THE COMPLEX DISCHARGE LIGHTNING EVENTS OBSERVED SIMULTANOUSLY BY THE SAFIR, RADAR, FIELD MILL AND MAXWELL CURRENT ANTENNA DURING THUNDERSTORMS NEAR WARSAW

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ABSTRACT: The complex discharge lightning events (CDLE) that occurred during several spring and summer thunderstorms in 2002 over the area surrounding Warsaw, have been examined. For this purpose the following facilities were used: the SAFIR network system installed recently in Poland, the simultaneous and independent electric field and Maxwell current measurements, and the routine thundercloud observations carried out by the meteorological radar. For some cases of the CDLE's, radar observations included vertical cross-sections of the corresponding cloud for the azimuths of lightning discharge patterns as well radar echo tops maps for appropriate 10 min time intervals. It was found that the majority of the CDLE's were composed of such sets of discharges as: intracloud (ic) and cloud-to-ground (c-g), or c-g and ic, or ic and c-g and second ic. The common distinct feature of all these discharges was a very short-time separation between them, usually it lasted less than 1 s, while their horizontal separation in space may be as large as 10 km. The observed CDLE's occurred mainly during dissipation stage of given thundercells and were not very frequent. The ratio of their number to that of all discharges recorded by the Maxwell current antenna has ranged from 0.05 to 0.21, depending on thunderstorm type. The special and rare class of the complex c-g lightning discharges recognized by the SAFIR detections presented the so-called bipolar flashes. They occurred during considered summer thunderstorms and were found to be 1% or 8% of all c-g lightning locations. All of them were multiple stroke flashes, having at least one positive and one negative return stroke. Their multiplicity has ranged from two to four strokes. Their other characteristic parameters obtained by the SAFIR network system are also presented and discussed.

INTRODUCTION

A possible existence of the cause-effect relation chain between an ic discharge and a next c-g discharge occurring in near space neighborhood is still an open question, especially, when these two discharges are separated in the time interval less than 1 s. Some suggestions how this phenomenon may be explained was given by *Moore and Vonnegut*[1977]. In some cases, during decaying stage of thunderstorm, the penetration of ic channels to different part of thundercloud can lead to redistribution of electric charge patterns by introducing negative and positive charge to regions of the cloud with charge of the opposite sign. These changes in charge and electric field configuration can be sources of the following CDLE's.

On the other hand, it was [*Williams*, 1989] reasonable to assume that also lower positive charge center (LPCC), creating by different mechanisms in extended negative charge layer in lower part of a thundercloud, is a triggering factor of majority of the observed CDLE's. The LPCC may be equally accounted for development of a positive return stroke in multiple ground flashes, being part of bipolar discharges, which have been energetically possible in multipole thunderstorm charge structures as well [*Marshall and Stolzenburg*, 2002].

The phenomena of complex and bipolar lightning discharges, although are intrinsic for better understanding of development of lightning processes and of the charge distribution during thundercloud evolution, still are not much known. To the efforts being in this direction undertaken in last time by more advanced, especially, interferometric techniques, the additional phenomenological data about occurrence of such phenomena are required [*Rhodes et al*., 1994]. The paper deals with a number of examples of such events observed in the range presently for us available. The phenomena of both complex and bipolar lightning discharges are yet not much known and demand further observations in different regional conditions.

DATA ACQUISITION SETUP

The measuring site with field mill and Maxwell current antenna is described in detail by *Baranski* [1996]. The electric field, E, and Maxwell current, I_M, recordings have been carried out simultaneously, but separately, in regard to the places of the routine radar and the SAFIR network operations. All data have been analyzed in the post time regime by superimposing the SAFIR lightning localizations on the appropriate radio echo maps of the meteorological radar. Moreover, the chosen SAFIR lightning detections in the area of our observations have been thoughtfully validated by independent and simultaneous electric field and Maxwell current changes, giving reference lightning discharge indications in the time domain. Such a validation procedure is strongly desired, because the SAFIR network system during its first year of operation has not achieved the assumed lightning detections efficiency of about 95% and in some cases it has even had trouble with correct determination of flash polarity [*Baranski et al*., 2002].

Our selected area for observations of thunderstorms near Warsaw during spring and summer in 2002, with the measuring devices used, is shown in Fig. 1.

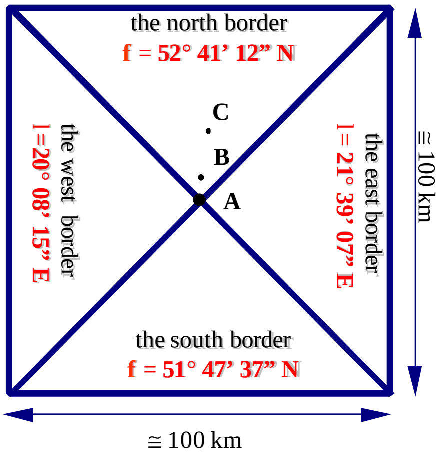

Figure 1. The selected area of thunderstorm observations together with the measuring site locations

A – the measuring site at the Institute of Geophysics P.A.Sci. with the electric field mill and flat plate antenna collecting the Maxwell current

B – the SAFIR detection station in Warsaw at the Institute of Meteorology and Water Management, site of the CPU of the SAFIR system (9 detection stations)

C – the meteorological radar in Legionowo

AC ≅ 30 km AB ≅ 10 km

RESULTS AND DISCUSSION

The results presented in this paper were collected during different thunderstorm days in spring and summer of 2002. They differed in lightning discharges electrical activity, but in all of them the occurrence of the CDLE’s was meaningfully great. Table 1 summarizes the gathered CDLE observations that have been done independently by three sensors.

Table 1. Lightning discharge identifications and electrical activity of six studied thunderstorms (index “b” denotes bipolar flash, “RS” is return stroke)

Thunderstorm		Sensor										
		SAFIR			Field mill (c-g & ic)				Maxwell current antenna (c-g & ic)			
Date	Time interval (UTC)	$(c\text{-}g)_-$	$(c\text{-}g)_+$	$(complex)_\pm$	$-\Delta E$	ΔE	complex -	complex +	$-\Delta I_M$	ΔI_M	complex -	complex +
13.05.2002 (with precipitation at IGF site)	12:18 ÷ 15:10	252 (327 RS)	2 (2 RS)	7	200	436	45	55	257	653	112	135
15.05.2002 (with rain & hail at IGF site)	10:31 ÷ 13:25	50 (69 RS)	1 (1 RS)	1	18	104	9	7	36	305	21	15
28.05.2002 (with little rain at IGF site)	10:22 ÷ 11:55	117 (218 RS)	1 (1 RS)	8	9	132	7	17	39	209	18	37
11.07.2002 (without precipitation at IGF site)	11:36 ÷ 12:40	70 (112 RS)	$[1]_b$	1	40	63	6	-	60	111	15	1
06.08.2002 (without precipitation at IGF site)	12:20 ÷ 13:58	87 (150 RS)	2 (2 RS) $[7]_b$	21	82	87	5	2	336	332	14	24

Numbers of the detected Maxwell current changes associated with c-g or ic discharges, or CDLE’s (±complex) are much greater than those obtained by field mill, because in the recorded jump of I_M , the ΔI_M, the most dominant component, i. e., the displacement current, is proportional to ($\partial E/\partial t$) and even a very small jump of electric field, the ΔE, is easily recognized by simultaneous ΔI_M. The examples of the electric field and Maxwell current simultaneous recordings with 1 s time resolution which show the several detected CDLE’s changes, are presented in Fig.2.

The SAFIR network c-g detections with their multiplicity factor, indicated between two arrows in Fig. 2, illustrate the detection efficiency of that system. Those SAFIR flash identifications can be quantitatively compared with the true electrical discharges activity, totally monitored by two others sensors, in the same time period (see Tab. 1). For all the observed thunderstorms, the ratio of the SAFIR c-g detections to the total number of all lightning discharges recorded by field mill ranged from 0.4 to 0.7 and from 0.14 to 0.4, if we have only taken into account the Maxwell current recordings.

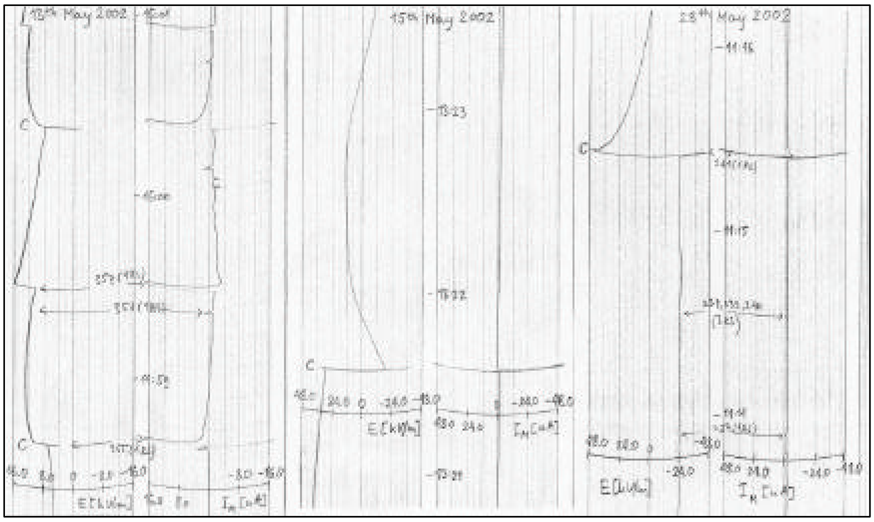

Figure 2. Examples of the electric field and Maxwell current recordings carried out from (IGF) measuring site in Warsaw and containing several CDLE's changes (denoted by C) during three spring thunderstorms in different stage of their development. Note that the electric field and current sign convention used means that the electric field and current are taken as positive, if there are positive charges aloft and if they move downwards to the Earth surface. It is opposite to the sign convention used in the SAFIR lightning data specifications.

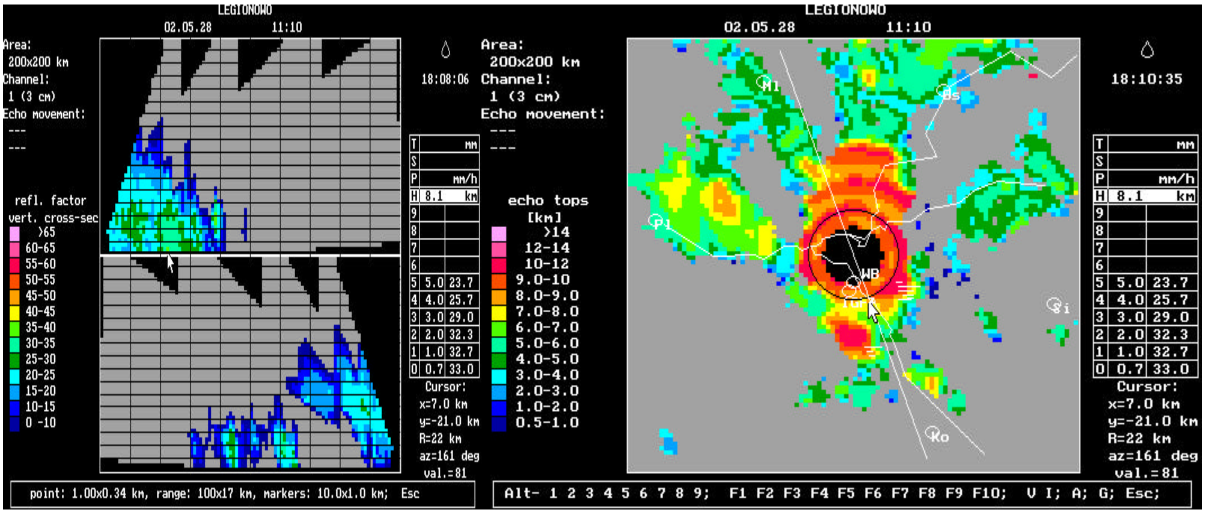

Figure 3. The radar echo maps connected with the example of the CDLE occurred during thunderstorm on 28 May, 2002 at 11:15:27 UTC with positive c-g component (41.6 kA, one return stroke), whose the SAFIR location is indicated by the arrow. The left panel is the vertical cross-section map for the azimuth angle 161°; the right panel is the respective echo tops map. The open circle, labeled IGF, gives the position of our measuring site in Warsaw and the other one, labeled WB, shows the position of the SAFIR sensor in Warsaw.

Remarkable and valuable information about the thundercloud region involved in generation of the CDLE's, preliminary recognized by field mill and Maxwell current antenna, has been obtained by superimposing its SAFIR localization on the appropriate in time, radio echo radar maps (see Fig. 3). In the majority of examined cases, the c-g component of the CDLE was connected to the volume of precipitation shafts in different stages of their development, while the ic components of the CDLE occur rather in the parts of thundercloud with small values of the reflectivity and more distant from these main precipitation cores. This may suggest that the driving factor responsible for initiation of such ic discharge is sooner related to rapid changes in the electric field patterns of the charge redistribution caused by the first lightning discharge opening the CDLE, than to random dynamical changes in air motions accompanying thunderstorm downdrafts. This statement is supported by the very short time interval separation (less than 1 s) between individual lightning discharges taking part in a such event.

The bipolar flashes, i. e., the flashes which are composed of return strokes with different polarity, are the second unusual group of the c-g lightning discharges that we have been able to distinguish due to the SAFIR network detections during two summer thunderstorms. Their some data characteristics are summarized in Tab. 2. All of them were multiple strokes, having the averaged striking distance equal to (4.4±2.7) km and the averaged time interval between successive strokes equal to (46.8±74.4) ms. Unfortunately, because of the radar system change in our country in that time, we have not got at our disposal any radar pictures which should show an appropriate precipitation shaft of the thundercloud region involved in generation of those bipolar c-g discharges.

Table 2. Characteristics of bipolar flashes obtained from the SAFIR network detection system during the thunderstorm observations

Date	Time	(μs)	Latitude	Longitude	E_{max} (V/m)	I_{max} (kA)	Rise Time (μs)	Decay Time (μs)	Multiplicity
11/07/2002	12:11:52	641600.0	52,349	20,6083	0.7	9.0	7.8	20	1
11/07/2002	12:11:52	901200.0	52,3559	20,6036	-1.2	-16.1	5.3	19	2
06/08/2002	12:27:34	792200.0	51,8232	20,6651	-8.2	-114.2	8.1	72	1
06/08/2002	12:27:34	832700.0	51,8314	20,6749	1.3	23.6	14.5	28	2
06/08/2002	12:27:34	863900.0	51,8452	20,6168	-1.0	-14.1	3.5	28	3
06/08/2002	12:27:34	879800.0	51,8485	20,6022	-0.9	-12.8	5.9	22	4
06/08/2002	12:29:33	051500.0	51,8252	20,6358	1.2	16.3	3.9	30	1
06/08/2002	12:29:33	065700.0	51,8203	20,6437	-2.0	-28.2	5.6	38	2
06/08/2002	12:30:52	919700.0	51,8198	20,6593	-2.2	-30.6	8.4	51	1
06/08/2002	12:30:53	068500.0	51,8322	20,7369	0.5	7.0	8.4	33	2
06/08/2002	13:07:06	938800.0	51,8446	20,328	1.0	12.4	4.6	23	1
06/08/2002	13:07:06	945200.0	51,8356	20,3096	-1.9	-23.1	4.4	54	2
06/08/2002	13:13:56	798900.0	51,8408	20,4141	-4.6	-76.2	11.5	62	1
06/08/2002	13:13:56	811500.0	51,8519	20,3897	0.9	13.3	13.1	39	2
06/08/2002	13:13:56	814700.0	51,8892	20,3974	0.4	7.0	14.3	55	3
06/08/2002	13:13:56	839400.0	51,8694	20,4522	-0.7	-9.9	8.1	22	4
06/08/2002	13:21:52	707800.0	51,8345	20,3831	-0.5	-7.2	10.0	21	1
06/08/2002	13:21:52	718200.0	51,8366	20,386	0.4	5.8	8.4	23	2
06/08/2002	13:21:52	722600.0	51,8481	20,3764	-1.2	-16.4	5.9	49	3
06/08/2002	13:52:20	891800.0	52,0002	20,1517	-9.3	-124.6	12.8	68	1
06/08/2002	13:52:20	928000.0	52,0023	20,1842	0.7	3.4	11.9	22	2

The repetition of bipolar flashes initiations in the observed summer thunderstorms may strongly suggest that a few LPCC's associated with main negative charge layer ought to appear in such thunderclouds [*Baranski*, 1999]. The occurrence of small positively charged pockets at the bottom part of thundercloud and the high electric fields created by them near the main negative charged layer extended above, can be a sufficient condition to initiate positive streamers of the following positive component of a multiple bipolar flash. It is still not well known how persistent are that LPCC structures in thunderclouds and what kind of cloud particles and dynamical forces are responsible for that phenomenon.

The further 3D instrumental SAFIR detections of such c-g flashes together with the radar pictures of the analyzed thundercloud, are strongly needed to be used. Studies of the VHF radiation by means of interferometric facilities bring much information about lightning development processes involved in the occurrence of complex and bipolar discharges. New type of hybrid breakdown events was revealed [*Rhodes et al*., 1994]. The data about occurrence of special lightning events gathered in many places in various conditions, even without use of the extended facilities, are able to give some important information about properties of these kinds of discharges as well about the corresponding thundercloud electric charge distributions.

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