Outlook research of application of model hydrometeor arrays for artificial initiation of lightning and thundercloud charge reduction

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Abstract. The use of model hydrometeor groups has prospects of application for the development of methods for artificially initiating lightning and thundercloud charge reduction. Experimental studies using the system of the artificial thunderstorm cells showed that the parameters of model hydrometeor groups located in the space between charged artificial thunderstorm cells affect the initiation and propagation of discharge. The efficiency of initiating channel discharges by hydrometeor of various classes is given. The use of model hydrometeor and methods for their delivery to a natural thunderstorm cloud to artificially initiate lightning or reduce the charge of a thunderstorm cloud are discussed.

Introduction

The problems of active control of the processes of initiation of lightning, its orientation and directed lead to a safe place remain relevant today [1, 2]. Lightning strikes into highly explosive and critical objects are fraught with disastrous consequences. In this case, a promising way of lightning protection will be the exclusion of the destruction of an object by lightning by artificially initiating it from a thundercloud before it approaches the object. Known methods of artificial initiation of lightning away from the protected objects are the initiation of triggering lightning (rockets pulling an extended metal conductor) [3] and laser initiation [4]. Currently, it is assumed that one of the possible factors for natural lightning initiating are arrays of large hail [5]. Therefore, the introduction of large model hydrometeors into a thundercloud is a promising direction for initiating lightning in thunderstorm clouds.

Another important problem in the development of methods for artificially initiating lightning in thunderstorm clouds may be the case when a thunderstorm cloud forms directly at the location of the object (for example, this is a situation quite characteristic of convective thunderstorms). In this case, it is necessary to artificially reduce the charge of the thundercloud forming above the object to a level when it will not be able to cause the formation of powerful channel discharges in the cloud itself and between the cloud and the ground. A known method of neutralizing the charge of a thundercloud is to “sow” it is connected with a large number of thin conductive particles (threads, needles, etc.) [6-8]. But field experiments showed that very often after sowing a lightning discharge still occurred, therefore, to solve this problem, it is proposed to introduce into the thunderstorm clouds groups of model hydrometeor, which, due to the streamer corona arising on them, will provide the accelerated discharging of the thundercloud.

The article summarizes the results of experimental studies on the use of the model hydrometeor groups for initiating of the channel discharges and reducing the charge of an artificial thunderstorm cell system, discussing the prospects for using them to develop methods for artificially initiating lightning and artificially reducing the charge of a thundercloud [9].

**Experimental results**

The experimental complex, designed to study the fundamental and practical problems of lightning physics and lightning protection, allowed us to conduct research on the initiation of discharges by arrays of the model hydrometeor [10].

Typical patterns of channel discharge initiation between artificial thunderstorm cells and the ground, and between cells of different polarity by groups of model hydrometeor are shown in Figure 1 and Figure 2, respectively.

![Figure 1](image1.jpg)  
*Figure 1. Initiation of channel discharges between the system of negative artificial thunderstorm cells and the ground with arrays of model hydrometeors*

![Figure 2](image2.jpg)  
*Figure 2. Initiation of channel discharges between a system of oppositely charged thunderstorm cells with the participation of arrays of model hydrometeors*

Experiments have shown that the efficiency of initiation of channel discharges depends on the size and shape of the conductive model hydrometeor, which can be divided into five classes depending on the electric field amplification coefficient ($k_a$). The following classes of model hydrometeors were distinguished: class 1 - $k_a \approx 3-4$; class 2 - $k_a \approx 5-9$; class 3 - $k_a \approx 10-19$; class 4 - $k_a \approx 20-49$; class 5 - $k_a > 50$.

A factor that significantly affects the efficiency of initiation of channel discharges in artificial thunderstorm cells is creation of an extended group of model hydrometeor through the formation of spark discharges between the adjacent hydrometeors in order to create an extensive discharge system capable of initiating a volume leader discharge.
It was revealed that with the introduction into an artificial thunderstorm cloud of several groups of model hydrometeors, the probability of discharge initiation and the total length of the discharge system increase. With the introduction of groups of model hydrometeors of class 1-3 into the space between the charged cells and the ground, the maximum length of the discharge system increased 2.5-3.5 times.

In addition, the method of combining model hydrometeors into an associated array plays an important role for hydrometeors with low electric field gains. Experiments have shown that the use of a dielectric string or dielectric tape between hydrometeors and their groups stimulates the formation of spark discharges between model hydrometeors and channel discharges between their groups, combining them into a conducting extended object without negative impact on the local electric field of the charged clouds.

It has been established that the probability of initiation of a channel discharge between charged cells by a group of hydrometeors increases with an increase in the number of hydrometeors forming a group. Such dependence has been revealed to a greater or lesser degree for all variants of the form of the model hydrometeor and methods of their association into a group. For example, when three, four, five, and six model hydrometeors were grouped into a group, the probability of channel discharge initiation from a group of hydrometeors grew by about an average of 10-15% with the addition of each subsequent hydrometeor to the group.

The parameters of model hydrometeors significantly affect their ability to initiate a discharge and stimulate its propagation between the artificial thunderstorm cells and the ground. The maximum probability of the channel discharge initiation between the negatively charged cells and the ground is 97% and between the positively charged cells and the ground 88% are achieved with the introduction of several groups of model hydrometeors of class 2 connected by a dielectric string. When the intracloud discharges have been initiated between the oppositely charged artificial thunderstorm cells by several groups of model hydrometeors 2 and 3 classes, the maximum probability of initiation was in the range of 86-90%.

The efficiency (from 1 to 3) of using groups of model hydrometeors of the different classes for the initiating of the artificial lightning from the artificial thunderstorm cells of the same and different polarity is summarized in Table 1.

Table 1. Effectiveness of the initiation of channel discharge from the artificial thunderstorm cells be the groups of model hydrometeors

| Class of model hydrometeor | Method of combining hydrometeors into a group | Type of artificial lightning initiation |
|---------------------------|---------------------------------------------|----------------------------------------|
|                           |                                             | Negative downward | Positive downward | Intracloud lightning |
| Class 1                   | Dielectric string                           | 2                      | 2                     | 2                       |
|                           | Dielectric tape                             | 1                      | 1                     | 1                       |
| Class 2                   | Dielectric string                           | 3                      | 3                     | 3                       |
|                           | Dielectric tape                             | 2                      | 2                     | 2                       |
| Class 3                   | Dielectric string                           | 3                      | 3                     | 3                       |
|                           | Dielectric tape                             | 2                      | 3                     | 2                       |
| Class 4                   | Dielectric string                           | 1                      | 2                     | 1                       |
|                           | Dielectric tape                             | 3                      | 2                     | 1                       |
| Class 5                   | Dielectric string                           | -                      | -                     | -                       |
|                           | Dielectric tape                             | -                      | -                     | -                       |
Thus, the most promising for the artificial initiation of lightning will be the groups of model hydrometeors of classes 2 and 3, joined by a dielectric tape.

For an artificial reduction of the charge of a thundercloud, hydrometeor with high field gains, which have shown the lowest efficiency for the formation of channel discharges, are promising.

With the introduction of groups of hydrometeors of class 4 and 5 in the space between the charged clouds, cloud discharges that form on the group of hydrometeors, prevail over the channel. This is due to fact that model hydrometeors which have a high electric field gain provide for the early formation of an avalanche corona on them with relatively weak external electric fields of a thundercloud. And for the transition of this avalanche corona into a streamer corona, greater external electric field strength is required. Thus, hydrometeor can contribute to the discharging of the parts of a thunderstorm cell nearest to them by ions of the avalanche corona (Figure 3).

![Figure 3](image)

**Figure 3.** Discharging of a part of a thunderstorm cell by an avalanche corona from a model hydrometeor with a large electric field gain (classes 4 and 5)

As a result, locally, at the location of the model hydrometeors with high electric field amplification coefficient, the intensity of the external electric field of a thunderstorm cloud will decrease. Such decreasing of the electric field strength in the place where a model hydrometeor has been disposed could reach up to 30-50 %. At the same time, the intensity of the thundercloud field required for the emergence of a streamer corona on these hydrometeors will not be reached or will be at a level at which only a weak streamer corona can form that cannot transform into a volume leader.

Experimental studies make it possible to generalize and identify the main stages for the development of methods for artificial initiation of the lightning discharge and reducing the charge of a thundercloud.

**Perspectives of application of model hydrometeor arrays**
On the basis OFA generalization and analysis of the experimental and theoretical results obtained in the system of the artificial thunderstorm cells of the same or different polarity, the influence of the form and method of combining of the model hydrometeors in groups on the initiation of various discharge phenomena has been established. This allows to determine the perspectives of application of the model hydrometeor array in natural thunderstorms for artificial lightning initiation or thundercloud charge reduction.

First of all, it is necessary to evaluate or to predict the state and characteristics of the thunderstorm situation and the approaching (emerging) thundercloud:

- electric field strength on the different places of a surface of the earth;
- electric field strength distribution at the lower boundary, in the lower part of the thundercloud and inside it;
- intensity, development trends and estimated characteristics of the initial discharge processes inside the approaching (emerging) thundercloud;
- the presence, location and size of the hail arrays in a thundercloud, their movement and tendency to precipitation.

Based on the data obtained, an array of quantitative and qualitative factors determining the possibility and the expediency of an application of the model hydrometeor groups for an artificial lightning initiation from an approaching thundercloud has been formed for the different possible nature situations:

- initiation of a downward negative lightning;
- initiation of a downward positive lightning;
- initiation of an intracloud lightning;
- stimulation of the repeated lightning strokes from a thundercloud and ensuring maximum discharging of the thundercloud.

For the chosen variant of artificial initiation of lightning, selection of groups of the model hydrometeors that are promising for this purpose is made (Table 1). And the possible ways of the delivery of the model hydrometeor arrays to the necessary part of the thundercloud have been proposed.

To artificially initiate a descending negative or positive lightning and to stimulate the negative repeated discharges or the discharging of a thundercloud, an introduction using probes of the groups of model hydrometeors to the lower boundary region of the main negative charge or the lateral boundary region of a shifted main positive charge of the thundercloud can be used. For artificial initiation of intracloud lightning, hydrometeor should be delivered into the space between the main negative and positive charges.

One from the possible ways of the introducing of the model hydrometeors could be the using of the unmanned aerial vehicles (Figure 4).
This method is characterized by the possibility of a complex sequential implementation of the beginning processes of an artificial initiation of the intracloud lightning, and then the following artificial initiation of the downward lightning if the model hydrometeor array will provide into the upper regions of the thundercloud.

Unmanned aerial vehicle as and small-sized rockets could be used for initiation of the separate kinds of a lightning discharge too (Figure 4). Especially if we could direct them to a part of a thunderstorm cloud with an increased electric field strength, in which the probability of artificial lightning initiation increases.

Thus, application of the large model hydrometeor arrays of the different types have the good perspectives as for an artificial initiation on the intracloud lightning and negative and positive downward lightning as for the directed discharging of the approaching or actively formed thunderclouds.

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