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15. The DSDP sample numbers in Fig. 1 include the core number, section within the core, and centimeters within the section. For example, 1-1, 25 cm means core 1, section 1, 25 cm within section 1. In Fig. 2 legend the DSDP site number is given first.

16. We appreciate technical assistance from D. Scales. Supported by NSF grant GA-35252.

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Ice Crystal Concentration in Cumulus Clouds: Influence of the Drop Spectrum

Abstract. *Secondary ice crystals are thrown off when supercooled cloud drops are captured and freeze on a moving target in a cloud at −5°C. The rate of production of these ice crystals is proportional to the rate of accretion of drops of diameter ⩾24 micrometers.*

We reported recently (*1*) on laboratory experiments which showed that when an ice particle grows by the accretion of supercooled cloud drops, copious ice splinters are thrown off if the cloud temperature is about −5°C. We suggested that this phenomenon would probably provide the long-sought explanation for the high concentration of ice crystals found in some cumulus clouds as compared with the concentration of ice nuclei measured in cloud chambers in the vicinity (*2*). We now report on further experiments which demonstrate the influence of drop size distribution on the production of splinters during riming.

We used a cloud chamber with walls of polyethylene sheet, 2 m by 1.2 m by 1.8 m high, enclosed in a cold room. We made a supercooled cloud by injecting steam into the chamber from a boiler with known power input. Rime was grown on a vertical metal rod (*3*), 30 cm long and 0.2 cm in diameter, which moved in a circular path of diameter 30 cm about a vertical axis at a velocity of 2.6 ± 0.1 m/sec, sweeping up supercooled cloud drops in its path. The air temperature at the midpoint of the riming rod was $-4.7° \pm 0.5$°C. Below the riming rod a beam of light traversed the cloud chamber. We counted the number of ice crystals appearing in the beam per minute and derived from this the fallout rate of ice crystals (*4*).

All experiments were continued long enough for a steady state to be reached so that it could be assumed that the rate of fallout of crystals was equal to the rate of production. Because our experiments were carried out at a fixed temperature and target velocity the only known variables affecting the production of splinters were the weight of rime accreted per unit time and the size distribution of the accreted drops.

We investigated the rate of shedding of ice splinters when rime was accreted on the moving rod at widely differing rates (*5*). The liquid water content of the cloud and hence the riming rate could be varied by changing the boiler input power. Figure 1 shows that there is no unequivocal dependence of splinter production on riming rate. Relatively low counts were obtained when the drop sizes (*6*) were deliberately reduced by introducing NaCl nuclei into the cloud from a hot wire, even when the riming rate was very high. Higher counts were obtained when the chamber was flushed with filtered air to reduce the numbers of drop nuclei and give significant concentrations of larger drops.

We have investigated the effect of drop size alone by selecting from the previous experiments a set in which the rate of accretion of rime was constant to within 20 percent. A wide range of drop size distributions was obtained by adding or removing nuclei as described above. The largest drops found in our cloud in any experiment were 36 μm in diameter (sample volume, 5 cm^3).

We plotted the rate of production of secondary ice crystals against the concentrations of drops of diameters larger than 18, 20, 23, and 25 μm present in the chamber. Because drops of these sizes are swept up with almost 100 percent collection efficiency by the riming rod (*7*), the rate of accretion of drops of these sizes can be assumed to be proportional to their concentration. We find a reasonably linear relationship between splinter production rate and drop concentration for all these sizes, the closest correlation applying to drops of diameter >23 μm, for which the results are illustrated in Fig. 2.

From the results of these experiments we suggest that the rate of production of secondary ice crystals is proportional to the number rate at which drops larger than about 23 μm are accreted and is not, in general, a function of the riming rate, that is, the mass rate of accretion of all drops. We see from Fig. 2 that about ten crystals are produced per second for every drop >23 μm in diameter present per cubic centimeter of cloud air. A rod 2 mm in diameter, 30 cm long, and moving at 2.6 m/sec sweeps out a volume of about 1600 cm^3/sec. Thus about 160 drops >23 μm are accreted for every secondary ice crystal that is shed. We showed previously (*1*) that at a temperature of −5°C and a target velocity of 2.7 m/sec, about 350 splinters are produced per milligram of rime accreted. It is now apparent that this result applies only to the particular drop size distribution used in those experiments. Our new work does not affect the validity of the main previous finding (*1*) that the production of secondary ice crystals during riming is virtually confined to the temperature range −3° to −8°C, with a maximum rate at about −5°C.

We now turn to the question of whether we can explain the high concentrations of the crystals found in some maritime cumuli (*8*) in the light of our new laboratory results. In these field investigations, concentrations of about 100 ice particles per liter were found in some clouds with summit temperatures warmer than $-10°C$. This is about 10^4 times higher than the concentration of ice nuclei expected to be activated at this temperature. The clouds in which this enhancement occurs are favorable both because they contain suitably large drops and because much of their supercooled depth lies between $-3°$ and $-8°C$, the temperature zone in which splintering was shown to be important (*1*). In addition, the updraft structure probably allows graupel particles—that is, ice particles growing by riming—to stay in this zone for a considerable time: the observations of graupel of diameter 2 mm and larger near the tops of clouds (*8*) indicates that this is not an unreasonable assumption.

Our experiments with artificial clouds show that the rate of splinter production is most closely correlated with the rate of accretion of drops >23 μm in diameter. Although this does not mean that smaller drops play no part in the process, for the sake of simplicity we consider only drops of diameter $\geqslant 24$ μm in applying our results to natural clouds.

In the maritime cumuli studied (*8*) it was not unusual to find drops of diameter $\geqslant 24$ μm in concentrations of 50 cm^{-3}. A 2-mm graupel particle weighing 1 mg, grown in a cloud with a liquid water content of 1 g/m^3, would contain a weight of water equal to that in 1 liter of cloud. Considering that the growing graupel would sweep up the larger drops preferentially, we see that a 2-mm graupel particle would contain at least 5×10^4 drops $\geqslant 24$ μm. Our experiments indicate that in accreting these drops such a particle would produce some 300 daughter ice particles, provided it stayed near the $-5°C$ level. If these secondary ice particles grew, rimed, and splintered in their turn, two such cycles would produce an overall multiplication factor of about 10^5, starting from a single ice nucleus. The rate of splinter production would be reduced if the graupel particle was carried away from the $-5°C$ level, and the time to reach any given multiplication factor would be correspondingly increased. Until we know more about the trajectories of growing graupel particles in these clouds it will not be possible to make more realistic calculations of their splinter production. But these rough

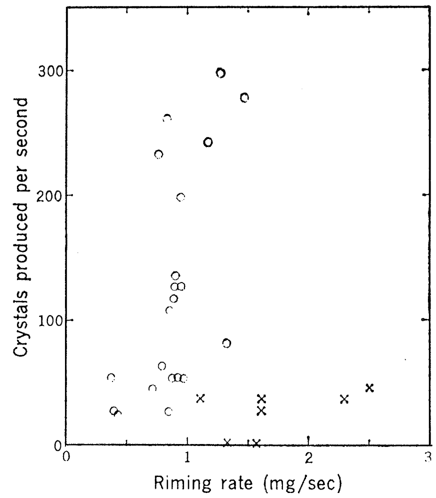

Fig. 1. Number of secondary crystals produced per second plotted against riming rate for experiments in which a rod (2 mm in diameter and 30 cm long) moved at 2.6 m/sec through a supercooled cloud at $-4.7°C$. The crosses apply to experiments in which NaCl nuclei were introduced into the cloud.

estimates indicate that the splintering phenomenon which we have investigated in the laboratory will probably account for the high concentration of crystals found in some maritime cumuli.

We are now in a position to give a more convincing explanation than before (*1*) for the apparent unimportance of ice crystal multiplication in certain continental cumulus clouds, in particular the winter cumuli over Israel studied by Gagin (*9*). Sampling traverses show that ice particles originate in these clouds at temperatures colder than $-12°C$. At these high levels, drops up

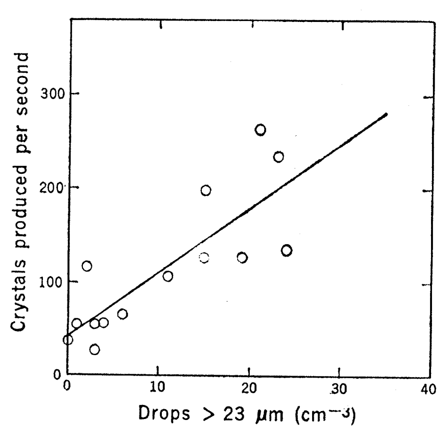

Fig. 2. Number of secondary crystals produced per second plotted against the concentration of drops larger than 23 μm in diameter in the cloud through which the riming rod was moving. The temperature was $-4.7°C$ and the riming rate was approximately the same in all experiments. The line of best fit by the least-squares method is shown.

to 36 μm in diameter are present and the ice particles grow by riming, but the temperature is unsuitable for splinter formation. The growing particles fall through the favorable temperature zone between $-8°$ and $-3°C$ but here the number of drops $\geqslant 24$ μm is seldom more than 0.1 cm^{-3} (*10*) and these are too few for any appreciable multiplication to take place. Hence the comparatively good agreement between the concentration of ice crystals and ice nuclei reported by Gagin.

The significance of our results for cloud seeding is obvious. Clouds in which appreciable concentrations of drops $\geqslant 24$ μm in diameter occur in the temperature zone $-3°$ to $-8°C$ are likely to produce abundant natural ice crystals, and artificial addition of crystals may be pointless. The greatest hope for increasing precipitation by artificial introduction of ice crystals lies with clouds having continental drop spectra and comparatively cold bases, where there is little chance of the development of drops $\geqslant 24$ μm below the $-8°C$ level.

Although we have not hesitated to apply our laboratory results to natural clouds, we emphasize that these results are preliminary and require confirmation. In particular, there are two respects in which our laboratory experiment does not fully simulate the natural riming process and which may have a bearing on splinter production.

1) Insofar as our rotating rod maintains constant orientation to still air, the shape of the growing rime, and consequently the rate of heat and mass transfer, may not simulate that of a freely falling conical or spherical graupel.

2) The rime accretion on our rotating rod is subject to centripetal acceleration. In the earlier experiments (*1*), with a rod moving at 1 m/sec, this was only about $0.7g$ (g = gravitational acceleration) and the rate of splinter production was still high. A steadily falling graupel particle is not subject to this acceleration, although such values could be attained by graupel particles of size greater than 1 mm as they oscillate by the shedding of lee eddies when the Reynolds number of the airflow exceeds about 200.

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5. Accretion rate was determined from the weight of rime gathered by the rod in a known time.
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Local-Regional Anesthesia during Childbirth: Effect on Newborn Behaviors

Abstract. *Administration of local-regional anesthesia during normal deliveries was correlated significantly with newborn behaviors as evaluated by the Brazelton neonatal assessment scale. Three days after birth, infants whose mothers received local-regional anesthesia were more irritable and motorically less mature than those infants whose mothers were not medicated.*

The pain-relieving drugs of labor and delivery were for many years administered to parturient women with little concern about the effects of these drugs on the other patient—the fetus. Recently, however, some serious fetal consequences of high dosages or repeated administration of maternal premedications and anesthetics have been recognized: meperidine and morphine may produce respiratory depression and the addiction-withdrawal syndrome (*1*); similarly, local anesthesia has been implicated in fetal bradycardia (*2*) and depression of respiration and circulation (*3*).

Effects of premedications on infant behaviors have also been demonstrated, especially in neonates born to mothers who received high drug dosages. Brazelton (*4*) noted the disorganizing effects of medication on the neonate, especially with regard to the effectiveness of infant nursing. Stechler (*5*) found that drug dosage was related to visual attentiveness in infants. Conway and Brackbill (*6*) found a combined effect of analgesia and anesthesia on muscle tension and on rate of extinction of the orienting reflex.

The behavioral effects of anesthetics have not been as well documented. Local anesthetic agents administered by regional routes are often assumed to be of no consequence to the healthy infant and have commonly been ignored as variables for study. Epidural anesthesia was found to affect limited neurobehavioral measures in one study (*7*), but infants whose mothers received low spinal, local, and no anesthesia were combined in the control group and the effect of analgesia administration was not controlled for statistically.

We studied the possible effects of local-regional anesthetics and analgesics administered during childbirth on behavior characteristics of infants 3 days of age. The sample consisted of 60 first-born, healthy infants between 48 and 72 hours of age. All were born of white middle-class women who had received routine antenatal care and had medically uneventful pregnancies and deliveries. The study is part of a larger longitudinal project on parent-infant interaction from the prenatal period to 1 month postpartum.

Information about labor and delivery and other birth data were obtained from hospital records: length of labor, type of delivery (spontaneous, forceps), the baby's birth weight, 1- and 5-minute Apgar scores, and analgesia and anesthesia administered. Labor times ranged from 2 to 18 hours. Forceps were used in 39 deliveries. Birth weights ranged from 2270 to 4226 g. Only five 1-minute Apgar scores were below 7, and all were normal at 5 minutes.

The analgesia score was computed from the dosage and interval between administration and delivery of the child. Drug dosage and time of administration were separately scored on a four-point scale ["4" being 150 mg or more of meperidine (or the equivalent) for drug dosage and within 1½ hours of delivery for time of drug administration]; these scores were multiplied to obtain a time-weighted dosage score. Sums of these scores for each woman comprise the analgesia variable. The most frequently administered analgesic agent was Demerol (meperidine) in conjunction with the preanesthetics Phenergan (promethazine hydrochloride) or Vistaril (hydroxyzine pamoate); morphine was given to two women. The first three drugs were considered equal in potency, and 10 mg of morphine was considered equal to 75 mg of the others. The woman with the highest analgesia score had received 50 mg of Demerol and 50 mg of Vistaril 3 hours before delivery and 75 mg of Demerol within the hour before delivery.

Anesthesia was scored as to whether or not local-regional anesthesia was administered; no woman received general anesthesia. Drug choice, dosage, and route of administration varied, but the maximum safe dose was never exceeded. Anesthetic solutions used were lidocaine, tetracaine, mepivacaine, and bupivicaine. Of the 52 women who received anesthesia, 42 were given spinal (saddle block) anesthesia. The routes of administration for the other women were pudendal (four), paracervical (one), epidural (two), both epidural and saddle block (two), and both pudendal and saddle block (one). Eight women received no anesthesia.

Infants were evaluated by the Brazelton neonatal assessment scale (*8*). This technique is more comprehensive than a standard neurological examination and assesses habituation to stimuli,

Table 1. Pearson product-moment correlations between childbirth medication scores and newborn behaviors.

Childbirth medication	Brazelton newborn scale clusters					
	Altertness		Irritability		Motor maturity	
	r	*N*	*r*	*N*	*r*	*N*
Analgesia	−.09	60	−.02	58	−.26*	61
Anesthesia	−.18	59	.26*	57	−.37†	60

* $P < .05$. † $P < .01$.