A Hypothetical Cloud-Seeding Method for Facilitating the Occurrence of Lightning

RICHARD F. GRIFFITHS

Atmospheric Sciences Research Center, State University of New York at Albany 12222
20 July 1976 and 14 April 1977

ABSTRACT

Drawing on available literature, arguments are presented to support the thesis that lightning initiation requires that positive corona streamers be produced in a region where the electric field $E$ exceeds a certain critical value $E_c$. Under normal circumstances electrically stressed precipitation particles provide this necessary corona.

A method of cloud seeding is proposed in which suitable corona-giving bodies are artificially introduced into the cloud so as to facilitate the triggering of lightning. The required properties of the seeding material are discussed, and possible applications of the technique are suggested.

1. Introduction

Experimental studies by Dawson (1969), Richards and Dawson (1971), Griffiths and Latham (1974a), Crabb and Latham (1974) and Griffiths (1975) reveal that the magnitude of the uniform electric field $E_c$ required to obtain corona discharges from various types of precipitation particles lies in the range $2.5 \times 10^4$ to $9.5 \times 10^4$ V m$^{-1}$, depending on the particle characteristics and the environmental conditions.

1 Present address: 32 Trafford Road, Alderly Edge, Cheshire, England.

Taken in conjunction with measurements of the electric fields produced in thunderclouds (Winn et al., 1974), these studies demonstrate that such discharges may occur naturally in mature thunderclouds.

A number of authors have examined the possible role of such discharges. The work of Dawson and Duff (1970) and Richards and Dawson (1971) extended and investigated the suggestion made by Pierce (1957), that residual charges held on large raindrops that have been in corona might result in sufficient local enhancement of the electric field to initiate the lightning stroke (also see Griffiths and Phelps, 1976a).
Other workers have concentrated on the subsequent behavior of the corona in the gas once the discharge has been started by the precipitation particles. Loeb (1953, 1966) suggested that lightning initiation might be attributable to field enhancement arising from the special propagation properties of positive corona streamers. The quantitative feasibility of this mechanism has been demonstrated by Griffiths and Phelps (1975, 1976a, b).

Griffiths et al. (1974) computed the magnitude of the expected increase in the ionic conductivity of cloudy air caused by the release of ions from ice particles in corona. This same physical process is produced in the technique described by Holitzka and Kasemir (1974) and Kasemir (1975), who have been seeding thunderclouds with metallized chaff fibers with the intention of introducing corona sites having a lower threshold ($\sim 3 \times 10^4$ V m$^{-1}$) than applies to natural precipitation. This treatment is premised on the idea that the seeding will lead to an artificially induced increase in the ionic conductivity within the cloud, tending to dissipate the electric field and thus reduce the occurrence of lightning.

It seems, therefore, that we can invoke corona as a medium for both the initiation and the suppression of lightning. In the next section we will attempt to resolve this dilemma by identifying the factors that determine which is the more likely result given certain initial conditions. In view of the fact that Richards and Dawson have shown that natural processes do not produce residual charges on raindrops of sufficient magnitude to initiate lightning on the basis of the process suggested by Pierce and examined quantitatively by Dawson and Duff, the discussion assumes that the most likely mechanism is that described by Loeb and by Griffiths and Phelps, in which positive corona streamer propagation is of prime importance. This assumption is made in order to limit the scope of the discussion, and should not be understood to imply any exclusion of other possible mechanisms.

2. Conditions needed for lightning initiation

According to the mechanism referred to above, lightning initiation depends on the production of positive corona streamers in a region where the electric field $E$ exceeds a certain critical value $E_0$ in order that the streamers may propagate and intensify. This high-field region must extend over a distance of $\sim 100$ m (Winn et al., 1974). $E_0$ is an experimentally determined parameter having a value of $\sim 4.5 \times 10^3$ V m$^{-1}$ at NTP, and falling approximately as the $\frac{3}{2}$ power of the dry air pressure at constant temperature. At $E = E_0$ the energy gained from the field by the charge in the streamer tip as it advances is just equal to that required to supply the energy losses due to ionization and excitation and other loss mechanisms inherent in replicating the advancing streamer. Under these circumstances streamers propagate without intensifying. If $E < E_0$, the losses are fed from the internal energy of the streamer, which is rapidly expended, so that the process rapidly extinguishes itself. However, if $E > E_0$, excess energy is available and the streamers intensify, carrying increasingly larger positive charges in their tips, and depositing net negative charge in their trails. This charge deposition is essential to the lightning initiation mechanism. Several such streamer systems must propagate in rapid succession in order to initiate lightning, and it is quite possible for the whole process to cease prematurely. Thus, if $E > E_0$, streamer propagation may lead to lightning initiation, but if $E < E_0$ neither one can occur.

We next consider the means whereby corona is produced in the thundercloud. As noted earlier, $E_0$ for natural precipitation particles lies in the range $2.5 \times 10^3$ to $9.5 \times 10^3$ V m$^{-1}$, depending on the nature of the particle, whether it is frozen or liquid, charged or uncharged, as well as on the altitude (gas pressure and temperature) at which the event occurs. Reviewing the available literature, Griffiths and Phelps (1976a) point out that for natural precipitation $E_0 > E_0$ in all cases excepting that of colliding drop pairs. For this case it appears that $E_0 < E_0$ for off-center collisions occurring in high- and low-altitude ranges, while in the mid-range $E_0 > E_0$ still applies.

Thus, in the majority of cases, the fields necessary to initiate corona are in excess of $E_0$, so that if the discharge is in the form of positive streamers subsequent propagation is assured. However, the positive streamers assumed necessary for the initiation process are only one of several possible forms of corona.

It is apparent that a great deal of corona activity takes place that does not give lightning. The effect of the ions released in such events is to contribute to the ionic conductivity within the cloud, thus contributing to leakage effects that tend to dissipate the electric field. In this class we place all corona events for which $E_0 \leq E_0$, any corona form other than positive streamers for which $E_0 > E_0$, and positive streamer systems that do propagate but ultimately fail to produce lightning. The tendency of such leakage effects will be to inhibit the attainment of fields of lightning onset magnitude.

Thus the conditions necessary for lightning initiation under the positive streamer assumption are as follows:

1) Bodies for which $E_0 \leq E_0$ should not be present in significant numbers.

2) Bodies for which $E_0 > E_0$ must be present.

3) The ambient field $E$ must be sufficient to initiate corona from the bodies for which $E_0 > E_0$, i.e., $E \geq E_0$. 
4) The discharge must be in the form of positive streamers which will propagate and intensify since $E > E_0$.

5) A number of streamer systems must propagate in rapid succession, and must produce the necessary degree of field enhancement.

The option for modification by artificial means arises in that it is feasible to introduce into the cloud objects for which $E_c > E_0$, thereby influencing its compliance with conditions 1) or 2). The scope is limited in that we can only increase the population of such bodies; their removal from the cloud does not seem to be a practical proposition.

Of the two approaches suggested by these considerations, one is already in use, viz., the method of chaff seeding described by Holttza and Kasemir, which makes use of conducting fibers 10 cm long for which $E_c \sim 3 \times 10^4$ V m$^{-1}$ at 1000 mb. It is clear that $E_c < E_0$ over the whole pressure range of the thundercloud, so that if dispersed in sufficient numbers these fibers could be expected to have a marked reducing effect on the lightning occurrence in the cloud, since its ability to conform to condition 1) should be spoiled. The definition of "sufficient numbers" in this case has not yet been irrefutably established.

In connection with this technique which depends on the presence of objects for which $E_c < E_0$, we should note that this is also true for some colliding drop-pairs. However, we would not expect this natural corona source to have a significant effect on leakage processes, because the frequency of such collisions is small, and the quantity of charge released per event ($\sim 10^{-10}$ C) is negligibly small, especially compared to that released from the chaff which is presumed to yield a continuous current of $\sim 1 \mu A$ per fiber.

A second means of modification is suggested by condition 2) above. As far as the author is aware this possibility has not previously been recognized, and it is here proposed as a new technique, described in the next section.

3. Description of the proposed seeding method

The technique consists of introducing into high-field regions of thunderclouds objects for which $E_c > E_0$. If the ambient field $E > E_0$, these objects may provide sites for lightning initiation. Their effect should be particularly marked where the local population of suitable natural precipitation particles is inadequate. Such regions could be expected to arise preferentially in clouds where the convective mechanism proposed by Vonnegut (1953) is the dominant means of electrification, but may well occur in any thundercloud.

In order to be most effective, the seeding agents must be designed so as to optimize their ability to yield positive corona streamers. It is known that colliding drop-pairs and large drops both yield this form of discharge under suitable conditions, but unfortunately neither one presents itself favorably for our purposes, since the former could not be produced conveniently in the cloud by artificial means, and the latter have values of $E_c$ which are rather too high to be useful (9.5 x 10$^5$ V m$^{-1}$ if initially uncharged and 5.5 x 10$^5$ V m$^{-1}$ if initially highly charged). One possible solution would be to use a material with a lower surface tension, such that $E_c$ was about $\frac{1}{2}$ to $\frac{3}{4}$ the value for the equivalent water drop. However, liquid drops have the disadvantage that for part of the range of air pressure encountered in a cloud the corona is initiated by a Taylor disruption mechanism. Although this tends to produce streamers when the discharge is positive, the fact that the corona is triggered by surface disruption means that $E_c$ remains constant until pressure-dependent corona onset without surface disruption takes over at lower pressures. For water this transition occurs at about 500 mb. Since $E_0$ falls with pressure over the whole range, the relationship between $E_c$ and $E_0$ is not as straightforward as it would be for a solid object for which $E_c$ falls linearly with pressure. In addition, at pressures below the transition point the discharges from liquid drops will not necessarily be of the positive streamer form (Dawson, 1969).

The corona-giving properties of ice needles (Griffiths and Latham, 1974a) appear better fitted to our purpose, since they not only have suitable values of $E_c$ that fall linearly with pressure, but are also capable of yielding positive corona streamers. This latter property appears to be a consequence of the surface electrical conductivity of the ice being marginal from the point of view of carrying the corona current. However, for pure ice samples the production of corona is drastically inhibited at temperatures of $-18^\circ C$ and below, because of the strong temperature dependence of the conductivity. This threshold temperature can be reduced by adding impurities such as ammonia to the ice surface (Griffiths and Latham, 1974b). However, although they are in some ways suitable, ice needles have only a limited temperature range in which they could be used.

In view of this, the most appealing solution is to design an object that acts for the purposes of corona onset as an ice needle. The conductivity of such an object must be chosen so as to produce the same electrical relaxation effect that causes ice to yield positive streamers. A manufactured substitute need not suffer from the temperature limitations of ice, and has the advantage that it can be produced in advance of requirements and stored, whereas ice needles would have to be produced in situ and deployed at once. A greater degree of control can be incorporated into the properties of a substitute, whereas ice is subject to a variety of extraneous in-
fluences, such as changes in $E_c$ caused by evaporative changes in surface geometry. For purposes of seeding, an equivalent object could consist of a needle, say, 0.5–1.0 cm long, made of some nonconducting material and coated with an appropriately conducting surface finish. It should be emphasized that highly conducting needles would not be suitable.

The possibility that the triggering of lightning could be assisted by this method is of itself interesting, but this technique could conceivably lead to a means of making controlled modifications to thunderstorms. For example, the ability to trigger the rain gush effect would be of importance (Moore et al., 1962). Additionally, it might be possible to divert lightning hazards from vulnerable locations by causing the thunderstorm to expend itself in a “safe” area. This would constitute an alternative approach to this problem to that currently being investigated in the chaff-seeding technique.

Acknowledgments. The author gratefully acknowledges the support of the National Science Foundation, Atmospheric Sciences Section, under Grant AO41166.

REFERENCES


