INFLUENCE OF WATER CONDUCTIVITY ON MICRODISCHARGES FROM RAINDROPS IN STRONG ELECTRIC FIELDS

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ABSTRACT: The influence of water conductivity on microdischarges from raindrops has been studied by submitting water drops of different conductivities to a strong horizontal electric field. The discharge onset field remains unchanged but the microdischarges characteristics are clearly affected by the nature of water - scarce high amplitude pulses for low conductivity water and numerous low amplitude pulses for higher conductivity water. A possible mechanism implying a better neutralization of space charge by conductive drops is proposed in order to explain these observations. On the basis of this laboratory experiment, one can suppose that water conductivity, governed by anthropogenic pollution, could affect larger electrical phenomenon such as lightning.

INTRODUCTION

Corona discharges from hydrometeors are supposed to be the first stage of lightning initiation. Several parameters that govern microdischarges from raindrops have been largely studied; particularly pressure, and water drop size and charge (Dawson, 1969; Griffiths and Latham, 1972; Georgis et al., 1995). Among these parameters, water conductivity has been seldom considered though its influence has been pointed out for water drops on an insulator surface (Windmar, 1994). Moreover, Griffiths and Latham (1974) noticed an effect of conductivity on ice particles. They showed that there is a critical temperature from which ice conductivity is too weak to allow microdischarges from ice hydrometeors. Contaminating ice particles with ammonia, which means increasing ice conductivity, leads to decrease this critical temperature from which corona emission is inhibited. Furthermore, several recent studies tend to suspect an influence of atmospheric contaminants on lightning. They show a modification of lightning activity over cities (Wescott, 1995; Soriano and de Pablo, 2002; Steiger et al., 2002) or during a fire of biomass event (Murray et al., 2000). This modification could originate from several parameters (urban heat island, CCN concentration...) and water conductivity, that is much affected by pollutants, could also play a part. A laboratory experiment has been performed so as to observe the impact of water conductivity on microdischarges from raindrops. Using different types of water, we submitted falling drops to a strong electric field. The signals produced by the drops were measured and the different electrical behaviors were analyzed. The second step in this study is trying to link laboratory results with large scale electrical phenomenon, which means trying to draw up conclusions about lightning activity.

EXPERIMENTAL PROCEDURE AND RESULTS

The experimental device is similar to that used by Coquillat et al. (1999): a drop of given size falls through a vertical tunnel and enters, at terminal velocity, a strong horizontal electric field at atmospheric pressure. The horizontal field is created between two polished and chromed copper plates separated by a distance of 10 cm (Figure 1). Each plate is connected to a high voltage DC power supply of 0 to ±100 kV via a resistor R of 100 MΩ which limits the discharge current intensity into the generators. The apparatus is designed to simultaneously detect the negative and positive currents emitted from both sides of the drops. Both discharge signals are analyzed through a resistor r = 50 Ω by a digital oscilloscope (50 Ω input impedance, sample rate of 50 MS/s). The current I is deduced from the observed voltage V: \( I = \frac{2V}{r} \). Both capacitors C = 60 nF prevent from any direct connection of the oscilloscope to the high voltage circuit. Two types of water are used: pure water and rain water. The latter contains higher ion concentration (chloride, nitrate, sulfate, Na\(^+\), K\(^+\), Ca\(^{2+}\), Mg\(^{2+}\)) than the former. Consequently, the rain water conductivity (1470 µS/m) is higher than that of pure water (260 µS/m). For three sizes of drops of radius equal to 1.94, 2.33, and 2.76 mm (± 0.1 mm), the electric field intensity was increased until disruption occurred.

The instability onset field remains quite unaffected by water conductivity, it decreases from about 800 to 650 kV/m for equivalent drop radius increasing from 1.94 to 2.76 mm, respectively (Figure 2). The differences remain in the range of accuracy of the disruption field (10 kV/m). Examples of current signals obtained for pure water and rain water drops (1.94 mm in radius) are displayed in Figure 3, they feature burst pulses current and exhibit series of sharp impulses. The positive and negative signatures are symmetrical, no time lag has been
detected between both polarities. However, the positive amplitude is slightly higher than the negative one, resulting in a negative charging (few nC) of the drops. The main differences that arise from the comparison between both types of water concern the repetition rate and the amplitude of impulses. For pure water, the repetition rate remains around about 1.7 kHz whatever the drop size is, meanwhile it ranges between 15.5 kHz (1.94 mm) and 3 kHz (2.76 mm) for rain water. The average peak current intensity of the pulses decreases from 40 mA (1.94 mm) to 20 mA (2.76 mm) for pure water, meanwhile it increases from 7 mA (1.94 mm) to 13 mA (2.76 mm) for rain water. Whatever the drop radius is, the charge flowed per pulse is higher with pure water than with rain water. The charge flowed per pulse decreases when drop radius increases for pure water (from 3.8 to 2.2 nC) whereas this charge increases with drop radius for rain water (from 0.16 to 0.99 nC).

DISCUSSION

The interpretation of these results depends on the nature of the signal that is observed. Two different processes could produce these signals: water droplets ejection or corona discharge. As seen in Figure 3, the impulse repetition rates are very different. If these signals were due to water droplets ejection, the marked difference in the electro-mechanical behavior of both types of water should unavoidably result in a marked difference in the disruption field intensity according to Dawson (1969). However, this one appears only slightly influenced by water nature (Figure 2). Furthermore, no water droplets were observed soon after each event on the chromed copper plates, though a specific care was taken to the cleaning of the plates because of possible violent flashing in high stress conditions. In this way, we doubt whether current impulses are due to charged droplets ejection. Maybe the drops were in phase of disruption but the residing time in the high field region would be, on one hand, too short for the drop to reach the onset of droplet ejection, but sufficient on the other hand for the corona emission to be triggered. This emission would be favored by the high enhancement of the local electric field due to the highly distorted shape of the drops.

Considering that we observe corona microdischarges, a possible mechanism implying water conductivity can explain the different behaviors of the two types of waters. We will consider the development of a positive corona since the positive discharge is expected to drive the whole discharge because of electrical circuitry considerations (A. Bondiou-Clergerie, personal communication). If the local field intensity in the vicinity of the drop is sufficient, atmospheric ions (mostly electrons) are accelerated. Electrons multiply by collisions and leave positive ions behind (Figure 4.a). The two growing opposite space charges move away. Between these two regions of charge, a local field opposed to the applied one is created and the resulting field is weaker (Figure 4.b). When the negative space charge is neutralized by the drop, the electric field increases again and a new avalanche develops while the positive space charge continues to propagate towards the cathode (Figure 4.c). When the positive space charge reaches the cathode, a current pulse is detected. A subsequent pulse is detected when a new positive space charge reaches the cathode (Figure 4.e) and the delay between the two impulsions depends on the time lag between the initiation of two successive avalanches. Water conductivity could influence this time lag. Actually, the higher the water conductivity, the faster the negative space charge is neutralized by
the drop and the faster the local field is sufficient to trigger a new avalanche. To sum up, water conductivity could govern a more or less rapid neutralization of the negative space charge and thus, a more or less rapid reactivation of electronic avalanches. This explanation can justify the higher pulses frequency observed with the rain water of higher conductivity. This mechanism can also explain the differences in pulses amplitude observed with the two different water types: ionization due to the electrons ahead of the avalanche, and thus positive ions accumulation, continues until the negative space charge is absorbed by the drop. Then, the positive space charge stops developing.

As neutralization of the negative space charge is more rapid with rain water than with pure water, the positive space charge that reaches the cathode is less important. Thus, pulses amplitude is weaker with rain water than with pure water.

**LARGE SCALE CONSEQUENCES**

With regard to large scale electrical phenomenon (lightning), it seems difficult to assess the possible role of conductivity on account of the large number of parameters that are involved in the cloud discharge process. The link between corona emission from hydrometeors and large scale discharge triggering relies upon streamer process development and its subsequent propagation. If we assume that the streamer onset field is lower with polluted water than with pure water because: 1) present experiment shows that the repetition rate of current signal is so important for rain water that the signal is almost continuous and tends to be like a streamer signal, and 2) this high repetition rate enhances the probability of occurrence of simultaneous impulsive from several interacting hydrometeors leading to a higher current necessary for streamer development (microscale branching process), one can draw several hypotheses about the possible part played by water conductivity in large scale discharge processes. For example, the branching involved in negative leader propagation during CG+ lightning (Mazur, 2002) is a mechanism that could be favored by the multiplicity of streamers triggered from higher conductive hydrometeors.

Recently, several studies focused on the lightning activity over cities (Wescott, 1995; Orville et al., 2001; Soriano and de Pablo, 2002; Steiger et al., 2002). All of them showed an enhancement of the lightning activity over urban areas compared with the neighboring areas. Some explanations were proposed, they rely on the expected enhancement of the convection produced by urban heat island and on the release of cloud condensation nuclei (CCN) by anthropogenic pollution. As a matter of fact, the presence of a large number of CCN would decrease the mean cloud droplet size and thus, the coalescence process efficiency. Subsequently, more supercooled water would exist at higher altitudes, larger graupels would be created, and more collisions with ice crystals could occur. In this way, the cloud electrification would be increased and, thus, lightning activity would be enhanced too (Wescott, 1995; Steiger et al., 2002). As far as water conductivity is considered, one can suppose that it could be added up to these parameters for enhancing lightning activity. However, the enhanced convection has probably a major influence in these cases.

On the contrary, one large scale study of polluted storms has been carried out that cannot be explained by a local enhancement of the convection (Murray et al., 2000). In May 1998, thunderstorms in the U. S. southern plains were polluted by smoke from fires from seasonal biomass burning in Central America. Murray et al. (2000) compared the cloud-to-ground lightning characteristics to that of May 1995-1997 and 1999. May 1998 exhibits a marked increase in the percentage and in the median peak current of positive ground flashes (more than 50% and 20 kA, respectively), and an invariance of CG+ multiplicity in Texas. These observations could probably be explained by means of branching process. According to Mazur (2002), negative leaders of CG+ are much more ramified than positive leaders of CG-, which means that the branching process is more important in negative leaders development. Thus, negative leaders would be more sensitive to cloud microphysics population. As each branch of the leader is an additional current source that feeds the return stroke channel, the higher the branching process is efficient, the higher the return stroke current is intense. Supposing that, according to present hypothesis, branching is facilitated by high water conductivity, peak current of CG+ should be more intense in presence of polluted water. CG-, that are less sensitive to branching efficiency, should be less affected. Concerning the CG multiplicity, we must notice that dart leaders do not follow the whole channel ramifications and thus, they must be less sensitive to water conductivity than the first leader. These conclusions correspond to the observations of Murray et al. (2000).
Present hypothesis on the water conductivity influence seem to fit with the observations. However, we must be careful: pollution properties are numerous and depend on the nature of contaminants and aerosols. Many atmospheric pollutants play the role of CCN and thus, widely modify cloud microphysics. Jayaratne et al. (1983) found that increasing impurities concentration (NaCl, NH₄ salts, …) into water droplets leads to increase the charging in an experiment of non inductive mechanism. Increasing salt concentrations leads also to increasing or decreasing the sign reversal temperature depending on the salt used. According to Avila et al. (1999), cloud droplets spectrum, that could be altered by pollutants, has an impact on graupel charge polarity with temperature. To sum up, as soon as we consider pollution effect, numerous parameters, with numerous influences, are involved and it seems difficult to conclude on the whole lightning activity.

CONCLUSION

The present experiment demonstrates that water conductivity has an indisputable impact on corona emission from raindrops. Thus, we can expect an influence on a large scale in thunderstorms. In order to validate such hypothesis, further laboratory experiments should be performed: the production of higher electric fields on larger distances than that used here would permit to observe streamers and not only burst pulses and, furthermore, the control of the pressure could help us to simulate the altitude dependence of this phenomenon. It could also be interesting to realize the same experiment with ice particles in order to draw conclusions on lightning triggered at high altitudes, where ice is dominant.

REFERENCES