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A PHYSICAL EVALUATION OF SUMMER CUMULUS CLOUD SEEDING EXPERIMENTS NEAR YELLOWKNIFE AND THUNDER BAY, CANADA

by

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A rainfall enhancement experiment, to determine if cumulus clouds drifting over forest fires could be seeded to produce rain, was operated out of Yellowknife, N.W.T., during the summers of 1975 and 1976, and out of Thunder Bay, Ontario, during 1977 and 1978. The rationale behind this experiment, descriptions of the equipment, and some of the Yellowknife seeding experiments have been reported by Isaac et al. (1977, 1978). Primary roles for the 3 aircraft used included cloud top penetrations by the T-33 for turbulence measurements and AgI seeding using wing mounted NEI TB1 pyrotechnic flares, cloud top penetrations by the Twin Otter for microphysical measurements and on-top dry ice seeding, and cloud base runs by the Beechcraft D-18 for rainfall detection and measurement.

A total of 58 cumulus clouds were examined near Yellowknife with 16 of these clouds being seeded with AgI. Near Thunder Bay, Ontario, 9 of 66 clouds were seeded with AgI and 2 clouds with dry ice. The measurements have been summarized in Tables 1 and 2. At selection, the cumulus clouds were usually relatively isolated, with depths >1 km, with solid and apparently growing tops, and with cloud top temperatures between -5°C and -20°C. Clouds were seeded only if they contained $<1\ \ell^{-1}$ of particles $>150\ \mu m$ and if they were not precipitating. Most, but not all, of the Twin Otter and T-33 penetrations were made approximately 300 m below cloud top.

The measurements described in Table 1 have been abstracted from a variety of data sets, some of which are incomplete. However, the median values of the paramaters presented can be treated as representing typical clouds. Both the Yellowknife and Thunder Bay cumuli examined had median cloud top temperatures of -9°C with the median T-33 and Twin Otter penetration level being near -7°C. Very few ice particles were observed in both Yellowknife (Isaac and Schemenauer, 1979) and Thunder Bay cumuli. Although the PMS FSSP cloud droplet concentrations are probably low due to an electronic dead time problem, the droplet measurements and the distance of both locations from oceans, indicate that the clouds examined can be classified as continental. However, it is interesting to note that the Thunder Bay clouds contained significant concentrations of droplets >24 μm. Thunder Bay clouds were also thicker, with higher cloud base temperatures and liquid water contents, and lower large particle concentrations (>70 μm) than Yellowknife clouds. Though not immediately obvious from the measurements presented, Thunder Bay cumuli tended to be more turbulent than Yellowknife clouds (MacPherson, 1979).

Table 2 summarizes data for the cloud seeding experiments. The J-W liquid water content, cloud widths and cloud depths refer to pre-seeding values. The time it took the J-W liquid water content to fall to 0.1 g m^{-3} within 300 m of the seeding level gives an indication of cloud lifetime. A large increase, a small increase, and no increase in ice particle concentration following seeding are designated as Y, M, or N seeding effects. If rain was observed falling from the cloud, it is noted. For the 17 July 1975 case, rain began before seeding, and for the 26 June 1978 case, it is possible that the rain, which began after seeding, was produced in an adjacent cloud turret.

Near Yellowknife and Thunder Bay, 55% and 45% respectively of the AgI seeded clouds contained higher concentrations of ice particles after seeding. Approximately 40% of the Yellowknife seeded clouds produced rain, and those that did not precipitate had lifetimes <20 min. Near Thunder Bay, it is doubtful whether any rain was artificially generated by AgI. Dry ice seeding also failed to produce rain in the 2 Thunder Bay cloud experiments. No statistical tests have been performed, but it appears that seeding was more successful near Yellowknife than Thunder Bay. However, Thunder Bay clouds were deeper, wetter, and had a lower background concentration of large particles (>70 μm) which should have made the clouds "more seedable". From the limited data available, it appears that the lifetimes of Thunder Bay clouds were too short for seeding to be effective. In fact, for both locations, the repeated observation that the ice particle concentration did not increase after seeding, although the ice nucleus concentration was often higher, may be related to short cloud lifetimes.

In conclusion, (1) significant microphysical and dynamical differences exist between cumuli in different Canadian regions; (2) AgI or dry ice placed into a cloud will not necessarily create large ice crystals or begin a precipitation-forming process; (3) rainfall augmentation for forest fire suppression may only be possible in certain specific areas. Unless the clouds are similar, successful results in other countries (e.g. USSR) may not be transferable to Canada.

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Location Year		Yellowknife 1975	Yellowknife 1976	Thunder Bay 1977	Thunder Bay 1978
Parameter	Units				
Number of Clouds		11	47	25	41
Maximum Cloud Top Height	m(MSL)	4000	4400	4900	5200
Minimum Cloud Top Temperature	°C	-9	-9	-9	-9
Minimum Cloud Base Height	m(MSL)	$\sim$1550	2300	1700	1800
Maximum Cloud Base Temperature	°C	+6	+3	+11	+13
Number of Twin Otter Penetrations		29	101	80	115
Penetration Height	m(MSL)	3800	4200	4300	4600
Penetration Temperature	°C	-7	-7	-7	-6
Penetration Length	m	2000	1600	1650	1100
Liquid Water Content, J-W	$g\ m^{-3}$	0.4	0.3	0.9	1.4
FSSP Droplet Concentration	cm^{-3}	--	>400	>400	>550
FSSP Concentration 24-45 μm	cm^{-3}	--	--	>26	>7
PMS Particle Concentration >70 μm	ℓ^{-1}	0.8	0.9	0.04	0.05
Ice Particle Concentration	ℓ^{-1}	--	0.0	0.0	0.0
*Twin Otter & T-33 Turbulence Runs		14	60	84	81
*Penetration Temperature	°C	-6	-9	-5	-5
*RMS Vertical Velocity	$m\ s^{-1}$	1.6	1.6	1.4	1.7
*Turbulent Dissipation Rate	$cm^2\ s^{-3}$	110	160	180	360
*Peak Up Gust	$m\ s^{-1}$	4.2	3.9	3.7	3.8
*Peak Down Gust	$m\ s^{-1}$	-4.5	-4.1	-4.1	-4.6

Table 1. Median values of penetration averages for Yellowknife and Thunder Bay cloud parameters. The microphysical data include only penetrations in unseeded clouds or before seeding in seeded clouds. The turbulence (*) data include some penetrations after seeding and were not analyzed for all possible penetrations or clouds.

Date	J-W $g\ m^{-3}$	T Seeding Level °C	T-Td Seeding Level °C	Cloud Width m	Cloud Depth m	AgI g	Time to $0.1\ g\ m^{-3}$ min	Seeding Effect? Y	 M	 N	Rain ? Y	 N
July 17/75	-	-10.0	-	7900	4400	350	-			N	(Y)	
July 19	.1	-8.0	2.0	1000	1000	200	-	Y				N
July 22A	1.1	-5.5	22.5	2100	2400	550	>23	Y			Y	
July 22B	.8	-6.0	14.0	1900	2100	300	>30	Y			Y	
July 25	.4	-5.0	7.5	2700	2100	300	>24	Y				N
June 28/76	.2	-5.0	3.5	1100	1100	300	3			N		N
June 29A	.3	-6.0	9.5	2200	-	350	<2			N		N
June 29B	.5	-5.0	17.5	1700	2300	350	<6			N		N
July 2A	.4	-8.0	13.5	2100	2400	350	8-11			N		N
July 2B	.2	-7.0	18.0	1500	-	300	<1			N		N
July 5	.4	-8.5	6.0	2600	2400	600	>12		M		Y	
July 11	.6	-7.0	14.0	1300	2600	200	>10	Y			Y	
July 15A	.3	-9.0	8.0	3500	2900	300	11-17			N		N
July 15B	.6	-8.5	8.5	1500	2300	350	>8	Y			Y	
July 16	.6	-9.5	8.0	1200	2000	300	>19	Y			Y	
July 17	.4	-10.0	8.0	1700	2400	300	<1		M			N
June 24/77	1.0	-8.5	18.5	1000	3400	200	<1			N		N
June 27	1.1	-5.0	5.0	1700	2400	350	$\sim$1			N		N
July 8	1.5	-7.5	19.5	1900	3100	300	$\sim$14			N		N
July 11	1.1	-9.0	11.0	2500	3800	300	3-6	Y				N
June 26/78	2.2	-6.0	25	1800	3300	350	2-11		M		(Y)	
July 1	2.5	-7.0	5	2200	3900	350	$\sim$2		M			N
July 4	0.9	-6.0	17.5	1600	3900	300	$\sim$2			N		N
July 4	1.8	-6.0	18.5	1900	3000	250	$\sim$8	Y				N
July 6	2.8	-7.0	14.0	2900	3500	350	$\sim$4			N		N
						CO_2						
July 6/78	1.2	-7.0		1900	3400	8.8 kg	$\sim$10		M			N
July 10	0.6	-4.0	9.5	2200	1000	9.7 kg	$\sim$20	Y				N

Table 2. A summary of the cloud seeding experiments. Bracketed (Y) values in the rain column were probably not caused by seeding.