COSMIC RAYS IN THE MECHANISM OF THUNDERCLOUD PRODUCTION

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Abstract

The mechanism of thundercloud production is given in which cosmic ray (CR) fluxes play a main role. They ionize air in the tropo- and stratosphere providing thundercloud formation. High-energy CR particles with energy $E \geq 10^{14}$ eV produce extensive air showers (EAS), which initiate lightning appearance.

1. Introduction

Atmospheric electricity plays an important role in the atmospheric processes, weather and climate changes. The global electric circuit is in operation and supports the negative charge of the Earth $Q \sim$ - 600000 C. In the quiet atmosphere over the globe there is an electric current $J \sim 2000$ A. The current could discharge the Earth during several minutes. To support the value of Q the generators of electric current are needed. The thunderclouds are such generators. Lightning charge the Earth by $J \sim 2000$ A. To provide the conductivity of the atmosphere and thundercloud formation ions have to be present in air.

The cloud coverage is considered as the main factor of the weather and climate changes on the Earth [1]. If lightning occur the cloud is called thundercloud. The various physical mechanisms explaining the unlike electric charge production inside of thundercloud, the large-scale spatial separation of charges, and also lightning generation were suggested [2, 3].

Below the mechanism of the formation and development of thunderclouds different from known ones is given [4].

2. Mechanism of thundercloud formation

The following observed facts are used as the main initial concepts: (1) The humid air near the Earth's surface is ionized by CRs and natural radioactivity of soil. In air the unlike charged aerosols are always present. These aerosols are the potential nuclei of water vapor condensation; (2) The thunderclouds are merely

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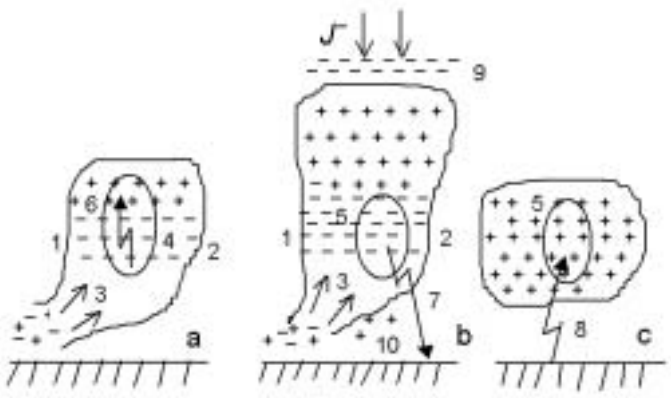

Fig. 1. The phases of thundercloud life: a - generation; b - maturity; c - degradation. Notations: 1 - region of a warm front; 2 - region of a cold front; 3 - upstreams of wet ionized air; 4 and 5 - extensive air showers produced by primaries with $E \geq 10^{14}$ eV and 10^{15} eV; 6 - intracloud electric discharges; 7, 8 - descending and ascending discharges; 9 - negative screen layer; 10 - positive charge in the cloud base; J^- - current of negative ions flowing from the ionosphere to the top of cloud.

formed if rather strong upstreams of wet and ionized air from the boundary layer exist; (3) In the atmosphere the process of water vapor condensation on negatively charged nuclei occurs at lower supersaturations than on positively charged or neutral nuclei; (4) During intracloud lightning inside of the thundercloud a large amount of free electrons is produced.

There are three phases of thundercloud development (see Fig. 1). The initial or growth phase is characterized by the presence of air upstreams in the cloud and the appearance of the first lightning. In the phase of maturity (second phase) the thunderstorm discharges are amplified, electrical activity and water content in cloud grow. In the third phase (phase of thundercloud decay) the vertical air motions are damped out, electrical activity goes down and precipitation are observed. Let us consider these phases in detail.

Near the Earth's surface and in the lower atmosphere there are many aerosol particles. Some part of light ions adheres to aerosols. Thus, in the lower atmosphere there are neutral and charged aerosols or heavy ions.

The process of water vapor condensation is the main reason of cloud and thundercloud formation. In this process the droplets are formed. The water vapor condensation on negatively charged nuclei requires lower supersaturations of vapor in comparison with positively charged nuclei or neutral ones [5, 6]. Consequently, the probability of negative charged waterdroplet production is higher in (10^3 - 10^4) times than one of positive charged droplet production. As the sizes and masses of drops increase their ups slows down as a result of gravitational force action.

In turn, the vapor condensation process on positive charged nuclei requires larger supersaturation which exists at higher altitudes. Because of this, the positive charged nuclei together with an ascending air mass continue to move up. We have got the macro - spatial separation of unlike electric charges in the cloud: a negative charge is in the bottom of cloud and a positive one is in the upper of it. The strength of an electric field F inside of the cloud increases. The measurements showed that in the thunderclouds the values of F are $F < 2$ kV/cm. However, in the moment of lightning discharge the values of $F \sim 3$ kV/cm were observed [7, 8].

The main reason of lightning appearance at $F \sim$ (2 - 3) kV/cm is EAS. Lightning discharges propagate along ionized tracks of EAS particles [4, 9]. The cloud is a dielectric. Within of the cloud electric charges are distributed. To produce an intracloud discharge it is necessary to have a widespread "conductive tree" along branches of which a substantial volume electric charge could be transferred from one part of "tree" to another one. In the atmosphere each cosmic particle with $E \geq 10^{14}$ eV produces an EAS - a widespread "conductive tree". When $F \sim$ (2 - 3) kV/cm the discharges within a cloud arise (see Fig. 1a). Owing to such discharge the electric field strength F decreases from $F \sim$ (2 - 3) kV/cm to $F \sim$ (10 - 20) V/cm and the discharge is terminated.

The negative ion current flowing to the top of cloud is higher in ~ 10 times than the positive ion current flowing to the base of the cloud (see Fig. 1b). It is due to that the mobility and concentration of ions above the cloud are higher than these values under the cloud. As a result of it, the electric dipole of the thundercloud becomes asymmetric one with the prevalence of negative charge in the low part of the cloud. It gives the increase of an electric field F between the cloud and the Earth's surface. The descending lightning are arisen which transfer the negative charge from the cloud to the Earth's surface.

From this moment the cloud is in the phase of maturity that extends over ~ 20 min. In this phase owing to a large number of cloud-to-ground lightning a water vapor condensation rate peaks maximum value and owing to a release of maximum values of latent heat, the maximum values of upstream rate, electric activity and water content of thundercloud are reached also. The descending lightning are running along the ionized tracks of the EAS particles that get the Earth's surface. The primaries with $E \geq 10^{15}$ eV produce such EAS.

With time within the thundercloud the growth of unfrozen and frozen water drops takes place as a result of processes of water vapor condensation and droplet coagulation. The drops become heavy and begin to go down by gravity. It causes precipitation and scattering cloud. Together with the precipitation from the lower part of the cloud the negative charge goes down and the positive charge being on hydrometeors in the upper part of the cloud comes into this place (see Fig. 1c). As a consequence, the direction of the electric field F between the

cloud and the Earth's surface is reversed [2]. It opens up the opportunities for the ground-to-cloud lightning production that transfer a negative charge from the Earth's surface to the cloud.

3. Discussion and conclusion

The given mechanism explains the origin of unlike electric charges in the cloud, their macro-scale separation and lightning appearance. In comparison with other known mechanisms this one has the following distinctive features. The unlike electric charges which are necessary to produce the initial intracloud discharges are made by cosmic rays and radioactivity in air. The main part of unlike charges is produced in widespread and high ionized channels of lightning. The macro-scale separation of unlike charges is under way owing to the existence of wet and ionized air upstreams and gravity together with the predominant condensation of water vapor on negatively charged nuclei. Lightning discharges are initiated by high - energy cosmic ray particles with energy $E \geq 10^{14}$ eV that produce EAS.

The main sources of ionization of air are cosmic ray flux (at the altitudes from the ground to $\sim$ (50 - 60) km and also X - and UV - solar irradiation (at higher altitudes). The X - and UV - solar irradiation and cosmic ray flux are determined by solar activity. Thus, thunderstorm activity depends on the activity of the Sun and the solar-terrestrial-climatic relationship has to exist.

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4. References

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