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SEVERE WINTER THUNDERSTORM IN POLAND, CASE STUDY

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1. INTRODUCTION

Since the SAFIR/PERUN lightning detection system has been installed in Poland, we were able to observe two severe thunderstorms events during winter season. One of them took place in January 2007 and the next almost exactly one year later in January 2008. In subsequent years the difference between them was only 5 days. Moreover, these two events were started in very similar day time, i. e., late afternoon 16-17 UTC, and finished about one hour later, after the midnight. Such events are rare phenomena in this geographical region. They are also interesting as being an example of specific type of lightning flashes that are initiating by the inclined winter cumulonimbus (Cb) thundercloud. Consideration of some existing differences and similarities between them can help us to prepare new classification of this severe meteorological phenomenon and can also point out some characteristic features of the time development of lightning flash clusters that are connected to this and other alike events.
Our investigation was done by using lightning data (the SAFIR-3000 based detection system with its 2D location method), radar data (Doppler radar with Meteor technology), and background meteorological data as wind, temperature, pressure field patterns and satellite data. In our study we have mainly used cloud-to-ground (CG) lightning detections, because that part of intracloud (IC) discharge detections, indicated by the SAFIR records in its VHF channel, were very incoherent for two considered cases.

2. DESCRIPTION OF SYNOPTIC SITUATION

For both cases air masses pattern was quite similar. In 2007 marine cold polar air masses were driven by advection with strong low vortex which was placed over northern Europe and was moving from Scotland through Northern Sea and heading east to Baltic Countries. This system caused pushing cool air from north over warm continent. As soon as moist, cool air reached shore line convection was started due to relatively high temperature of ground (up to 11 ˚C at 2 m above ground level). After front passage temperature has fallen down to 2 ˚C. On the other hand, very strong system of high pressure was placed over Spain and was covering with its ridges all Mediterranean Sea up to Balkans. Difference in pressure between low and high was about 70-60 hPa. While deep low was approaching Poland its density of isobars was rising, and thus strong wind occurred in the area between low and high. The cold air mass heading SEE (110 azimuth) has effected creation of very strong cold front parallel to the shore. The front line was supplied continuously by cool and moist air advected from north. In this case thunderstorms were inducted in spatial extent starting in Holland, through Germany and ending in Poland and Czech Republic. The spatial range of the thunderstorm system was 200 km in width and about 600 km in length. The time of its life was about 8,5 hours, taking into account the occurrence of the first and last CG flash event detected by the PERUN network.

In 2008 strong high system was standing over France and covering half of Europe from western England and Spain to the west of Black See and Greece. Whereas a low system had formed over Sweden and Baltic Countries and then moved eastwards to Belarus and northern Ukraine. Cool air advected from northern Scandinavia was moving parallel to isobars, that means, in SE direction and over Poland. When it has reached the shore strong convection was started giving the same situation as for the case from 2007 and creating cumulonimbus (Cb) thunderclouds. Big difference in pressure (about 70 hPa) between low and high system caused strong winds feeding storms with fresh and moist air. For this case air masses were advected on warmer ground with surface temperature was up to 10 ˚C. But, after front passage minimal temperature was only 1 ˚C. For this case there was one thunderstorm system developing inland and starting 300 km away from coastline, and elongated for 600 km and having about 100 km in width. Thunderstorm time life was almost 7 h long.

From above superficial comparison basing only on analysis of some background meteorological parameters we can see that two presented events have shown very similar characteristics. Additionally presentation of scrutiny of more sophisticated meteorological data, as e. g. the soundings which was presenting atmosphere stratification and radar reflectivity vertical cross sections showing that there was some differences in cloud top height, is here omitted. Nevertheless, for the case of 2008 satellite images analysis showed that cloud's tops had temperature from 210 to 230 K in thunderstorm region. For this case cloud tops have reached 6 km, what is similar to the model of Japan winter thunderstorms given by (Rakov, Uman 2003).
In both considered cases in Poland wind speed at 850 hPa level was exceeding 35 m/s and was agree with velocity of the advection of particular thundercloud cells that was computed from radar reflectivity data. Obtained flash count rates for these winter storms were very low in comparison to summer ones. There were only 33 flashes/hour for 2007 event, and 12 flashes/hour for 2008 event. Above flash counts were only determined for Poland region and with the spatial domain resolution available from the PERUN system.

2. INSTRUMENTATION AND DATA ACQUISITION

All meteorological archive data such as field pattern of temperature, pressure, humidity, geopotential, wind, soundings, was taken from web sites:
http://wetterzentrale.de,
http://profi.wetteronline.de,
Archive meteorological data (taken from GFS model) are not showed in that paper. Satellite images was taken from NOAA server. Lightning data were obtained from the PERUN system data base (database of the Institute of Meteorology and Water Management). The PERUN system is based on the SAFIR 3000 technology. It uses 2 types of antenna which are working in two bands of radio frequency (LF is recorded by plate antenna and VHF by 5 dipole antennas array). The used LF range is from 300 Hz to 3 MHz and VHF one is between 110 – 118 MHz. System detects electrical component of e-m pulses emitted by lightning discharge. There are 9 sensors sites placed in Poland with base line about 200km. The accuracy of location of return stroke from CG flashes is about 1km and with 40% efficiency. Radar data are taken also from the IMWM database. Doppler radars are working on 5650 – 5660 MHz frequency.

3. RESULTS AND DISCUSSION

During time life of a thunderstorm we can distinguish three storm stages: developing, mature, and dissipating (Rakov and Uman, 2003). This kind of classification can be done regarding to the changes of relevant meteorological parameters, as e.g. : temperature, wind speed, cloud top level. Such characteristic scheme (develop, mature stage, dissipation) was also observed for stronger storm case in 2007 during its lightning activity development. However, for the case of 2008 thunderstorm, in its mature stage, we observe evidently less lightning activity than at the beginning and end of that event (see Fig. 1). But both thunderstorms have character of winter events, i. e. the relatively high peak of lightning current (Moore and Orville, 1990).

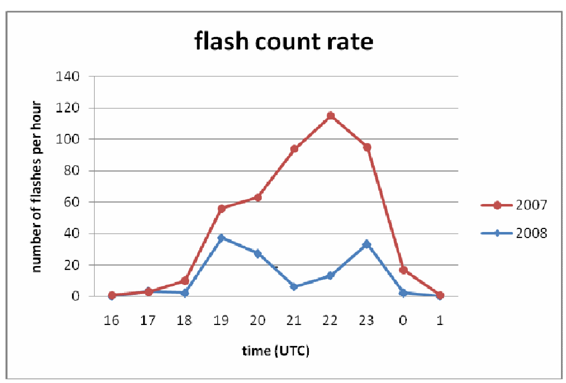

Figure 1. Flash count rate for 2007 and 2008 severe thunderstorms events.

Nevertheless, as we can see in Fig. 2 and 3 that two analised storm cases are significantly different regarding to their lightning activity characteristic. On the other hand, if we examine the ratio of CG(-) to CG(+) flash counts during these winter storms then we can revelal that such ratio is very similar to that one observed during summer storms.

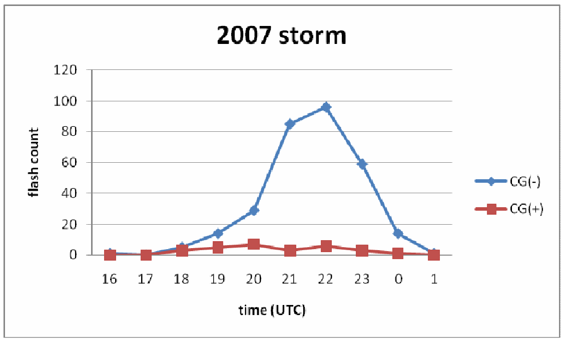

Figure 2. CG(+) and CG(-) falsh count time evolution for 2007event

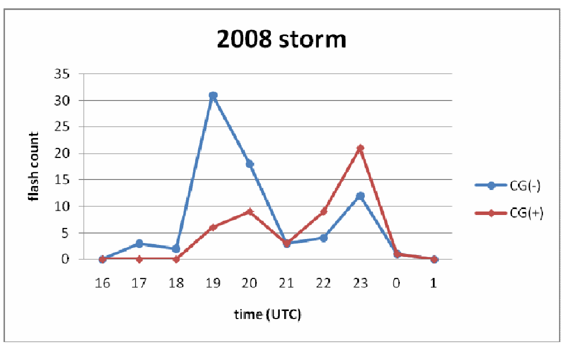

Figure 3. CG(+) and CG(-) flash count time evolution for 2008 event

Next, if we look on histograms presented in Fig. 4, we can also see clearly two different types of lightning current characteristics recorded during compared winter thunderstorms.

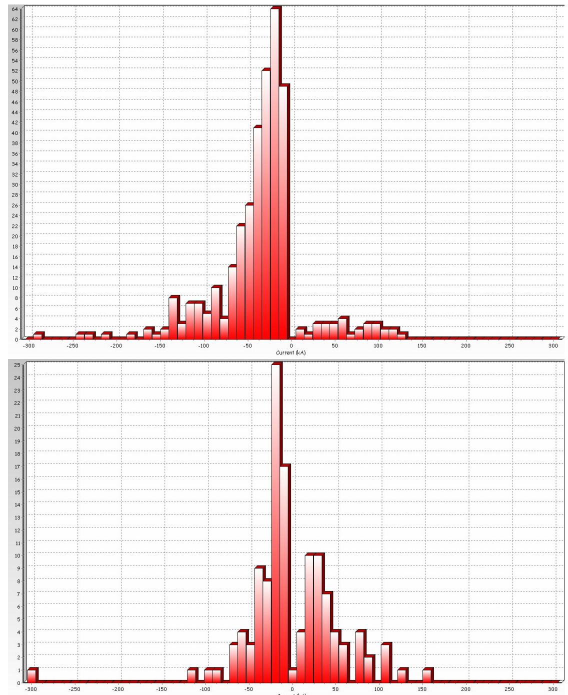

Figure 4. Histograms of lightning current for 2007 case (upper) and 2008 case (lower). Vertical axis is event number and is ranging from 0 to 64 (upper histogram) and from 0 to 25 (lower). Horizontal axis range is from -300 kA to 300 kA.

The same behavior we can see in Tab. 1which is containing some statistics on lightning data connected to that storms. However, these two cases especially differ in number of detected CG(+) events. Possible explanation of this fact is given in the next part of this paper. Lightning data from 2007 are rather resembled by their characteristic features some types of summer thunderstorms observed in this geographical region.

It worth to note that for both cases of winter storms extreemly high lightning currents were observed. In 2007 maximum value for negative lightning current was -289 kA (at 01:30 UTC, 19.01.2007) and for positive 128 kA (at 00:00 UTC, 19.01.2007). Respectively, for 2008 event: negative current max.=-300 kA (at 19:00 UTC, 26.01.2008) and positive current max.= 150 kA (also at 19:00 UTC, 26.01.2008).

TABLE 1. Lightning data characteristics for two winter storm events; IC - cloud discharges; CG+ – cloud-to-ground positive, CG- – cloud-to-ground negative; CG – cloud-to-ground in total; % CG+ – percent of CG+ in total lightning; % CG – percent of total cloud-to-ground in total lightning. In 'factor' column values from 2007's column are divided by values taken from 2008's column

Storm:	2007	2008	factor 2007/2008
Total lightning	3609	498	7,24
IC	3322	375	8,8
CG+	28	49	0,57
CG-	304	74	4,18
CG	332	123	2,7
% CG+	8,4	40	0,21
% CG	9,1	24,7	0,36
Duration	16:50-01:11 UTC 8h20min (500min)	17:30-00:13 UTC 6h40min (400min)	1,25

Radar images presented in Fig. 5 and 6 show that structure of convective cells is visually very similar, although their front lines are organized in different directions. Such organization of fronts may be determined by pressure field. However, the spatial parameters and reflectivity radar image characteristics tend to be the same for both considered cases. Maximum reflectivity was greater in 2007 event and exceed 50 dBZ value. In 2008 maximum reflectivity was noted about 50 dBZ level.

Supplementary in Fig. 6 is shown the situation from 2007 with lightning flash locations overlaid on the relevant radar product. Such technique allows us to define that region of storm which is collocated with lightning discharge detections and correlated with high radar reflectivity levels. Moreover, this kind of analysis has revealed that there were no lightning discharge detections in the region of the highest radar reflectivity, that means in the precipitation core of the considered thundercloud.

4. RADAR AND LIGHINING DATA ANALYSIS

The vertical cross section of thundercloud was performed in several chosen parts of the considered storm and was crossing the front part of thundercloud with the greatest value of the radar reflectivity. Such radar data were used for generation of the vertical cross section profile. But, applying this method it was hard to state if thundercloud top is indeed inclined according to direction of the observed advection. Actually, there was only a weak hint of such behavior, but it was not strong evidence of its real existence. Even when cross section was compared with meteorological soundings it was hard to evidently define relevant thundercloud structure. For better analysis of this kind of thundercloud feature is necessary to use some 3D tools for easy operating with radar reflectivity data.

Lightning detection data given by Figs. 7a and 7b illustrate the spatial and temporal range of that data connected with the considered cases of winter storms. Color denotes the time intervals when lightning discharges were detected. Stars on the map indicate particular location of detection stations.

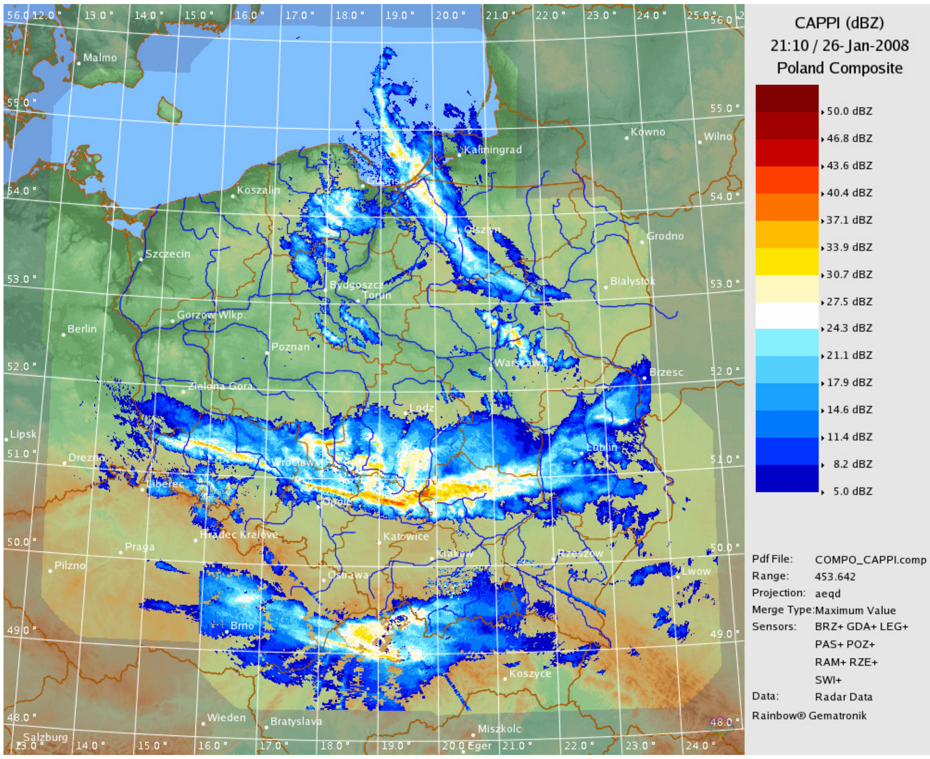

Figure 5. Thunderstorm system from 2008 in mature stage. TheCAPPI composite product from IMWM radars.

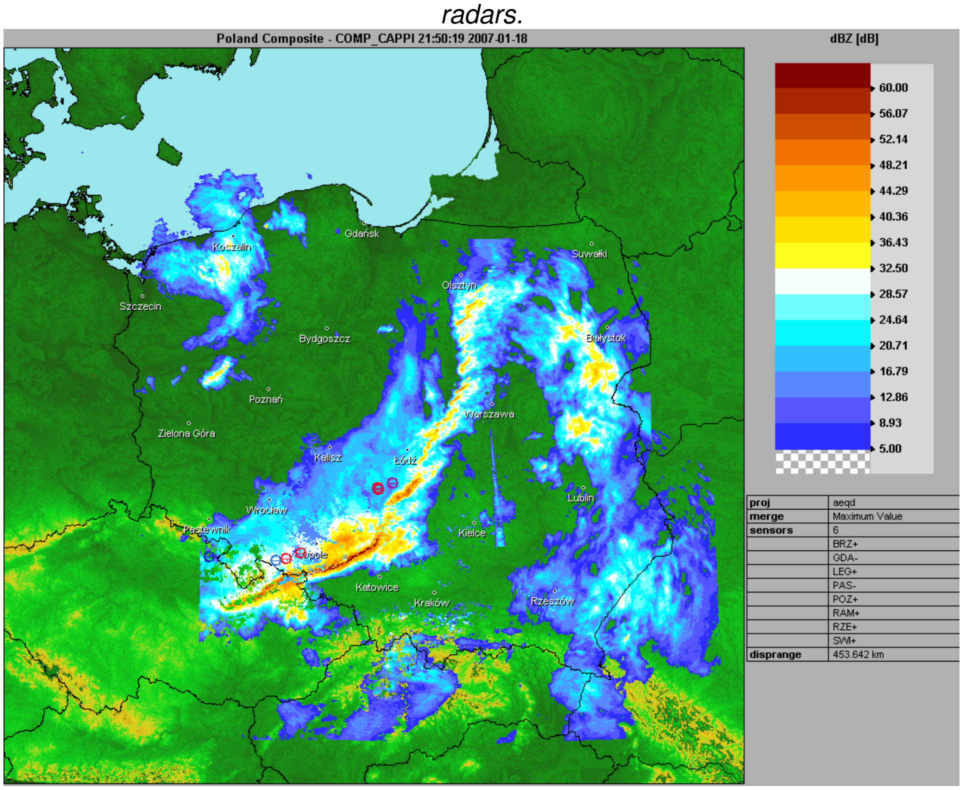

Figure 6. Thunderstorm system from 2007 in mature stage additionally with lightning flash events overlaying on the CAPPI composite product of radar reflectivity image

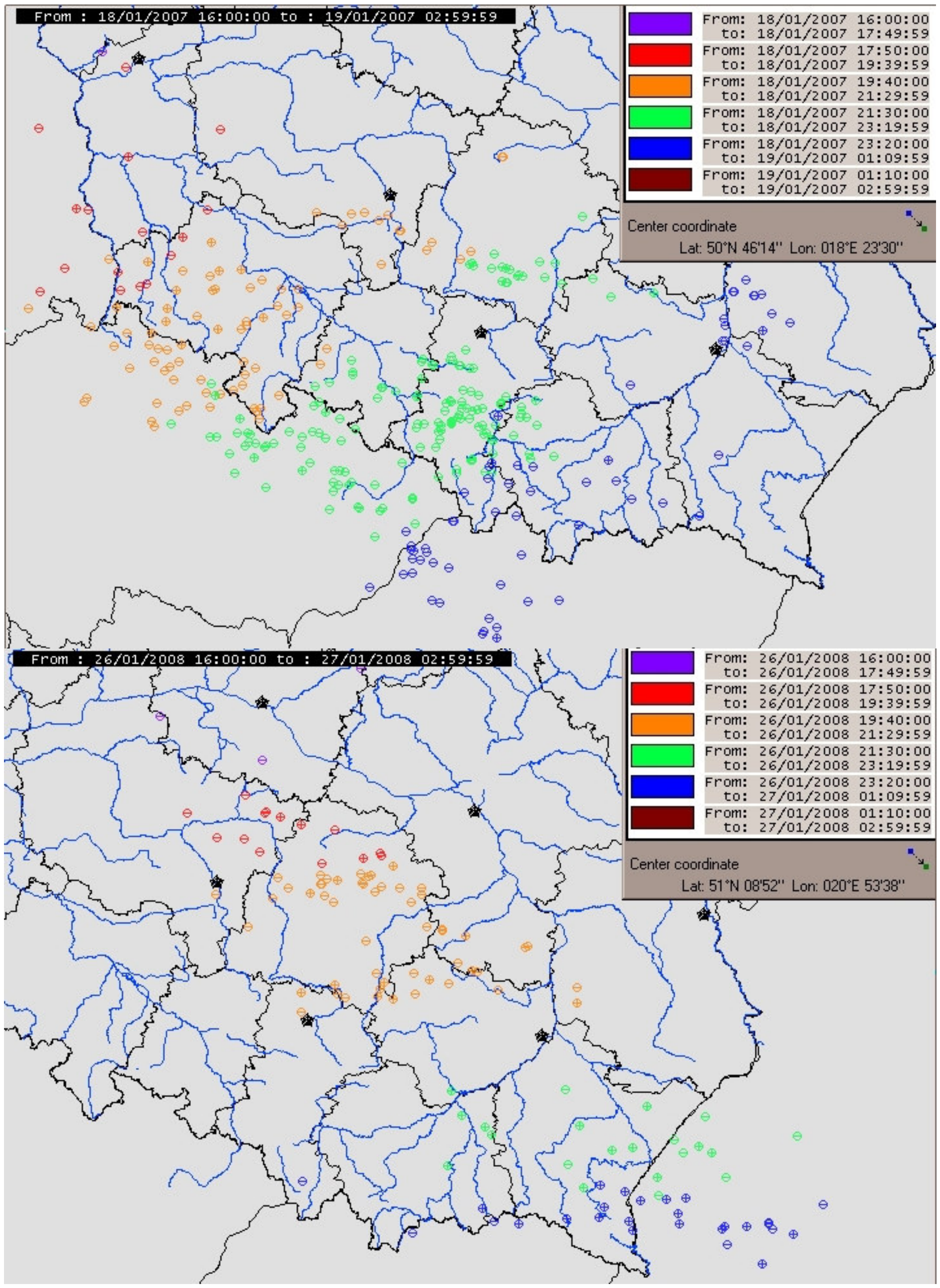

Figure 7. The CG lightning detection data during 2007 (upper) and 2008 (lower)winter thunderstorm

5. FAINAL REMARKS

From above analysis we can see that severe winter thunderstorms are complex systems and even with similar meteorological situation they can vary depending on small differences in initial conditions. Two cases are quite similar, but after deeper insight into their phenomenology we can see some crucial differences.

One of reason of such differences is higher temperature contrast between colliding air masses for 2007 event. It caused stronger convection which resulted in higher cloud vertical development. The second reason is that when stronger wind was blowing, there was bigger change in the pressure field over Poland region. Stronger wind helped also in convection because was bringing new masses of the moist and cool air. Advected air was transforming in unstable air mass and so continuous lightning activity was maintained. A possible explanation of 2008's high positive to negative CG flashes ratio can be caused by spatial layout. Lower than for 2007 case cloud tops level connected with strong wind shear could result in bending of precipitation core of thundercloud. In such situation there is bigger probability that instead of initiation of new intracloud discharge some of electric charges, inside thundercloud and trying to be neutralized, are separated once more by convective processes and are able to create there higher cloud-to-ground activity. An argument that may be confirming such explanation is IC/CG ratio for two considered cases.

For case from 2007 when cloud tops were higher, greater amount of IC events were recorded. It is in accordance with assumption that there is a positive correlation between cloud top and IC/CG factor. A hypothesis which could explain the change of ratio positive to negative flashes during storm development may be supported by some electric charge rearrange mechanism inside the cloud, when at the first time some negative charge is being neutralized by CG- flashes, as its layer is closer to ground. Then upper layer of positive and top charge is beginning to be more active and is involved in generation of following CG+ flashes. Such argumentation is in accordance with lightning activity scheme shown in Fig. 3. However, for better and deeper insight to this problem more detailed analysis should to be done, e.g. deeper examination of slow and fast electric field changes caused by CG- and CG+ flashes, occurrence of bipolar flash events, their multiplicity and other important lightning parameters.

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