SURFACE PRECIPITATION ELECTRIC CURRENT PRODUCED BY CONVECTIVE RAINS DURING MAP

S., Soula, S. Coquillat, S. Chauzy, J.F. Georgis, and Y. Seity[*]

Laboratoire d'Aérologie, UMR UPS/CNRS 5560, 14 av. Edouard Belin, Toulouse, France
[*]Centre National de Recherche en Météorologie, GMAP, 42, av. G. Coriolis, 31057 Toulouse, France

ABSTRACT: This study deals with the role of the precipitation in the charge transfer between the thundercloud and the ground. Data were collected during the Mesoscale Alpine Program (MAP) Special Observing Period (SOP) in Autumn 1999 in Northern Italy. Ground measurements of electric field, precipitation current density, individual drop charges, and rainfall parameters were locally performed at the site of the Lago Maggiore. Three ground-based Doppler radar allowed to retrieve 3-D precipitation and wind fields. Several days of the period provided substantially charged rainfall of both polarities. A case of deeply convective cell occurring on September 17th 1999 and several shallow convective cells passing over the experimental site on October 3rd are analyzed. In the case of the deeply convective cell, the charge carried by the rain is mainly negative and the current density corresponding is firstly positive, reaches more than 100 nA m^{-2}, and changes its polarity when the rainfall is maximum with a value close to 200 mm h^{-1}. The thundercell producing this rainfall is strongly developed with an echo top at about 12 km. In the second case, eight convective cells passing over the site produce short rain showers, and six of them produce substantial precipitation currents and electric field increases. The six charged cells do not produce any lightning flash. Both charge polarities are also observed on the rain produced by these electrified cells, first the negative one and then the positive one. The analysis of the individual drop charges at the ground shows that most of the time, both polarities are not mixed, even at the reverse of the precipitation current polarity. For all these observations, a very tight correlation between surface electric field and precipitation current is observed, displaying the mirror image effect. The ground electric field could be due to the cloud charge of an opposite polarity to that carried down to the ground by the rainfall.

INTRODUCTION

The first measurements of precipitation current were performed by Simpson (1949), simultaneously with those of potential gradient under disturbed weather conditions. He noted similar trends with opposite polarities for both parameters, what is called the mirror image effect. He interpreted the presence of charge on falling raindrops by the corona ions Wilson capture above ground. These considerations were revisited by Moore and Vonnegut (1977) to interpret the field excursion associated with precipitation (FEAWP) observed below thunderstorm. Generally the approach of the rain charge is responsible for the field reverse.

Both polarities of the precipitation current can occur and the values of its density usually reach some nA m^{-2}, as indicated by Rust and Moore (1974) or Soula and Chauzy (1997). Within or below the cloud this density is generally higher (Marshall and Winn, 1982). The Wilson capture (1929) could be responsible for the differences observed between altitude and ground. However, other interpretations were given to justify the predominance of the positive polarity in the rain charge. So, the positive charge center located in the lower part of the thundercloud could provide the positive charge carried at the surface by the rain (Holden et al., 1980 ; Marshall and Winn, 1982). In this case, several interpretations are proposed for the origin of this positive charge, either due to the non-inductive processes at low altitude where the temperature is larger than –10 °C (Takahashi, 1978) or deposited by the lightning flash at the cloud base (Marshall and Winn, 1982). This mechanism leads to interpret the surface field reverse as the result of the approach of the positively charged rain.

From ground measurements of precipitation current, Soula and Chauzy (1997) presented a budget with a predominance of negative charge transferred to ground. They proposed a new interpretation for the electric field/precipitation current relation in which the rain charge corresponds to that creating the electric field before the shower. So, the field reverse results from the arrival of the rain at the ground and not of its approach. The mirror image effect was then observed after this reverse.

In fall 1999, the special observing period of the Mesoscale Alpine Program (September 7th – November 15th 1999) took place over the Alps area. Several ground-based Doppler radars allowed to characterize the dynamics and the microphysics of the rainy events. This experiment provides an opportunity to study the characteristics of the precipitation current produced by convective rains and its eventual correlation with other characteristics of the cloud. In this study, the electrical data collected during IOP 2A (September 17th 1999) and IOP 5 (October 3rd 1999) are analyzed concurrently with the Doppler-derived wind fields.

MEASUREMENT CONDITIONS

The measuring system used for the study of the precipitation current included four ground-based sensors: an electric field mill, a specific sensor for the precipitation current, an induction ring for the individual charge of the drops, and a disdrometer for the raindrop spectrum and rain rate. The sensors were installed on the flat roof of a building, thus the value of the detected electric field was probably enhanced by the building but we essentially take into account the variation of the electric field in this study. The measurement head of the electric field mill was downward directed. The precipitation current measurement was performed by a new sensor developed at the laboratory, according to the principle proposed by Soula and Chauzy (1997), i.e., a conductor isolated from the ground and shielded with a grid connected to ground. The 0.8-m high sensor contains a 0.6-m high funnel (Soula et al., 2003). A previous study showed an efficiency of 84% for very large and rare drops (5 mm in diameter) and better for smaller drops. The individual charge of the drops were measured through an induction ring with a threshold of detection of 2 pC. The fourth sensor was a disdrometer devoted to the detection of the rain rate and the raindrop size. This apparatus is able to detect and count the number of raindrops of all sizes from 0.2 to 5 mm in diameter with a 0.2-mm class interval. It calculates the rain rate every minute.

CASE STUDIES

Case of September 17th 1999

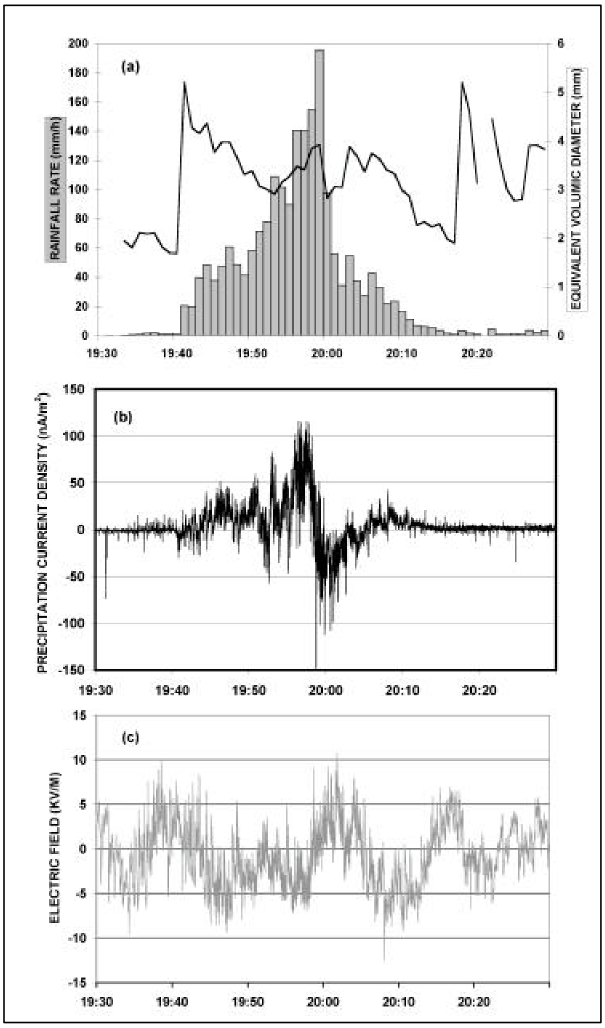

Fig. 1 : Case of September 17th : (a) Evolution of the rain rate in mm/h (histogram) and of the equivalent volumic diameter in mm (black curve) recorded by the disdrometer, (b) Evolution of the precipitation current density in nA/m² (c) Evolution of the electric field in kV/m.

Figure 1 displays the different evolutions of precipitation and electrical parameters. These evolutions last 1 hour and include the signature of a specially strong thunderstorm. As a matter of fact, according to Fig. 1a the rain rate averaged over 1 minute periods reached 195 mm h^{-1} at 1959 UTC after a progressive increase during about 20 minutes. It rapidly decreases after the maximum.

The precipitation current density detected simultaneously to the precipitation rate is displayed in Fig. 1b. Both polarities occur during the evolution, first the positive one between 1940 and 1958 UT and the negative one after the maximum of the precipitation rate between 1958 and 2005 UT. So, the maximum of the rain rate does not correspond to the maximum of precipitation current but rather to its reverse. The density of this current reach very large values, close to 100 nA m^{-2} in positive values. A new reverse is observed after 2005 UTC, while the rain rate is quite low and progressively decrease.

As indicated in Fig. 1c, the electric field is always large during the sequence and its variation is characterized by many discontinuities produced by lightning flashes. The rate of lightning flash is so high that it is difficult to count them from Fig. 1c. Actually, the activity was so strong in the whole area that some small discontinuities can be due to other thundercells. At the beginning of the recording before the rain reached the ground at the site, the electric field was high with values close to 5 kV m^{-1}. This type of evolution is typical of the thunderstorm activity (Standler and Winn, 1979 ; Chauzy and Soula, 1987). Before the rainfall starts the electric field presents both polarities and slowly changes from one to the other. This slow change can be due to the change in the polarity of the dominant charge above. After 1940 UT, the electric field progressively changes from positive to negative, i.e. the associated charge also varies from negative to positive. A new electric field reverse is observed just before 2000 UT when the rain current reverses. So, the mirror image effect between both parameters is mostly observed. The values reached by the electric field are not very high, but the precipitation parameters reach exceptionally high values in terms of rain rate and current density. In fact, the field reached the classical limit between flashes by slow variation (<10 kV m^{-1} in absolute value), even for this very strong thunderstorm. This observation is consistent with those made by other authors about the stabilization of the surface electric field above land (Gunn, 1954; Standler and Winn, 1979 ; Soula and Chauzy, 1991).

Case of October 3rd, 1999

Measurements recorded between 1430 UT and 1650 UT are displayed in Fig. 2. The rain rate (Fig. 2a) clearly displays the showers corresponding to the convective cells passing over the site. Each shower lasts several minutes with a maximum rate from 10 to more than 50 mm h^{-1}.

Figure 2b shows the evolution of the electric field and of the precipitation current density. The current density can be either positive or negative. From Figure 2a-b, we can clearly distinguish 8 showers from the rain rate and 6 substantial current density increases. In most cases, the current density starts to increase in positive values, and then quickly reverses. In term of carried charge, the charge is firstly negative and then positive which clearly indicates the bi-polarity of the rain during a shower. For 2 out of the 6 showers, around 1435 and 1550 UT, the bi-polarity is less pronounced. We can also suppose that the whole electrical signature is not detected at the measuring site because of the cell displacement. We observe two showers without any electric current signature or with a very weak one, between 1531 and 1541 UT and between 1610 and 1620 UT. However the rain rates are relatively high at these moments, with maximum values of 30 mm h^{-1} and 12 mm h^{-1}, respectively. This observation is related to lower values of the vertical velocity in both convective cells (Soula et al., 2003).

In the cases of cells producing a substantial precipitation current with a reverse of its polarity, the maximum of the rain rate frequently corresponds to this reverse. It is the case at 1436, 1449, 1524, and 1644 UT with a rain rate of 11, 42, 25, and 53 mm h^{-1}, respectively. The reverse of the current density is generally rapid. Very low values of the precipitation current with a high rain rate can be explained either by uncharged drops or by a bipolar and balanced drop population. Fig 3 displays the distribution of the individual charge of the raindrops for the same period. It shows that the zero crossing of the current generally corresponds to that of the individual charges of the raindrops too (Coquillat et al., 2001). In most cases of convective cells, both charge polarities of the raindrops reaching the ground are well separated. During the passage of the cell, the negative raindrops first reach the ground and then the positive ones.

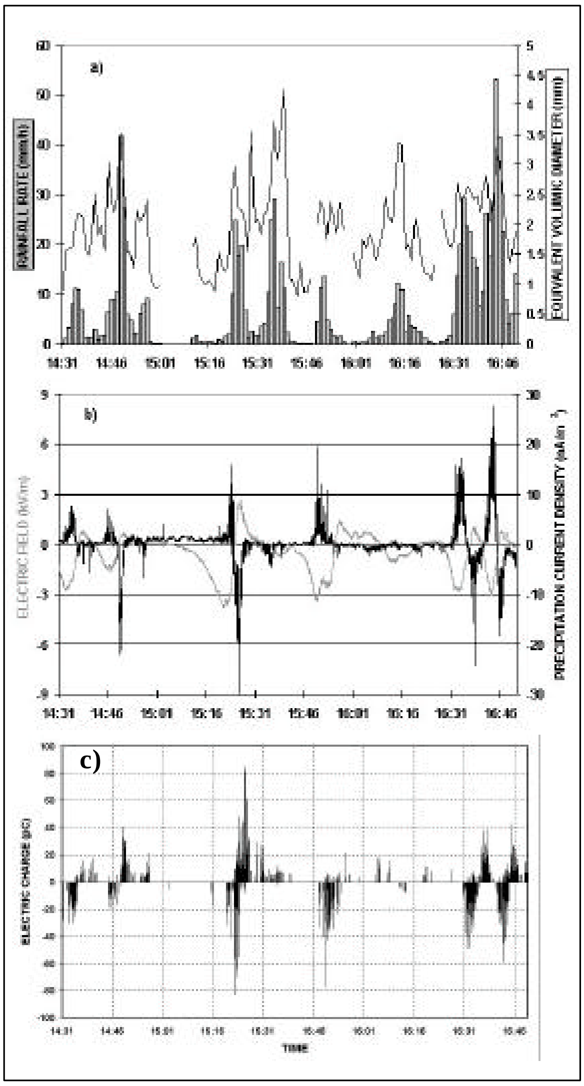

Fig 2 : Case of October 3rd: (a) Evolution of the rain rate in mm/h (histogram) and of the equivalent volumic diameter in mm (black curve) recorded by the disdrometer, (b) Evolution of the electric field in kV/m (grey curve) and of the precipitation current density in nA/m² (black curve), (c) Distribution of the individual charges recorded with an induction ring.

DISCUSSION

The cell of the 17th of September is largely more active than the other cells in term of lightning flash production, as indicated by the field evolution of Fig. 1. However, the electric field values are not much higher than those measured in the cases of October 3rd. We know that the surface electric field measured over land is limited at intensities lower than 10 kV m^{-1} by the point discharge effect (Standler and Winn, 1979 ; Soula and Chauzy, 1991). For this cell, before the rain reaches the site (before 1941 UT), the electric field increases in positive value. After 1941 UT, the precipitation current starts with substantial values and a positive polarity, the electric field reverses towards negative polarity. It corresponds to the classical observations of the polarity of these parameters produced by a thundercloud (Moore and Vonnegut, 1977). When the field reverses between 1940 and 1945 UT, it corresponds to that created by a positive charge above, while the precipitation carried a majority of negative charges. The net reverse of both parameters occurs just before 2000 UT when the rain rate is maximum. On October 3rd, six electrically active thundercells passed over the measurement site and for each one, the electric field evolution is characterized by a reverse during the rainfall. This behavior could correspond to the electric field signature produced by a dipole almost horizontal and traveling above the site. It could also be due to the fall of a vertical dipole, the positive charge zone being topped by the negative one. The problem with this second scheme is that the detected charges carried down by the rain do not correspond to this chronology since the negatively charge rain firstly reaches the surface. The best model to interpret the evolution of the current and of the electric field is to consider charged zones passing over the site, with a polarity opposite to that of the precipitation charge. The mirror image effect is observed after the arrival of the rain at the ground because the surface field is due to the charge remaining in the cloud and not to the charge carried by the rain approaching the ground as proposed by other authors (Moore and Vonnegut, 1977).

CONCLUSION

Precipitation rate and electric current measurements associated with electric field detection have been made during MAP experiment. From the 2-month observation period in Autumn 1999, two events with local electrical activity in term of electric field and precipitation current are considered : A deeply convective thundercell and several weakly convective cells passing over the site. The chronology of the charge carried by the rain is constant since in each convective rainfall, the charge is firstly negative and then positive. The electric field evolution is disturbed by the arrival of the rain at the ground The precipitation electric current often reverses when the rain rate is maximum. The polarities of the electric field and of the precipitation current density are more often opposite, which leads to the well-known mirror image effect.

The electric field and the precipitation current are tightly correlated but the origin of the charge of the raindrops falling down is not definitively established. A new interpretation of this relation is proposed : the charge carried by the rain at the ground is opposite to that which is responsible for the surface electric field. Actually, the electric field at the ground should be the result of a charge loss in the cloud because of the rain. The mirror image effect observed cannot be explained by the Wilson capture because the time delay theoretically necessary is not respected.

REFERENCES

Chauzy, S. and S. Soula, 1987. General interpretation of surface electric field variations between lightning flashes, J. Geophys. Res., 92(D5), 5676-5684.

Coquillat, S., O. Pace, S. Chauzy, and S. Soula, 2001, Microphysical characteristics of surface precipitation produced by convective systems during the MAP experiment, *Proceedings of the 5th International Workshop on Physics of Lightning*, Nagoya, Japan, September 10-13, 19-20..

Gunn, R., 1954, Electric field regeneration in thunderstorms, J. Met., 11, pp 130-138.

Holden, D. N., C. R. Holmes, C. B. Moore, W. P. Winn, J. W. Cobb, J. E. Griswold, and D. M. Lytle, 1980, Local charge concentrations in thunderclouds, in Sixth International Conference on Atmospheric Electricity, University of Manchester, Manchester, England.

Marshall, T. C., and W. P. Winn, 1982, Measurements of charged precipitation in a New Mexico Thunderstorm: Lower positive charge centers, J. Geophys. Res., 87, C9, 7141-7157.

Moore, C.B., and B. Vonnegut, 1977, The thundercloud, in Lightning, Vol. 1: Physics of Lightning, edited by R.H. Golde, Academic Press, San Diego, CA, 51-98.

Rust, W. D. and C. B. Moore, 1974, Electrical conditions near the bases of thunderclouds over New Mexico, Q. J. Meteor. Soc., 100, pp. 450-468.

Simpson, Sir G., 1949, Atmospheric electricity during disturbed weather, Geophys. Mem., N° 84, Lond.

Soula, S. and S. Chauzy, 1991. Multilevel measurement of the electric field underneath a thundercloud: 2. Dynamical evolution of a ground space charge layer, J. Geophys. Res.,96(D12), 22,327-22,336.

Soula, S, and S. Chauzy, 1997, Charge transfer by precipitation between thundercloud and ground, *J. Geophys. Res., 102*, 11061-11069.

Soula S., S. Chauzy, M. Chong, S. Coquillat, J.F. Georgis, Y. Seity, and P. Tabary, 2003, Surface precipitation electric current produced by convective rains during MAP, J. Geophys. Res., in Press.

Standler, R. B. and W. P. Winn, 1979: Effects of coronae on electric fields beneath thunderstorms. Quart. J. Roy. Met. Soc., 105, N° 443, 285-302.

Takahashi, T., 1978, Riming electrification as a charge generation mechanism in thunderstorms, J. Atmos. Sci., 35, 1536-1548.