms, Cu=cumuli) in northeastern Colorado and in South Dakota.

Date	Time (MDT)	Updraft V (m sec ⁻¹)	Intercept c	Slope k	Maximum super- saturation S_{max} (%)	Activated nuclei N (cm ⁻³)	Class
NE Colorado							
10 Jul. 65	1717	2.5	840	0.98	0.61	520	TRW
	1737	11.0	1000	1.00	1.24	1200	TRWA
	1808	6.0	940	1.30	1.37	1320	TRWA
23 Jul. 65	1506	1.8	3500	1.00	0.61	320	Cu
26 Jul. 65	1851	2.0	3650	0.87	0.56	425	Cu
11 Aug. 65	1445	5.0	750	0.85	1.60	215	TRW
30 Jul. 66	1745	3.5	370	0.30	1.10	217	TRW
1 Jul. 66	1724	4.5	5400	1.20	0.98	590	TRWA
6 Jul. 66	1919	4.5	4400	1.06	0.97	610	TRWA
13 Jul. 66	1723	3.0	2000	0.80	0.83	380	TRW
16 Jul. 66	1740	2.5	3700	1.06	0.75	355	Cu
18 Jul. 66	1616	10.0	1100	0.51	1.61	535	TRWA
19 Jul. 66	1756	3.0	1100	0.78	1.00	250	TRW
20 Jul. 66	1915	3.0	800	0.40	0.32	240	TRW
21 Jul. 66	1529	7.5	1300	0.86	1.60	395	TRWA
27 Jul. 66	1600	3.0	2500	0.75	0.73	475	TRW
	1851	6.5	1500	0.40	0.84	625	TRWA
	1734	1.0	1900	0.58	0.41	390	Cu
3 Aug. 66	1754	2.0	1200	0.58	0.71	350	Cu
	1919	3.0	2550	0.78	0.75	465	TRW
5 Aug. 66	1625	1.5	1700	0.60	0.55	380	Cu
16 Aug. 66	1736	0.5	1600	0.64	0.28	180	Cu
18 Aug. 66	1758	3.0	4000	0.80	0.64	600	Cu
	1505	1.0	2050	0.50	0.32	395	Cu
20 Aug. 66	1410	2.5	2600	0.92	0.76	355	Cu
	1439	2.0	8800	1.20	0.59	465	Cu
	1747	1.0	1200	0.54	0.41	265	Cu
23 Aug. 66	1751	2.5	1120	0.65	0.82	280	Cu
30 Aug. 66	1722	0.5	960	1.00	0.50	71	Cu
	1746	1.0	9800	1.70	0.61	175	Cu
	1038	1.0	1800	1.60	0.90	72	Cu
1 Sept. 66	1100	2.0	860	1.00	1.14	143	Cu
	1643	2.5	520	0.68	1.12	148	Cu
South Dakota							
14 Jul. 67	1540	4.5	6000	1.20	0.95	575	TRWA
15 Jul. 67	1453	4.5	16,000	1.15	0.69	1130	TRW
24 Jul. 67	1656	2.0	1700	0.85	0.99	330	TRW
	1723	3.5	8000	1.25	0.81	585	TRW
	1918	5.0	200,000	2.35	0.74	1200	TRWA
25 Jul. 67	1520	5.0	13,000	1.45	0.97	795	TRWA
	1544	7.5	330,000	2.87	0.69	3900	TRWA
	1628	3.0	2000	0.50	0.69	615	TRWA
26 Jul. 67	1450	7.5	14,000	1.80	1.31	675	TRWA
27 Jul. 67	1547	3.5	40,000	1.85	0.69	710	TRW
	1411	2.5	14,000	1.78	0.81	325	TRW
28 Jul. 67	1423	4.5	14,000	1.78	1.03	505	TRW
	1446	5.0	41,000	2.38	1.10	520	TRWA
	1527	4.0	520	0.92	1.93	160	TRWA

2. Observations

During the summers of 1965 and 1966 in northeast Colorado and 1967 in South Dakota, updraft measurements and air samples were gathered simultaneously beneath cloud bases of cumulus, towering cumulus, thundershowers and hailstorms. The clouds were selected based on the visual observations of the on-board meteorologist and without prior knowledge as to the presence of hail in the precipitation curtain. Those cases

in which the convective cloud penetrated the cirrus cloud are not considered in this analysis. The convective activity was classified into the above cloud categories according to its most intense activity within ± 30 min of the observations. Using the technique outlined by Auer and Sand (1966), a mean updraft was measured by the aircraft during the period required to fill the air sample bag. The air samples were returned to the ground and promptly analyzed in a thermal diffusion nuclei

FIG. 1. The number of activated nuclei vs updraft velocities for cumulus clouds, thunderstorms and hailstorms in northeastern Colorado and in South Dakota.

chamber (Squires and Twomey, 1966) at supersaturations of less than 3%. Nuclei concentrations were measured at three differing values of supersaturation in the thermal diffusion chamber. These three data points were used to determine the straight line plot of the nuclei-supersaturation relationships on log-log paper, thereby yielding the values of the intercept constant c and the slope k for use in Twomey's equation. The number of activated nuclei was then evaluated by use of the Twomey equation. The observations were corrected for the diffusion of nuclei through the walls of the metalized mylar bags between the time the sample was taken until it was analyzed. The data are presented in Table 1.

3. Results

The results as shown in Fig. 1 indicate that the dominate variable in identifying storm intensity is updraft strength, with 4–5 m sec⁻¹ being the cutoff point between thunderstorms and hailstorms. The data gave no clear indication that cloud nuclei concentrations play a significant role in identifying storm intensity. Since $N \propto V^{3k/(2k+4)}$ and the values of k obtained from the analyzed air samples ranged from 0.4 to 2.9, it was determined that in the case of High Plains convection, the resulting relation between activated nuclei and updraft strength is $N \propto V^{0.25}$ to $V^{0.89}$. It is therefore suggested that in the case of High Plains convection, activated cloud nuclei concentrations have a greater dependence upon updraft strength than was found by Squires and Twomey (1960).

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