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Isaac, G. A.; MacPherson, J. I.; MacHattie, L. B.

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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40001372
NAE misc, 1975-05

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FOREST FIRES AND CUMULUS CLOUDS

BY

G. A. ISAAC, ATMOSPHERIC ENVIRONMENT SERVICE

J. I MACPHERSON, NATIONAL AERONAUTICAL ESTABLISHMENT

L. B. MACHATTIE, CANADIAN FORESTRY SERVICE

TO BE PRESENTED AT THE CANADIAN METEOROLOGICAL SOCIETY
NINTH ANNUAL CONGRESS, UNIVERSITY OF BRITISH COLUMBIA,
VANCOUVER, MAY 28-30, 1975

OTTAWA, CANADA

MAY, 1975

NAE MISC 51

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G.A. Isaac, Atmospheric Environment Service

J.I. MacPherson, National Aeronautical Establishment

L.B. MacHattie, Canadian Forestry Service

1. INTRODUCTION

Approximately 1/2 of Canada's land is forested with 1/2 of that land being considered productive. Forest fires are a serious threat to this resource and $50 million is spent annually upon forest fire control. However, there is no effective method available to combat large forest fires. Although large fires are few in number, they account for most of the area burned each year and they sometimes force the evacuation of populated areas. If 1 mm or more of rain could be artificially induced to fall on a fire, whether small or large, a very powerful fire control technique would be available to the forest industry.

In 1973 a delegation from the Canadian Forestry Service (CFS) visited the USSR (Kourtz, 1973) and, as part of their visit, they examined weather modification techniques being used to suppress forest fires. Cumulus clouds that were about to drift over USSR fires were being seeded with AgI or PbI_2 in order to induce rain to fall on the fire (Artsybashev, 1974). The technique was reported to be economically feasible and successful in suppressing fires which occur in some portions of the country. Consequently, the Atmospheric Environment Service (AES) was asked to examine the possibility of using weather modification techniques, similar to those used in the USSR, to control fires.

In 1974, the CFS and AES, in cooperation with the National Aeronautical Establishment (NAE), began a pilot research project; a portion of the results are reported below. The environment of several forest fires was examined in 1974; some fire-cloud interactions were observed. Ice nucleus concentrations, in-cloud ice particle concentrations, cloud droplet distributions, and in-cloud and out-of-cloud turbulence parameters were measured. From these observations, a simple cloud seeding plan has been developed for use in a weather modification experiment. Only the mechanics of cloud seeding are considered in this report; programs for statistical and physical evaluation are not presented. Studies on cloud availability and economic feasibility are continuing and will be reported elsewhere.

Eventually, it should be experimentally determined if cloud seeding can help suppress forest fires in Canada. One cannot simply use similar techniques as are being used in the USSR and expect the same results. Western scientists have had great difficulty in reproducing the successful weather modification results that have been reported in the USSR. Hail suppression is one clear example of this problem. It is difficult to assess the effect of slight differences in climate, seeding agents and seeding techniques from one country to another, because very little is known about the physical processes involved in producing weather modification effects.

In an earlier Canadian project, Orr et al (1949) (Mason, 1971) examined the possibility of seeding Cu clouds for forest fire control. The results of dry ice seeding are summarized in Fig. 1 using a combination of Australian and Canadian experiments. Their results, although not being verified by statistical randomization, were certainly encouraging. The conclusions were that isolated cumulus clouds could be modified to produce rain but the main usefulness of the technique would be in preventing rather than extinguishing fires because of the difficulty of directing the rainfall. They did not know whether such weather modification schemes would be economically useful. However, USSR scientists (Sorokovik, 1972 and Sumin, 1971) have developed economic methods in some portions of the country for targeting precipitation to fall on large fires and there is little emphasis on fire prevention.

2. AIRCRAFT AND INSTRUMENTATION

Three National Aeronautical Establishment aircraft were used; a T-33 a DHC-6 Twin Otter and a Convair 580. The Convair was used mainly to carry observers over fires. The T-33 turbulence research aircraft has extensive turbulence, wind and temperature measuring equipment. The Twin Otter was instrumented with specialized equipment for use in the project. Unfortunately, because of the short lead time available, this aircraft did not have its equipment operational until late summer.

During 1974 the aircraft were flown on 20 days for the project for a total flight time of 66 hours. On three occasions simultaneous data flights by the T-33 and Twin Otter were flown over the Gatineau Hills north of Ottawa. For two periods in July, the T-33 was operated out of Winnipeg over the large fires burning near Red Lake in northwestern Ontario. On one of the operations out of Winnipeg, AES/CFS personnel conducted cloud observations over these and other fires from the NAE Convair 580. The Twin Otter was flown on an additional 6 flights in the Ottawa area to test the operation of the cloud physics instrumentation during cloud penetrations. A further 5 flights by the T-33 were required for instrumentation test purposes.

2.1 T-33 Instrumentation

The T-33 is capable of measuring the three components of atmospheric motion along the longitudinal, lateral, and vertical axes of the aircraft in terms of the true gust velocities. This provides a description of the air motion completely independent of the characteristics of the aircraft over a range of wavelengths from 18 to 2850 m at an aircraft speed of 160 m/sec. Primary air motion sensors are the angle of attack and sideslip vanes mounted on a boom on the aircraft nose and a differential total pressure transducer attached to a total pressure probe on the lower surface of the aircraft nose. Measurement of the 3-axes accelerations, angles, and angular rates allow for calculation of the aircraft transient inertial velocities along the 3 axes, and, when combined with outputs from the primary air motion sensors,the true gust velocities are obtained. These are then resolved into earth-fixed axes aligned with the mean wind direction, as computed from the measured true airspeed, heading, and on-board Doppler measured ground speed and drift angle. Fast response (0.1 sec time constant) static temperature is computed from total temperature corrected for dynamic heating, and then multiplied by the vertical gust velocity to produce time histories of the vertical heat flux.

Outputs from the digitally-analyzed T-33 data include printed lists of the wind speed and direction, temperature, dew point, humidity, altitude, airspeed, heading, ground speed, and drift, as well as plotted time histories of the gusts, temperature fluctuations, heat and momentum fluxes, and the event marker. These data are also dumped to disk for storage and subsequent data analysis. A complete description of this aircraft, its instrumentation, and data analysis methods has been given by MacPherson (1973).

2.2 Twin Otter Instrumentation

The Twin Otter was instrumented with a Cambridge dew point hygrometer, a Rosemount temperature probe, a MEE ice particle counter, an AES cloud particle replicator and an AES ice nucleus sampling system. The temperature and dew-point probes are of standard design and require no explanation.

The MEE ice particle counter (see Sheets and Odencrantz, 1974) was designed to optically descriminate between water and ice particles passing through a measuring section. It was mounted with the sampling cylinder 20 cm above the roof of the fuselage just behind the windscreen.

The replicator was designed and built at AES such that 2 small slides (4 mm x 35 mm) were exposed simultaneously at 20 and 35 cm from the skin of the top of the cabin fuselage just behind and offset from the MEE ice particle counter. The innermost slide was exposed at the same distance from the aircraft skin as the center of the ice particle sampling section.

By pulling outside air through 2 Millipore filters (type MAWGO 37A0, pore size 0.8μ) an aerosol sample was obtained. These filters were then processed in a laboratory thermal diffusion chamber (Isaac, 1974). Ice crystals were grown on ice nuclei activated at set values of temperature and humidity and ice nucleus concentrations in the sampled air were obtained.

3. OBSERVATIONS OVER FOREST FIRES

The Red Lake fires were very large and burned out of control for several weeks. The T-33 monitored the wind, temperature, and humidity fields over these fires and was able to measure the turbulence structure of clouds in the area. Fig. 2 shows a photograph of a large fire just before the T-33 flew below cloud base across the fire front at an altitude of 520 m AGL. It was anticipated that some increase in temperature and humidity would be measured above the fire; no such increase was observed.

However, on one day when no aircraft observations were made, several fires did generate very large pyrocumulus clouds (tops approximately 10 km) which dropped more than 50 mm of rain downwind of the fires. From some of the T-33 photographs it does appear as if cloud growth was slightly stimulated just above the fire and that clouds were generally less frequent upwind of the fire. These observations are general impressions and it would be useful to make an attempt in future years to obtain objective data which would verify them.

4. CUMULUS MICROPHYSICAL MEASUREMENTS

Using the equipment described in 2.2,the Twin Otter measured cumulus cloud droplet distributions and cloud ice particle concentrations. Millipore filters were exposed while the aircraft flew over forest regions. These filters were analyzed in the laboratory to determine ice nucleus concentrations.

Fig. 3 shows the droplet distribution 400 m above the base of a small cumulus cloud. The calculated liquid water content was 1.0 gm/m^3. The dashed and solid lines refer to the slides exposed at 20 and 35 cm above the aircraft cabin. There appears to be little difference between these two sampling locations. However, when large particles > 100µ were being sampled, more particles appeared on the outer slide.

Ruskin and Scott in Hess (1974) show that, for a C-130 flying at 90 m/sec,droplets tend to concentrate near the top of the cabin fuselage. Between sizes 50-500µ there exists a shadow zone which is 50 cm high for 100-200µ particles. Although the theoretical analysis for the C-130 described above cannot be directly applied to a Twin Otter, the top of an aircraft cabin appears to be a poor sampling location.

Fig. 4 shows the ice nucleus concentrations obtained from Millipore filters exposed in a Cessna 411 flying between 1220-2130 m MSL in Alberta during 1974. The filters were processed at 96, 100 or 102% relative humidity with respect to liquid water at the indicated temperatures (Isaac, 1974). It is evident from this figure that the ice nucleus concentration is only dependent upon the percent supersaturation over ice. These results are very similar to those of Huffman (1973). It must be remembered that this nucleus detection method only activates sublimation and/or condensation-freezing nuclei. Nuclei which activate effectively through collision with a droplet would not be detected.

Fig. 5 shows the ice nucleus concentrations obtained during the project while flying the Twin Otter near Ottawa. Two sets of points are plotted; one set for days when cumulus clouds were predominate and the other for days when stratiform clouds were observed. Stratus days produced much lower concentrations than cumulus days. Stratus clouds could act as efficient scavengers of nuclei and the Twin Otter flew within or close to these cloud layers throughout most of each of these 3 flights. The cumulus data on Fig. 5 indicate slightly lower concentrations than the Alberta data of Fig. 4.

Table 1 summarizes the measurements made with the MEE ice particle counter and the simultaneous ice nucleus concentration measurements. Because of some difficulties in getting the MEE instrument mounted on the aircraft, only stratiform clouds were examined. On each of the three days, the aircraft flew below the freezing level in light rain where the ice particle counter was zeroed. Then flights were made through the stratiform clouds at approximately -5C where ice crystals were present. The manufacturer claims that the ice particle counter can detect ice crystals greater than 40μ in diameter and will not count water droplets if they are less than 1 mm in diameter. No authoritative checks were obtained for these two threshold numbers. However, the instrument did not detect light rain hitting the windscreen; in heavy rain the counts were very high. It appears, from some preliminary measurements, that the minimum threshold crystal size might be as high as 200μ. The Millipore filters exposed on these flights were later processed in the laboratory to obtain the ice nucleus concentration at 96, 100 and 102% relative humidity and at -16C and -20C. The ratio of the median ice particle concentration at -5C to the ice nucleus concentration at -16C 100% R.H. is greater than 50 for each day. Some mechanism must be producing more than one particle per nucleus and/or the nucleus detection scheme is not adequate. The relevance of these conclusions to cloud seeding will be discussed below.

5. TURBULENCE MEASUREMENTS

The T-33 research aircraft examined the turbulence structure of several clouds during 1974. Some problems were encountered in filtering data collected during cloud penetrations. High-pass filtering of the computed gust time histories is required to remove the integrated effects of small electronic drifts in the basic accelerometer and rate gyro signals. Step changes in temperature or gust velocity on entering a cloud updraft or downdraft were not correctly represented when the usual high-pass filter was applied to the data. Fig. 6 shows a run with the high-pass filter applied while Fig. 7 shows the unfiltered data. This problem was described by MacPherson and Bobbitt (1974) and a new cosine digital filter was proposed as the ultimate solution. The same run processed with the new digital filter is presented in Fig. 8 and shows that the step changes in gust velocity and temperature have been retained but the long-term drift evident in some of the traces of Fig. 7 has been eliminated. In the data described below the type of filter used is indicated.

Table 2 shows a summary of turbulence data describing 5 clouds selected for detailed analysis. The time in-cloud, time out-of-cloud, and the penetration altitude and temperature are indicated. The turbulent dissipation rate was calculated from the u component of turbulence in aircraft axes. The RMS values of the fluctuations in the u, v and w components (in earth-fixed axes) have been calculated for wavelengths from ∿ 18 m to 2.9 km. The remarks column indicates where the penetration was made in relation to cloud base or top. Most runs were made 100 m above (below) cloud base (top). Although cloud base height was not measured for Cloud 1 or Cloud 4, a reasonable estimate can be made from measurements on other clouds which occurred nearby. Consequently, from Run 8-3 Cloud 1 would have a base at 1970 m and from Run 10-3 Cloud 4 would have a base at 1170 m. Both Clouds 1 and 4 were very large cumuli with their cloud top temperature close to the value necessary for seeding with AgI. Clouds 1 and 2 were sitting over forest fires while 3, 4 and 5 were over forest regions where the fire hazard was high. Two runs were made through Clouds 1a and 1b at approximately the same altitude. These clouds were very close together.

Measurements were made near the cumulus base and top for Clouds 2, 3 and 5. For Cloud 3 at the base, the turbulent dissipation rate was not significantly higher in-cloud from out-of-cloud measurements and it was not significantly higher just beneath the cloud for Cloud 5. However, for Cloud 2 the cloud was more turbulent inside at cloud base.

The measurements at cloud top were more consistent; the dissipation rate was always higher in-cloud as compared to the out-of-cloud values. With the exception of 7-7, ε was at least a factor 10 higher inside the cloud top. For Clouds 2, 3 and 5 the out-of-cloud dissipation rate was much lower at the top than it was at the base.

The RMS values of the turbulence in the 3 components gives an idea of the total energy in the wavelength range 18 m to 2.9 km. The u component is in the direction of the mean wind, the v component is perpendicular to that axis and the vertical component is indicated by w. The in-cloud values are generally higher than out-of-cloud values. The difference between components in-cloud can be quite large (see Run 10-4) as can the differences between out-of-cloud components (see Run 8-4). The w RMS values tends to be higher than u or v RMS. However, the filters are definitely affecting the data. The difference between filtered and unfiltered data in Run 7-7 is large. It appears that unfiltered data do not give satisfactory answers for the RMS values of turbulence. The values of ε, calculated from unfiltered data, do not suffer as much from this inaccuracy since only spectral data above 2Hz are used in its calculation.

Figs. 9a-f show the u, v and w components of turbulence for Runs 10-6 and 7-7 for in-cloud and out-of-cloud measurements. The 7-7 in-cloud values have been obtained by combining the 5 clouds penetrated (Fig. 8). However, 10-6 in-cloud data represent a pass through one very wide continuous cloud. The old high pass and the new cosine filter have been used in the analysis of 10-6 and 7-7 respectively. The turbulent dissipation rates have been calculated for the separate components. A line with a slope of -5/3 has been drawn on the spectra for comparison purposes. Most of the 7-7 data appear to follow this power law but portions of the 10-6 data do not. There is no major difference in the spectrum shape for in-cloud versus out-of-cloud measurements.

6. CONCLUSIONS RELEVANT TO CLOUD SEEDING

If cumulus clouds are seeded, just before they drift over a forest fire, it has been decided that AgI would be the most suitable ice nucleating agent. Although dry ice might lower the depth of supercooled layer required for seeding, weather modification technology using AgI is better established and materials are easily available.

When large fires are burning, many forestry aircraft fly beneath cloud base performing a variety of functions. If cloud base seeding was attempted, coordination between these aircraft and the seeding aircraft would have to be maintained. If droppable flare pyrotechnics were injected at cloud top then these flares might become an aircraft hazard or they might hit the forest while lit and become a fire threat. Consequently, cloud top seeding by an aircraft-mounted ice nucleus generator appears to be the safest technique.

Cloud top seeding is also preferred because the T-33 measurements suggested that small cumulus clouds are turbulent with poorly defined updrafts. If one seeded at cloud base, the updraft might not carry the ice nucleating material to the supercooled layer. Consequently, it seems adviseable to dispense the material at the height where it should act (-5 to -10C for AgI). Techniques that test the nucleating effectiveness of the material simulate these conditions. There are many uncertainties in such things as contact nucleation and the solubility of seeding material. Laboratory chamber tests (Garvey, 1974) closely model these uncertainties and give reasonable estimates for the ice crystal production rate in a cloud seeded at the proposed nucleus activation temperature.

If an aircraft seeded the top of a cloud by flying through and dispensing material in the flight path, Table 3 shows the diameter (d) of the plume of nuclei as a function of time (t) and turbulent dissipation rate (ε). A relation used by MacCready and Vickers (1966), Summers et al (1972), and Kyle (1974) $d^2 = \varepsilon t^3 \quad t < 1000$ sec was used. The measured value of the dissipation rate at cloud top (Table 2) was from 100-500 cm^2/sec^3. Consequently, the values in the 100 and 500 cm^2/sec^3 column are the best estimates.

Table 4 shows the concentration of nuclei at -10C which could be expected in a cloud 2000 m wide with $\varepsilon = 100$ or 500 cm^2/sec^3 when one flare with TB1 (LW-83) formulation, which produces 50 gm of AgI in 20 sec, is burnt on an aircraft flying 150 m/sec (e.g. T-33). Note that 1/3 of the 50 gm flare would be burnt outside of the cloud. A flare of TB1 produces AgI particles by burning a mixture of silver iodate, aluminum, magnesium and binder. The estimate for the production of ice nuclei from TB1 (6×10^{10} nuclei per gram at -10C) has been obtained from the data of Garvey (1974).

It is difficult to estimate the ice nucleus content required for efficient precipitation production. Jiusto (1971) gives a method for calculating the critical concentration (N_c) of ice crystals with radii r for increasing the ice/water concentration ratio in a cloud with an updraft velocity v.

$$N_c = \frac{Q_1 v/Q_2}{8G'S_i\rho_i r} \qquad \text{Eq. 1}$$

Q_1, Q_2 and G' are thermodynamic functions; S_i and ρ_i are the supersaturation with respect to ice and the density of ice respectively. If r = 100μ and v = 50 cm/sec then N_c at -10C would be 180/litre. This gives a critical concentration for a cumulus cloud which is not growing rapidly. If the updraft at the seeding level is 5 m/sec then N would be 1800/litre. (A planar unrimed 200μ crystal grows in approximately 2 min at -10C (Jiusto, 1971).)

Eq. 1 and Table 4 show that it would be difficult to reach N_c throughout a 2000 m wide cloud by seeding if a one-to-one correspondence between ice nuclei and ice crystals were assumed. However, as Table 1 shows, some ice multiplication mechanisms probably do exist. In such a case N_c would be reached.

It is unrealistic that a cloud must be glaciated in order to produce precipitation as has been assumed above. Much more cloud modelling must be performed in order to determine the critical concentration of ice nuclei. However, successful experiments by Bethwaite et al (1966), McNaughton (1974), Stalevich and Uchevatkina (1971), and Titov (1971) indicate that seeding a cumulus cloud with 1-10 50 gm flares of TB1 would have some chance of producing precipitation. For example, Titov (1971) claims that nucleus concentrations of 0.62 ℓ^{-1} produced "heavy" rain. Table 4 indicates that this concentration can be produced with TB1.

7. RECOMMENDATIONS FOR 1975

It was found in 1974 that temperature measurements in-cloud by means of standard Rosemount total temperature probes were affected by cloud droplets cooling the probe. Consequently, a reverse-flow total temperature probe, as described by Pettit (1967), will be made and used in 1975.

The sampling location of the top of the Twin Otter fuselage was poor. Alternate locations such as beneath the wings are being considered.

Cloud droplet and ice crystal replication was not adequate with the slide replicator used in 1974. Consequently, a continuous replicator and a particle measuring system (made by PMS) will be used in 1975.

Because aircraft position was poorly recorded in 1974, a continuously recording navigation system will be considered for 1975.

Cloud seeding trials should be attempted to determine if precipitation can be induced by cloud seeding. The problem of targeting artificial precipitation to fall on a fire should be evaluated.

An attempt should be made to determine if the ice crystal concentration can be adequately modified by cloud seeding. The problem of how many ice crystals are produced from one ice nucleus must be examined.

It is anticipated that "dynamic" cloud seeding (Simpson et al, 1972) which causes explosive cloud growth by releasing the latent heat of freezing will not produce precipitation in the Canadian climate. This argument is supported by the observations of Orr et al (1949) in Canada and Bethwaite et al (1966) in Australia. Consequently, adequate numerical models of the Bergeron-Findeisen mechanism for producing precipitation should be developed so that realistic seeding rates can be estimated and the physical characteristics of a susceptible cumulus, which can be artificially stimulated to produce rain, can be determined.

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DATE	ICE PARTICLE CONC l^{-1}			ICE NUCLEUS CONC l^{-1}					
	5%	MEDIAN	95%	-16C			-20C		
				96%	100%	102%	96%	100%	102%
Sept 10	.022	1.3	18		.021 .0089	.034	.011	.029	.046
Sept 13	.027	4.0	40	.004	.046	.065	.026	.087	.145
Sept 17	13	32	80	.0026	.026 .0030	.044 .012	.0078 .0030	.060 .015	.133 .015

TABLE I

TABLE 2

CLOUD DATE	RUN NUMBER	ALTITUDE (M) MSL	TEMP. (°C)	TIME (sec)		ϵ cm^2/sec^3)		FILTER TYPE	REMARKS	U/V/W RMS VALUES m/sec	U/V/W RMS VALUES m/sec
				IN	OUT	IN	OUT			IN	OUT
Ia (July 17)	7-6	4760	-4	13	151	494	.08	UF	100m below top	2.3/4.0/7.3	1.5/1.6/5.2
	7-6					483	.27	COS		2.1/3.2/5.0	.5/.4/.6
Ib (July 17)	7-7	4600	-3.5	31	69	384	85	UF	100m below top	4.3/3.5/3.9	3.8/2.5/1.5
	7-7					287	52	COS		1.9/2.2/2.7	1.1/1.1/1.2
2 (July 17)	8-4	2450	12.3	20	153	228	2.2	UF	100m below top	2.3/1.8/3.8	1.3/1.5/2.6
	8-3	2090	13.0	40	212	374	21	UF	100m above base	4.8/3.3/4.0	4.7/2.6/3.4
3 (July 31)	10-4	2840	-0.2	7	135	294	1.6	UF	freezing level, below top	3.2/1.2/5.1	1.4/1.5/1.5
	10-3	1280	8.3	17	60	40	29	UF	above base	1.5/1.9/2.9	1.8/1.7/2.4
4 (July 31)	10-6	3870	-7.9	42	51	107	1.2	UF	1300m below top	1.6/1.7/1.9	1.1/.5/.8
	10-6					114	17	OLDHP		1.4/1.6/1.5	.8/.5/.4
5 (Aug 13)	11-1	3510	0.7	26	52	162	3.2	UF	150m below top	2.8/2.3/2.6	1.1/2.0/1.0
	11-3	1250	14	74	71	19	15	UF	150m below base	1.1/2.1/3.7	1.0/1.9/1.8
						A/C axes				EARTH FIXED	Axes

UF- unfiltered , COS- new Cosine digital high-pass filter , OLDHP - old high-pass filter

$$d^2 = \epsilon t^3 \quad t < 1000 \text{ sec}$$

DIAMETER OF SEEDED PLUME (m)

TIME (min)	ϵ ($cm^2 sec^{-3}$)			
	10	50	100	500
1	15	33	46	104
2	42	93	131	294
5	164	367	520	1162
15	853	1910	2700	6040

TABLE 3

CONCENTRATION OF ICE NUCLEI AS FUNCTION OF TIME AFTER SEEDING

Nuclei / liter at -10 C

TIME (min)	ϵ (cm^2/sec^3)	
	100	500
1	600 lit^{-1}	120 lit^{-1}
2	74	15
5	4.7	.94
15	.17	.035

For burning 33.3 gm. of TBI in cloud 2000 m wide with 6×10^{10} nuclei / gm at -10C

A TBI 50 gm flare which burns in 20 sec would deposit 33.3 gm in cloud 2 km wide if aircraft flew at 150 m / sec .

TABLE 4

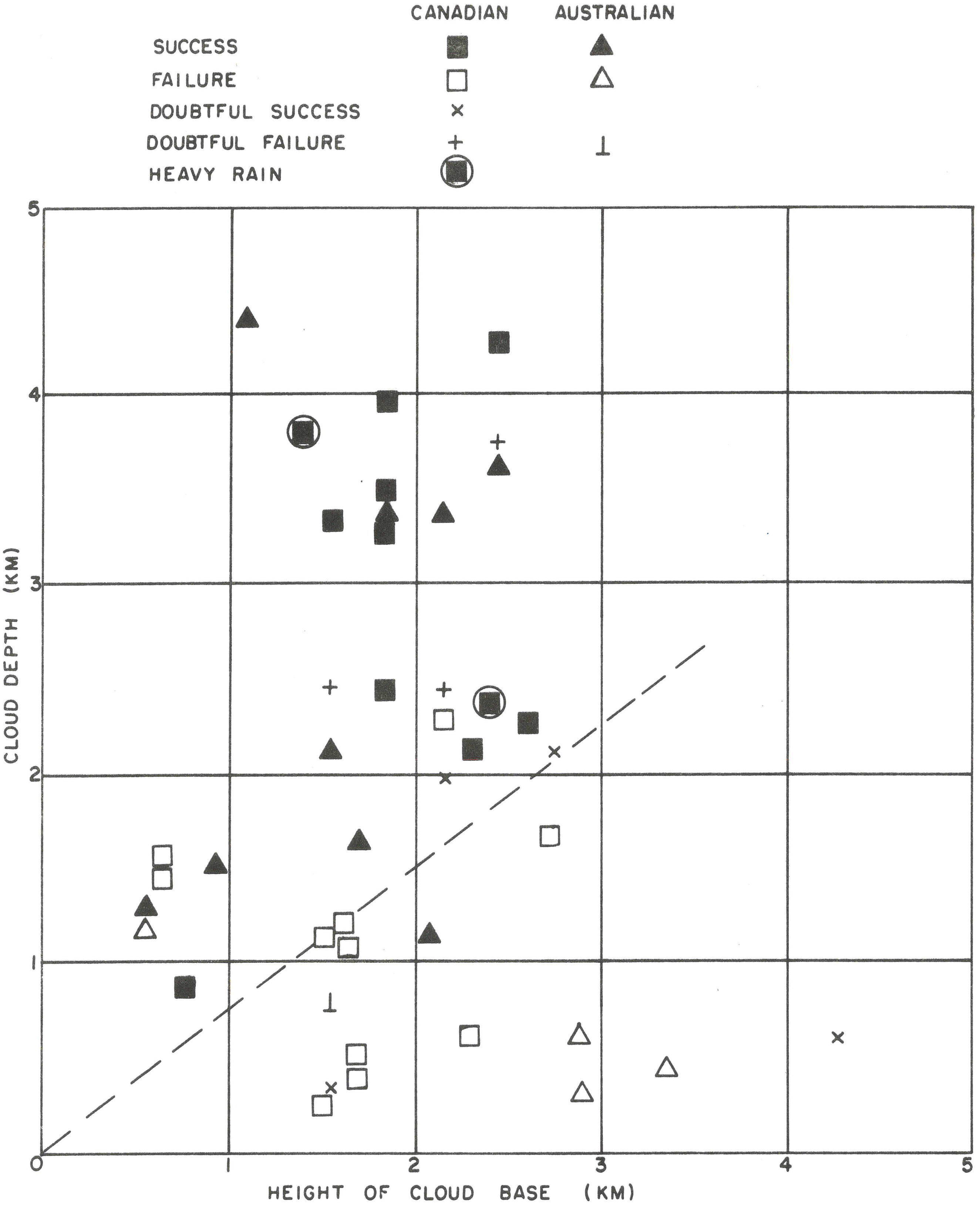

FIG I PRECIPITATION REACHING GROUND AS A FUNCTION OF CLOUD DEPTH AND CLOUD BASE HEIGHT

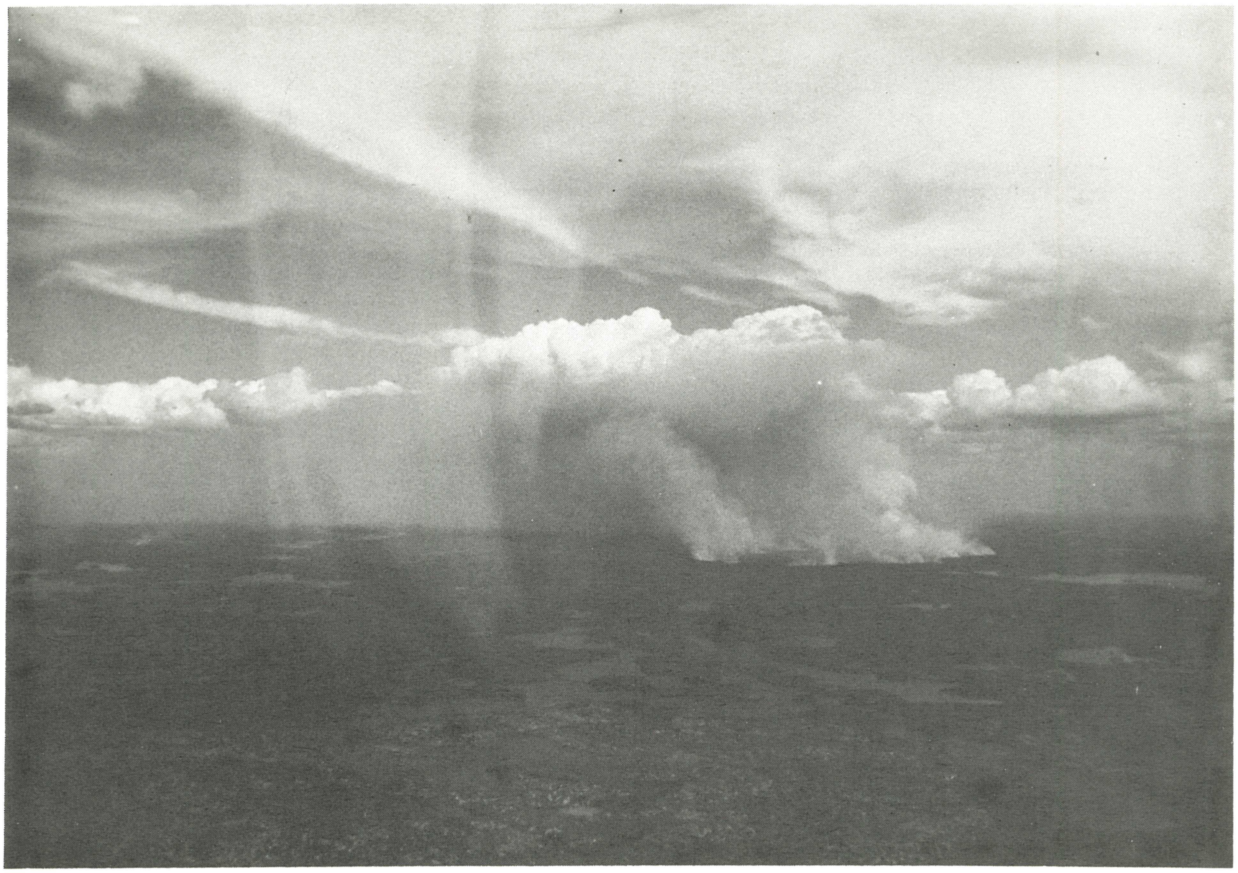

FIG 2 FIRE NEAR GAMMON LAKE, ONTARIO - July 4, 1974

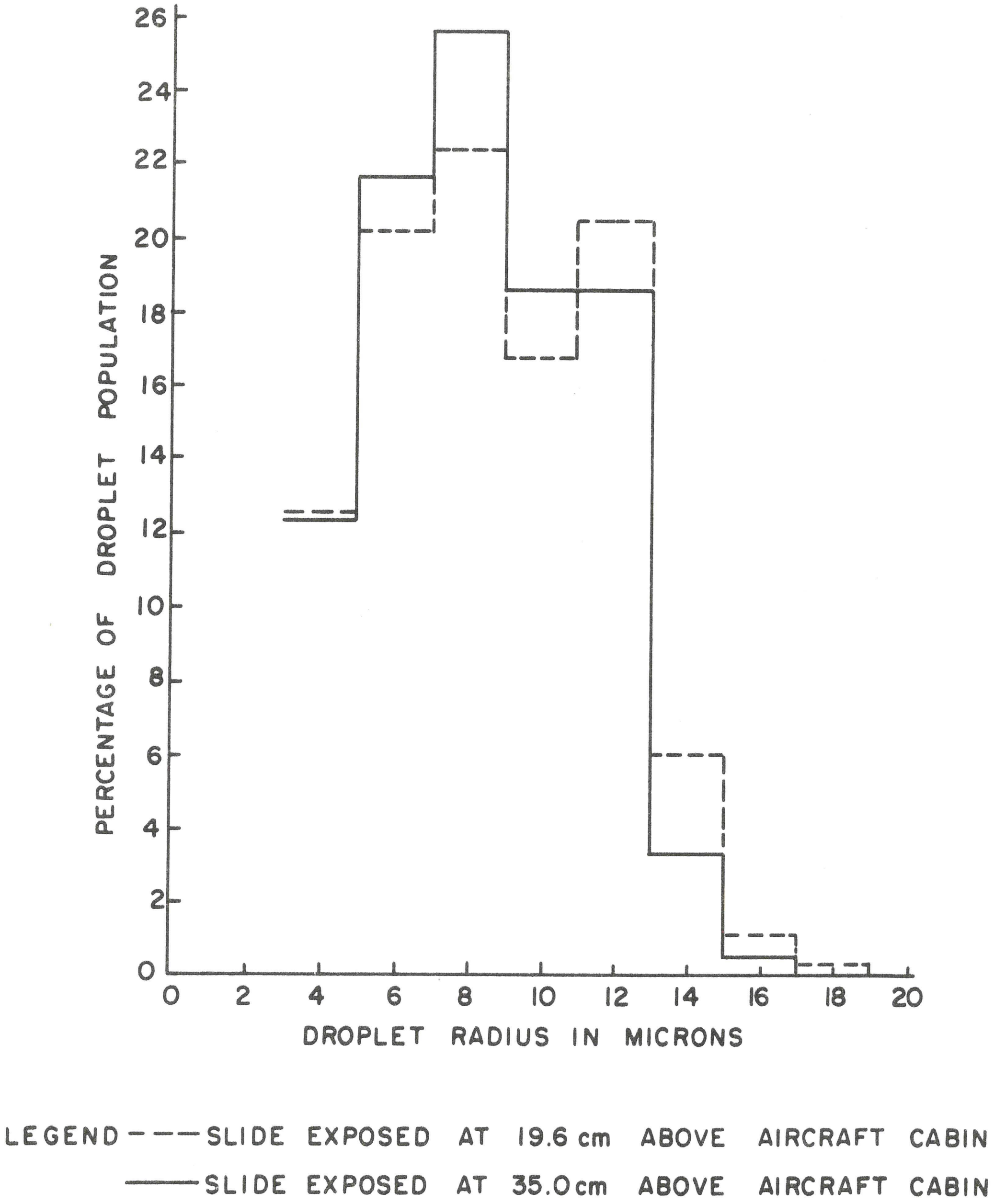

FIG 3 DROPLET SIZE DISTRIBUTION FROM REPLICATOR

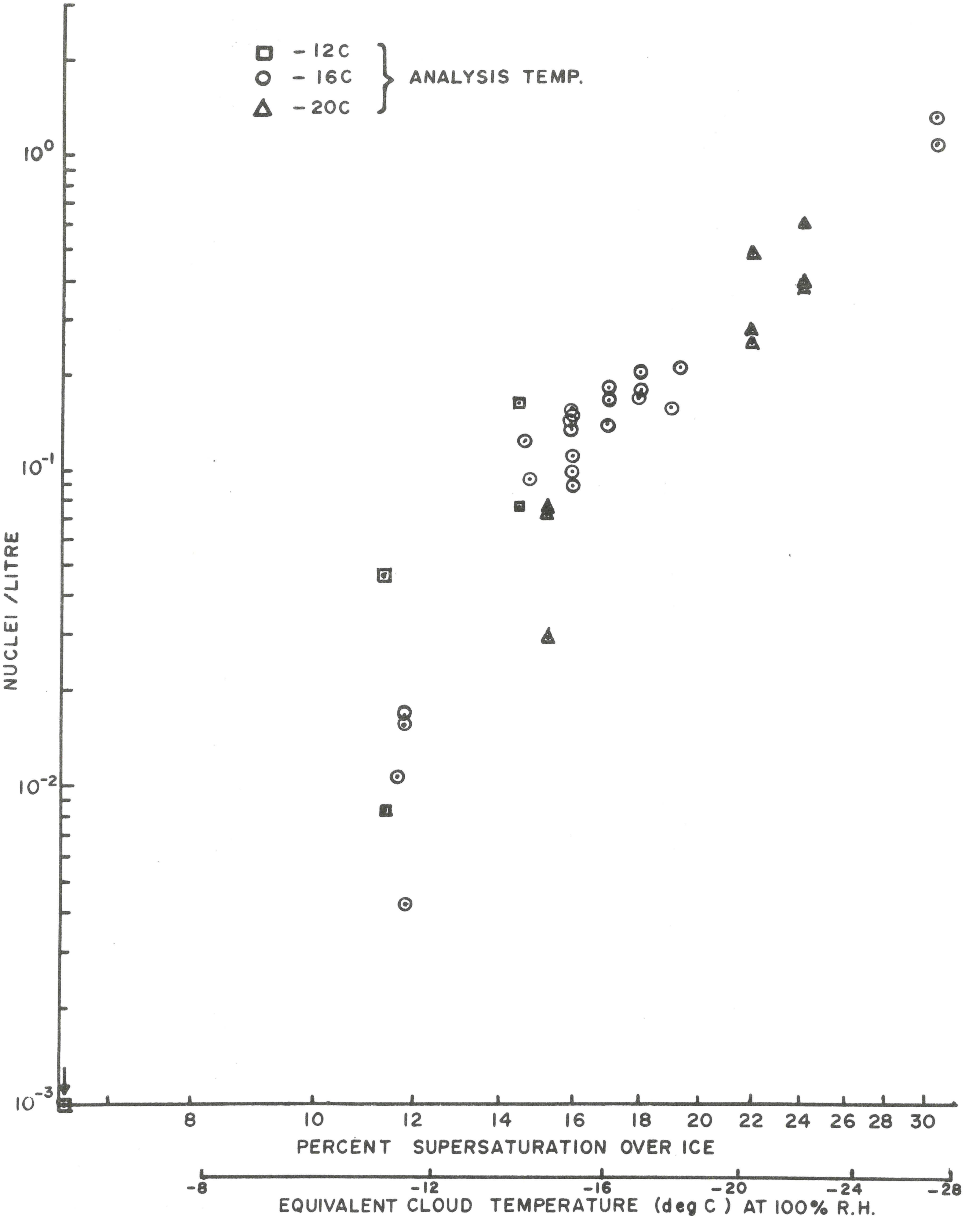

FIG 4 ICE NUCLEUS CONCENTRATIONS - ALBERTA 1974

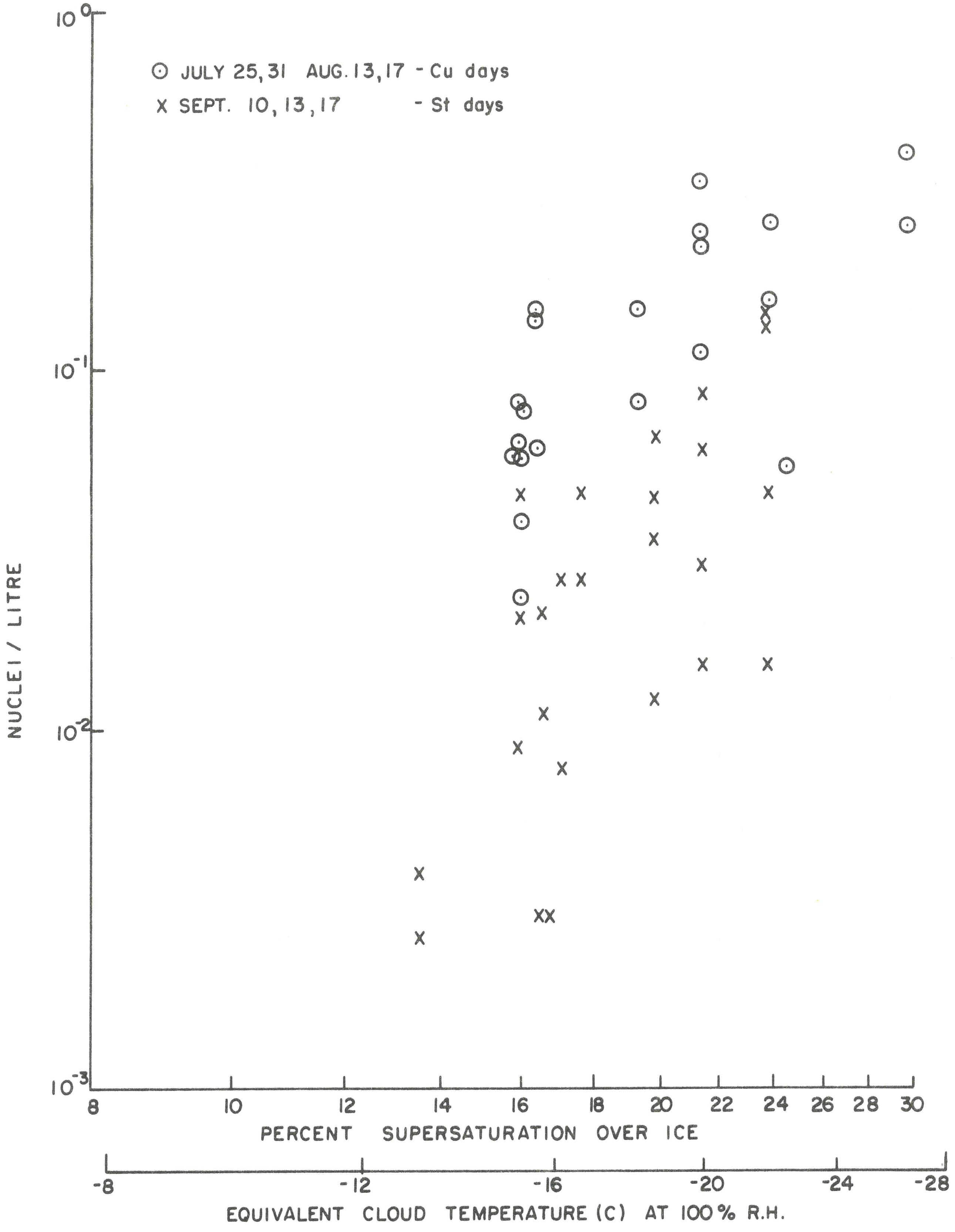

FIG 5 ICE NUCLEUS CONCENTRATIONS - TWIN OTTER NEAR OTTAWA

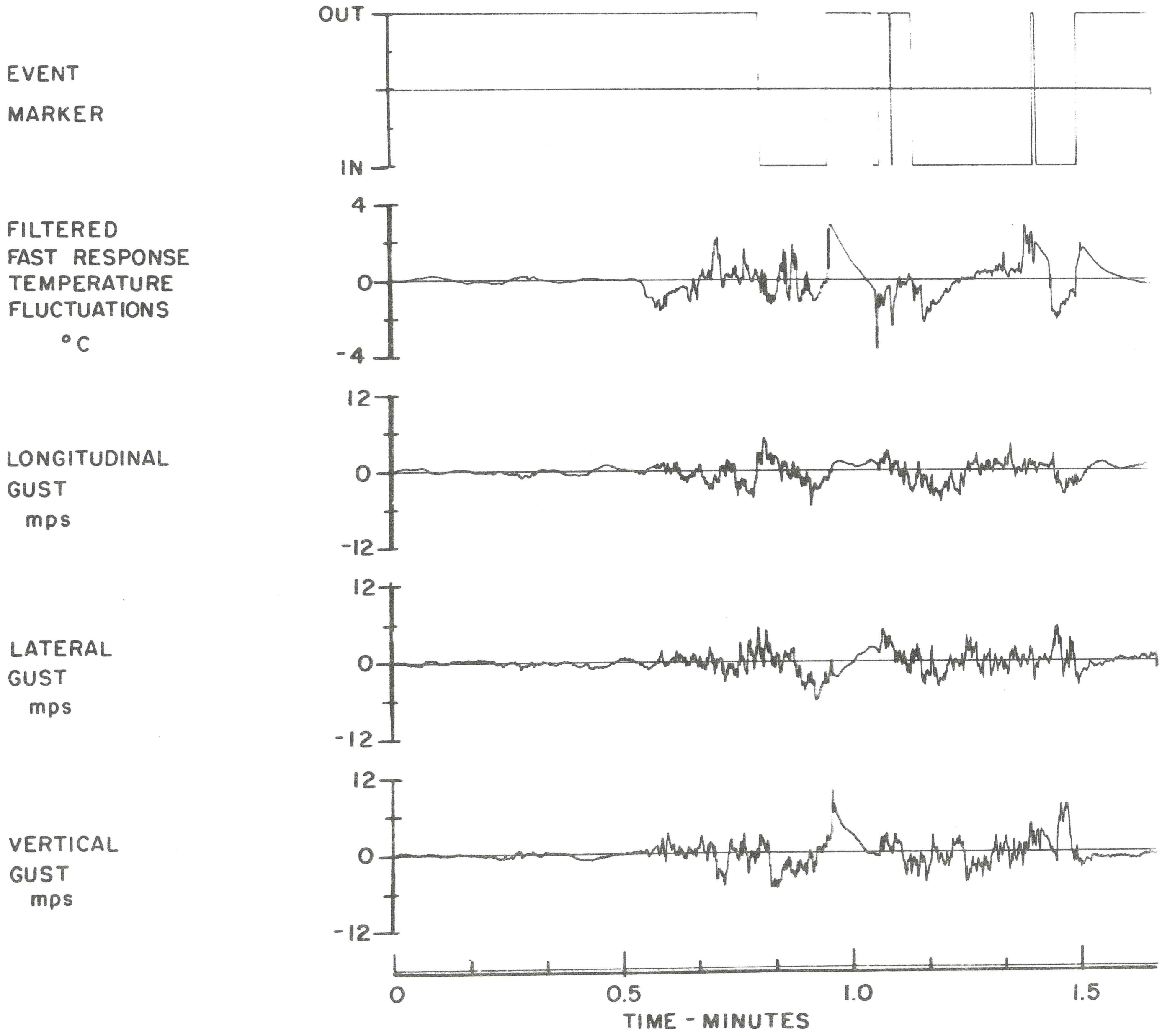

FIG 6 SCC 7 RUN 7 - ORIGINAL FILTERS

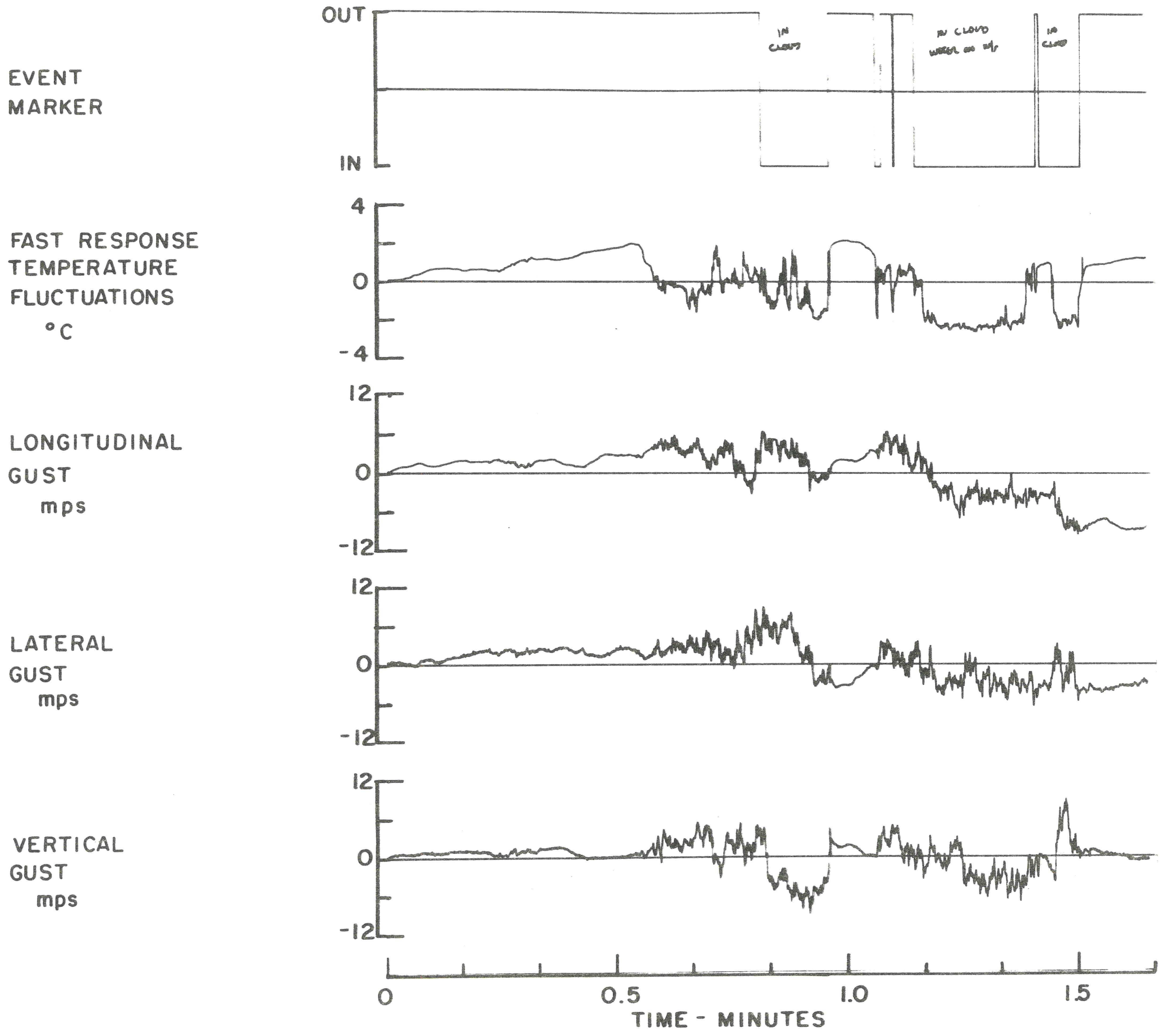

FIG 7 SCC 7 RUN 7 - UNFILTERED

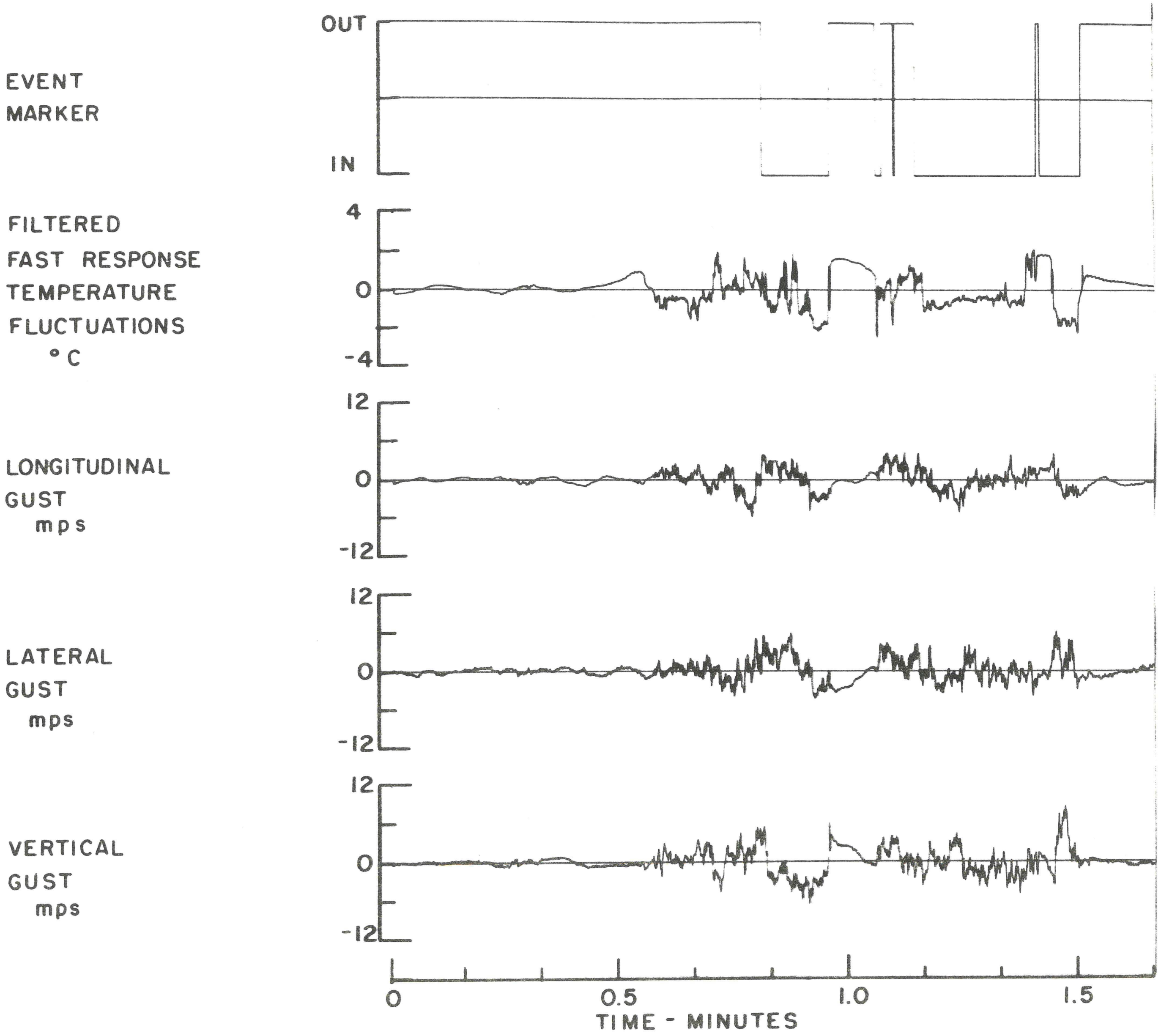

FIG 8 SCC7 RUN7 - NEW COSINE DIGITAL FILTERS

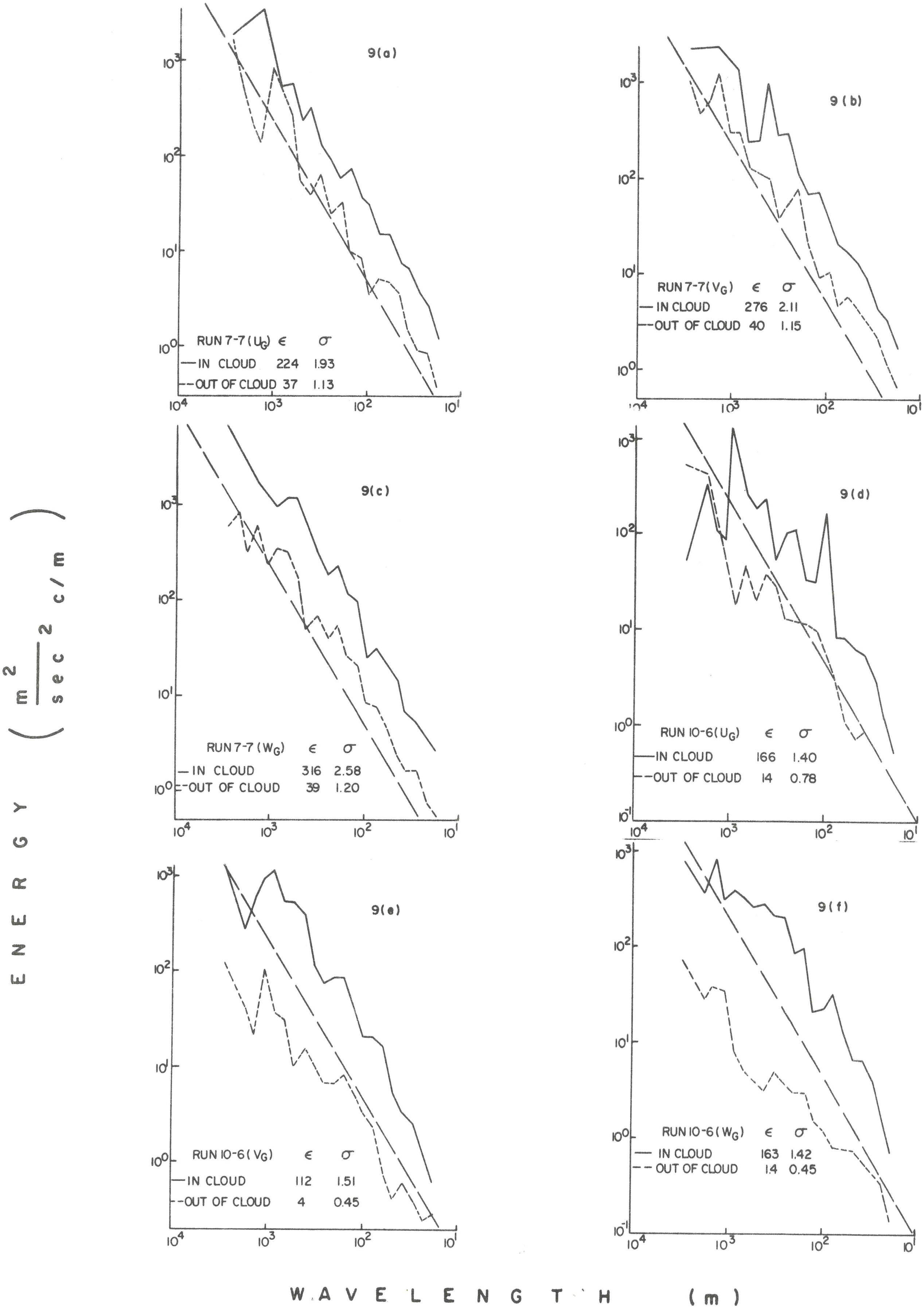ENERGY (m²/sec² c/m)
WAVELENGTH (m)
9(a)
RUN 7-7 (U_G) ε σ
— IN CLOUD 224 1.93
-- OUT OF CLOUD 37 1.13
9(b)
RUN 7-7 (V_G) ε σ
— IN CLOUD 276 2.11
-- OUT OF CLOUD 40 1.15
9(c)
RUN 7-7 (W_G) ε σ
— IN CLOUD 316 2.58
-- OUT OF CLOUD 39 1.20
9(d)
RUN 10-6 (U_G) ε σ
— IN CLOUD 166 1.40
-- OUT OF CLOUD 14 0.78
9(e)
RUN 10-6 (V_G) ε σ
— IN CLOUD 112 1.51
-- OUT OF CLOUD 4 0.45
9(f)
RUN 10-6 (W_G) ε σ
— IN CLOUD 163 1.42
-- OUT OF CLOUD 1.4 0.45
10⁻¹
10⁰
10¹
10²
10³
10⁴

FIG 9