Preliminary Analysis of Dynamic Evolution and Lightning Activity Associated with Supercell Event: Case Story of the Severe Storm with Tornado and Two Heavy Hail Gushes in Poland on 20 July 2007

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Abstract

A violent explosion of deep convection struck many countries in Europe on 20 July 2007. In that day, severe thunderstorms were accompanied by floods and harmful winds, and even by one 8-minute incident of tornado in Poland. In this paper we have presented the detail analysis of supercell dynamic development connected with tornado incident and the time and space behavior of its lightning activity detected by the SAFIR/PERUN network system. For this purpose, we have used reflectivity data from four Doppler radars, i.e., in Ramża, Pastewnik, Brzuchania and Legionowo, to obtain as realistic as possible history of the 3-dimensional dynamic evolution of convective complex which started to develop over south Poland. We were able to distinguish 5 stages of such a convective evolution, i.e., for the time interval 00–04 UT – the nocturnal dissipation of previous convective structures; between 04 and 10 UT – the further development and dissipation of few new convective cells; between 10 and 14 UT – the development of one large convective cluster and a new convective single cell – a precursor of the next aggregation and supercell; between 14 and 16 UT – the further growth/enlargement of the supercell; and finally between 16 and 18 UT – the mature stage of supercell with tornado near Częstochowa associated with a growth of a new convective complex developing over the Tatra mountains and Slovakia. To perform relevant interpretation of the composite radar pictures we prepared, we used two computer simulations with different grid resolutions; the first one concerned the region over Europe, with 14 km grid step and divided into 35 levels, and the other one, nested over Poland (the COSMOLM model, see Steppeler et al. 2003), with grid step squeezed up to 2.8 km and vertical resolu-
tion of 50 levels. Moreover, we have taken into account two additional important sources of data: the cloud coverage from satellite observations and the accompanying lightning activity from the SAFIR/PERUN detection system. The numerical forecast model applied predicted many characteristic singularities of the observed real weather situation and gave us also a possibility to get a much deeper insight into some fine mechanisms which could be considered as steering for the studied case, e.g., the occurrence of right- and left-mover wind patterns during convective development of the tornado system. We have also included to our analysis the examination of the observed lightning rate changes of particular convective complexes before and after the supercell aggregation. On the other hand, locations of positive and negative return strokes of cloud-to-ground flashes (RS$_+$ and RS$_-$), and intra cloud discharges (IC) given by the SAFIR/PERUN system in the supercell area revealed their specific clustering co-located with precipitation/hail shafts and previous widespread IC lightning activity followed by grouped CG, flash strokes.

**Key words:** supercell storm, tornado, hail gush, lightning activity, lightning detection.

1. **Introduction**

On July 20, 2007, about 16:05 UTC, the Rędziny, Klomnice i Mostów regions of the Częstochowa district were struck by tornado, which destroyed dwelling houses, farm buildings, transmission lines and poles, falling down tens of hectares of forest, and displacing automobiles (Bebłot et al. 2007). The Katowice branch of the Institute of Meteorology and Water Management made an inspection of the site, aerial photographs, interviewed the eyewitnesses (a videotape is available), and estimated the losses. Strong hailstorms were observed an hour before, during, and after the tornado. According to the eyewitness reports, the hailstones were initially of pea size, then large and irregular ice pieces, some 5 cm or more in diameter. The ground was covered by a thick ice layer reaching to the knees. During the tornado and right afterwards, horizontally moving hailstones of a tennis-ball size were observed. The tornado trail length was about 14 km, and the width of the destruction track was up to 500 m. The mean speed of displacement was some 45 km/h. On the basis of the type of damage, the tornado was classified as between F1 and F2 in Fujita-Pearson scale (Fujita 1981), or T4 in the 11-step TORRO scale. The wind speed in the vortex could reach 60 m/s (Bebłot et al. 2007).

2. **Measuring equipment and main sources of data**

Our database prepared for examination of the considered supercell incident in Poland is based on four Doppler radar observations carried out routinely within 10 minute interval for 250 km range. These radars of METEOR 500C type and GEMATRONIK production are placed at Ramża, Pastewnik, Brzuchania and Legionowo site and are a part of the national Polish radar net named POLRAD. More information about the POLRAD net organization is available on the web site: www.pogodynka.pl.
On the other hand, all data about IC and CG lightning flashes activity detected over Poland territory and connected with the analyzed supercell and tornado occurrence were obtained from the Polish SAFIR/PERUN lightning location and detection network system. This network consists of nine VHF/LF detection stations of the type SAFIR 3000 (Vaisala 2003, Chap. 2 pp. 7-87) covering the whole Poland country and giving the lightning flash location accuracy below 1 km for 90% of that area. Additional technical data and information about basic principles of its operational and discrimination rules can be found in some manual reference books supplied by the present producer of that system (e.g., SAFIR 2001: Chap. 3, pp. 9-11, Chap. 5, pp. 16-20 and SAFIR 2003: Chap. 2, pp. 18-45).

The changes in cloud coverage over Europe in the visible light range during the analyzed severe weather condition period were taken from the satellite observations done by the EUMETSAT which were received and processed by the IMWM Department in Cracow.

3. Synoptic background

Going back to July 12, 2007, in the 300 hPa temperature field over the Atlantic the drop of cold Arctic air started moving from Greenland towards the British Isles, eventually modifying the formation of the Atlantic branch of the polar jet stream. Figure 1 presents the 300 hPa temperature field at 00 UTC on July 20, 2007, i.e., after 8 days of the cold air movement over North Atlantic. In Fig. 2 we see the isotachs which indicate the location of the polar jet stream. These two objects determined the synoptic situation which led to the explosion of convection over Europe on this day, including the tornado over Poland. The Atlantic branch of the jet stream extended northeasterly and was pumping the hot and moist tropical air masses over Europe, as shown in the 850 hPa temperature field (see Fig. 3).

In Fig. 4 we present the 315 K isentrope (potential temperature surface) with a characteristic swelling over England which represents the above-mentioned cold drop, and a jet stream embedded into it. The isobars at the 8 km level make it possible to evaluate their mutual vertical configuration. After 16 hours, the jet stream over Europe was torn away by an abrupt explosion of convection (Fig. 5), still retaining its two weakening branches: the one directed towards the British Isles and the other directed easterly, over Germany and Poland.

The synoptic situation was difficult to analyze because of the fact that the dominant driving process for the abrupt convection over Europe was an inflow in the upper troposphere of a cold arctic air over a warm and humid tropical air; such a mechanism has been well recognized in meteorology (Browning 1985). Differences in the msl synoptic analysis made by English, German, Dutch, and Polish services point to a difficulty in working out a concept how to analyze the development of upper fronts.

While the large-scale traits of synoptic process, expressed through the pressure field, horizontal wind, and even the humidity, were satisfactorily reproduced by the model, the cloud water of the convective clouds was underestimated; see Fig 6 and compare it with the satellite photo (Fig. 7).
Fig. 1. July 20, 2007, 00 UTC, temperature at the 300 hPa level.

Fig. 2. July 20, 2007, 00 UTC, jet at the 300 hPa level.

Fig. 3. July 20, 00 UTC, temperature at the 850 hPa level.

Fig. 4. The 315 K isentrope with the jet stream.

Fig. 5. 16 UTC: Jet at 30 m/s surface and wind speed on 10.2 km level. Pressure on 1.5 km altitude and radar reflectivity over southern Poland. Vertical cross-section of potential temperature, where squeezing temperature isopleths represent passage to the stratosphere.
Fig. 6. Cloud water from the model for 16 UTC and radar reflectivity against the background of jet stream.

Fig. 7. Infrared satellite photo at 16 UTC which displays the supercell in the Częstochowa region and the convective complexes over the Tatra mountains and Slovakia.
On the three-dimensional image in Fig. 6, at 16 UTC, we see a jet stream (in blue) disrupted by convection and the cloud cover (cloud water): (a) the image (light green) generated in 4-hour forecast (tumbled structures not much elevated above the orography surface), (b) the real cloudiness reconstructed from the radar reflectivity; the bright two objects are the convective complexes, the one in the region around Częstochowa and the other around the Tatra mountains. The convective complex around Częstochowa was identified as a thunderstorm supercell (Browning and Ludlam 1962), underneath which the tornado had formed. The object is 30 km wide and 18 km high.

4. **History of the convective system development over south Poland: synthesis and stages**

An analysis of the whole material makes it possible to distinguish the following main synoptic processes that led to the formation of tornado: (a) the inflow of cold and dry arctic air mass in the upper troposphere over warm and humid tropical air prevailing underneath, (b) cyclone-genesis in the shade of mountains (the so-called lee cyclonesis) north of the Moravian Gate, (c) extremely high maximum temperature values, reaching 40°C, (d) local vorticity transport, with distinct positive (cyclonal, anticlockwise) and negative (anticyclonal, clockwise) directions. The following periods of the convective situation development were distinguished:

(A) Nocturnal disintegration of the preceding convective complex; 00-04 UTC,
(B) Development and disintegration of individual convective cells; 04-10 UTC,
(C) Formation of a convective cluster, i.e., a slowly moving clockwise convective object of the right-mover type, and an initiating cell for a further supercell formation, i.e., a very strongly moving and abruptly upwelling huge cumulonimbus cloud with a supposed anticlockwise rotation of the left-mover type; 10-14 UTC,
(D) Formation of a supercell from the merging of slowly-moving clockwise convective complex with a huge cumulonimbus cloud abruptly upwelling, being embedded in the positive vorticity region; 14-16 UTC,

(E) Mature supercell stage, with a tornado in the Częstochowa region (16:05 – 16:15 UTC) and a convective complex originated over the Tatra mountains and Slovakia; 16-18 UTC.

The variability of convective situation is illustrated by the satellite photographs in visible light.

The lee cyclone-genesis effect (equivalent to the increase of vorticity in the lower layer), as shown in Figs. 14A and 14B, and the effect of surface temperature growth...
5. Comparing computer simulations on different grid nets and examples of 3D analyses at a dense grid

5.1 Comparing computer simulations on different grid nets (downscaling): PL14/35 vs. PL2.8/50 for 16:00 UTC

The following computer simulations by COSMO-Lm model have been performed: (a) for domain over Europe: grid 14 km/35 levels, simulation range 00-18 h; grid 07 km/35 levels, range 12-18 h; grid 07 km/50 levels, range 12-18 h; (b) for domain over ...
Poland: grid 2.8km/50 levels, range 12-18 h. The initial and boundary data has been provided on the operational routine basis according to mutual agreement between DWD and IMGW. The detail comparison between all the simulations would be time consuming and deserves separate work; here we investigate the most distinguished runs and limit the area of search to Poland: PL14/35, PL2.8/50 and concentrating on 16 UTC, the term close to tornadogenesis. By their nature, tornados (especially the weak ones) „omit” the standard surface observation network. For this case, out of the neighboring Częstochowa SYNOP reports, only in Częstochowa SYNOP (only 5 km from the place and 5 min past the term the tornado has gone) we found some significant wind turn and wind gust between 15 and 17 UTC. According to code DD FF FF_911: (060, 04, -1000) => (330, 10, 19) => (320, 8, 17), with pressure practically the same. The most credible testimony of the tornado event remains eye-witnessing and analysis in situ (Bebłot et al. 2007). The tornado impact is seen also on radars reflectivity (in dBZ) and radial wind from Doppler radars (however, within the distance limited to 100 km), and on infrared and visible satellite pictures. Having knowledge on the tornado event we may look for signs of confirmation in the products of computer simulation. The following meteorological elements were chosen as sensitive to the case: msl pressure, vertical motions, cloud water, wind direction and velocity over the surface with its maximal velocity for 6 h, temperature at 2 m, tops of convective clouds, vorticity. Not always, the higher resolution forecast PL2.8/50 was better enlightening the event. And so:

(a) For the msl pressure, PL2.8/50 better than PL14/35 reflects the lee cyclone-genesis in the East Sudetes mountain range,

(b) For vertical motions, simulations with PL2.8/50 generated chaotic pattern and difficulties with interpretation comparing to PL14/35,

(c) The cloud water content is strongly correlated with the heights of cloud tops (i.e., atmospheric instability). Both model versions faulty forecasted cloud water. PL14/35 creates a fictive band of cloudiness over Wielkopolska Lowland, PL2.8/50 dried this band and creates singular clouds cells south of Poland border, which is possibly better,

(d) For the direction and wind velocity 2 m over the surface, both simulations give in general the same flow pattern. However, PL2.8/50 provides far more details and occasionally strengthens the wind velocity,

(e) For the maximal wind velocity over 6 hours we found significant enforcing and particularisation by PL2.8/50: it shows the zone of the very strong winds on the tornado domain. Despite the fact that the zone of strong winds is moved north, it must be unequivocally associated with supercell. PL2.8/50 is significantly better than PL14/35 (see Figs. 16A and 16B),

(f) For the temperature 2 m near the surface, the general view of the field is preserved by both model versions; PL2.8/50 gives some new values of T-2 m > 36 deg near the tornado track,

(g) vorticity (hcurl according to the program GrADS) is calculated as a mean value in the lower atmosphere, and the streamlines of direct and relative wind are taken for this particular mean level. Vorticity (hcurl) and the streamlines of direct and relative wind are presented in Fig. 17A and 17B.
Fig. 16A. VMAX according to PL14/35, where VMAX denotes maximal wind.

Fig. 16B. VMAX according to PL2.8/50 velocity over 6 hours.

Fig. 17A. Vorticity curl and streamlines: PL14/35.

Fig. 17B. Vorticity curl and streamlines: PL2.8/50.

The PL2.8/50 view is significant particularisation, but rising ambiguity (loss of transparency). In general, the relative motion pattern remains preserved. Despite the track near the tornado, we got new rotational nuclei. Thus, PL14/35 stands for clarity, especially distinctly separates area of positive and negative vorticity (see Fig. 17A).

Concerning 3D analysis we concentrate on PL2.8/50 simulations trying to interpret compound 3D composites in favour of the model ability to reproduce, as expected, “real” tornado. Many synoptic futures were correctly reproduced by the model and helped to understand the mechanisms of the case and deduce even such subtle processes like right and left moving wind patterns of tornado convective system. Nevertheless, the QC (cloud water) convective structures as simulated by the model remain underestimated. One of the reasons of the fault is that the proper radar assimilation scheme was not adopted, but the second suspicion is that the ageostrophic flow just under the jet stream was not adequately represented.
5.2  *Clockwise movement of a supercell – the right-mover type*

![3D structure of a right-mover type supercell](image)

**Fig. 18.** The 3D structure of a right-mover type supercell reconstructed from radar reflectivity, with the current lines in relative movement obtained by subtraction of the selected horizontal velocity vector profile over the tornado site from the horizontal wind profile in the whole domain. The selected fixed wind profile represents the supercell movement as one compact object; once the wind field is subtracted, there remains the relative air movement in the cell itself, and the reduction of horizontal velocity makes the effect of vertical velocity more pronounced. The array of horizontal current lines depends on the altitude. The vertical extent: 15 km.

5.3  *Vertical cross-section of the supercell: wind jump and the vortex pipe*

![Vertical cross-section](image)

**Fig. 19.** The vertical cross-section of the supercell with wind field streamlines in the velocity field. A characteristic wind jump in the lower troposphere, with a trace of vortex pipe in the velocity field above the jump is seen. The radar reflectivity in the background. The vertical extent: 15 km.
5.4 Vertical cross-section of the supercell: wind field in the relative motion

Fig. 20. The vertical cross-section in the rear part of the supercell, with wind field streamlines in the relative motion: the effect of the vertical velocity is enlarged. The vertical extent: 15 km.

5.5 Vertical cross-section of the supercell: exaggerated relative motion

Fig. 21. Vertical cross-section of a supercell with the wind field streamlines in the relative motion. The view from the south. The vertical extent: 5 km. The wind vector profile is on the axis of supposed mesocyclone. Characteristic “chimney” alignment of the upgoing and down-going currents next to each other is a certain approximation of how the real movement field is organized.
6. An analysis of thunderstorm lightning activity during the supercell and tornado formation process

From our collected database of the considered tornado formation, we have presented in Figs. 23 and 24 the overlapping of reflectivity radar maps obtained from the Legi-nowo radar and lightning discharge locations, both for cloud-to-ground and intracloud ones, that were detected by the SAFIR/PERUN system at the moment just before the merging of the convective complex with the abruptly rising cumulonimbus cloud, which

Fig. 23. The Leginowo radar reflectivity map, at 14:40 UTC, in dBz, indicated by colored scale and lighting strokes locations denoted by small grey squares during the time interval 14:40–50 UTC.

Fig. 24. The Leginowo radar reflectivity map, at 15:20 UTC, in dBz, indicated by colored scale and lighting strokes locations denoted by small grey squares during the time interval 15:20–30 UTC.
was fast moving northward from the Moravian Gate region. Two instants of time were selected for the presentation, i.e., 14:40 and 15:20 UTC, to indicate the appearance of a possible interaction mechanism between the particular thunderstorm lightning activity pattern and dynamic convection evolution directed toward a supercell formation. However, this problem should be explained in greater detail, with an attempt of determining the electric space charge structure of merging active thunderstorm cells. Thus, further field investigations are needed to be performed, e.g., by using in situ balloon electric field soundings of aggregating thunderclouds and at least 3D lightning locations mapper giving more information about the height distribution of cloud/electric space charge region involved in initiation of IC and CG lightning strokes.

6.1 The course of lightning activity recorded during the development of supercell convective complex

6.1.1 Changes of lightning rate

Taking into account the particular stages of dynamic evolution of the considered supercell convective complex and using the space domain that was especially chosen for this purpose, we also examined the time variation of frequency of different types of lightning discharges detected by the SAFIR/PERUN network system, i.e., positive and negative return strokes (RS− and RS+), cloud-to-ground flashes (CG), intra cloud discharges (IC), and other, not fully recognized discharges, and named isolated points (IP), in order to obtain and display some characteristic features of special kind pattern of lightning activity accompanying the studied severe weather phenomena. Namely, we have found (see Fig. 25) that the first peak of lightning frequency histogram, with a total of 1422 lightning strokes per 10 minute interval and for 4 stroke types detected by the SAFIR/PERUN system, preceded by 25 minutes the onset of first heavy hail gush, by 1 hour and 10 minutes the moment of visible tornado onset, and by 1 and half hour the second episode with heavy hail gush. On the other hand, the next, much more distinct peak of such lightning frequency, with a total of 5065 lightning strokes per 10 minute interval, followed by 65 minutes the onset of first heavy hail gush and by 20 minutes the moment of visible tornado and overlapped with the onset of the second episode with heavy hail gush. Thus, it seems reasonable to expect that such information about the rapid and great changes of lightning rate, operationally supplied by the SAFIR/PERUN detection network system, could be used as a significant predictor for nowcasting and preparing warnings of approaching dangerous storm hazards.

Some details of peculiar changes of lightning activity connected with the biggest increase of lightning rate that occurred between 15:50 and 16:10 (see Fig. 27) are given more distinctly by Table 1. Thus, we can see that the tornado incident was preceded by meaningful jump of IP and IC counts per 10 minute interval, whereas counts of RS− were decreased slightly, with nearly the same small number of RS+. In result we obtained increasing and a great value of ratio IC/RS−+RS+, which was finally about 6 times greater than that one observed during ordinary thunderstorms in Poland (Barański et al., 2002).

Many lightning characteristics gathered during supercell event observations reviewed and reported recently by Tessendorf (2009) have indicated that the IC/CG ratio
Fig. 25. Histogram of lightning frequency for different types of discharges detected by the SAFIR/PERUN network system in the chosen area containing two separated convective cells (see Fig. 26A) and the considered supercell complex after cell aggregation (see Fig. 26B), i.e., positive and negative return strokes of cloud-to-ground flashes (RS+, and RS−), intracloud discharges (IC), and not fully recognized discharges named isolated points (IP). Additionally the time changes of radar echo top of those cells and supercell are overlapped with the same time interval.

Fig. 26A. Brzuchania radar echo top map at the 14:20 UTC showing two separated convective cells A (bigger but lower) and B (smaller but higher).

Fig. 26B. Brzuchania radar echo top map moment 15:20 UTC showing the supercell complex just after connection of A and B cells.

tends to increase with increasing storm severity and its electrical activity. Thus, it could also be used as an indicator of enhanced severe weather potential. Moreover, Goodman et al. (1999), basing on his experience with severe and tornadic storms in
Central Florida (USA), has noticed that sudden increases in the lightning rate, which he referred to as lightning “jumps”, have preceded the occurrence of severe weather phenomena by 10 or more minutes. These jumps were typically 30–60 flashes/min², and were easily identified as anomalously large derivatives in the flash rate. For our case of supercell event (see Fig. 25), the maximum value of total lightning rate was of the order 10 strokes/min² and occurred about 5 minutes before the tornado visible appearance.

![Graph](image)

Fig. 27. Number of RS⁺ (yellow curve) and RS⁻ (violet curve) strokes per 10 minute interval compared with radar echo top of the considered two aggregating convective cells (A and B) and the resulting supercell complex.

<table>
<thead>
<tr>
<th>Time [UTC]</th>
<th>IP</th>
<th>IC</th>
<th>RS⁻</th>
<th>RS⁺</th>
<th>IC/RS⁻+RS⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:50</td>
<td>2625</td>
<td>2559</td>
<td>375</td>
<td>11</td>
<td>6.63</td>
</tr>
<tr>
<td>16:00</td>
<td>2987</td>
<td>2902</td>
<td>348</td>
<td>13</td>
<td>8.04</td>
</tr>
<tr>
<td>16:10</td>
<td>3014</td>
<td>2919</td>
<td>326</td>
<td>12</td>
<td>8.64</td>
</tr>
</tbody>
</table>
6.1.2 Clustering of CG lightning discharges during the observed supercell event

To show how clustering of CG flashes detected by the SAFIR/PERUN system in time of supercell evolution was progressing, we have distinguished, basing on Fig. 25, five characteristic time episodes of its development as follows:

- at 14:50, i.e., the first peak of lightning frequency rate with a total of 1422 lightning strokes detected per 10 min interval and before the supercell onset with two separated convective complexes,
- at 15:20, i.e., the beginning of the first hail event connected with the local minimum of lightning frequency rate and with a total of about 1100 lightning strokes detected per 10 min interval,
- at 16:00, i.e., the beginning of tornado incident with its visible appearance and with a total of about 4200 lightning strokes detected per 10 min interval,
- at 16:10, i.e., the end of tornado incident with a total of about 4600 lightning strokes detected per 10 min interval,
- at 16:20, i.e., the second hail event with the maximum value of lightning frequency rate reaching a total of 5065 lightning strokes detected per 10 min interval.

All the stages mentioned above are depicted in Figs. 28–32, respectively. On the other hand, the existence of a mature stage of the supercell formation is indicated by finding of the so-called bounded weak echo region (BWER), first described by Chisholm and Renick (1972), and is shown in Fig. 33. According to Browning hypothesis (Browning and Ludlam 1960) the BWER is a result of very rapid air rising by very strong updrafts so that insufficient time is available for the formation of precipitation particles, which may be detected by radar scan.

Time evolution of the considered supercell formation together with time and space changes of the accompanying CG activity shown by the sequence of five episodes in Figs. 28–32 have revealed that the majority of CG flashes detected by the SAFIR/PERUN system was negative and they were located very close to the main precipitation shafts indicated by simultaneous radar scans. Hence, these observations may point out that, likewise for a typical thundercloud, also for our case of supercell event the precipitation phenomena are a driving factor for the initiation of the CG lightning strokes and their amount. However, it is worth to note that in the case of supercell it has covered not only one, but several large regions with high-altitude intense precipitation/hail shafts. It was also an amazing and unexpected observation result that this supercell precipitation shaft connected with tornado event has generated only one single and strong CG stroke. The possible reason of such weak lightning activity behavior in tornado area may be a fast removal of small lower positive charge centers (LPCC’s) from that part of supercell by an appearing tornado wind field pattern.

Taking into account simultaneous time changes of lightning rate for different types of lightning flash activity and radar echo top parameter recorded during supercell storm event in Poland (see Fig. 25 and Fig. 27) we can note that the local minimum value of supercell echo top has coincided with the maximum value of total lightning rate, while the maximum value of lightning rate for RS strokes has preceded the maximum value of supercell echo top by 20 minutes (see scale zoom given in Fig. 27).
Fig. 28. Brzuchania radar data and lightning detections before the supercell onset; description of radar reflectivity and altitude of radar echo scale is given in Fig. 31. Space collocations between particular CG clusters and radar reflectivity/precipitation cores are indicated by arrows.

Fig. 29. Brzuchania radar data and lightning detections at the beginning of first hail event; description of radar reflectivity and altitude of radar echo scale is given in Fig. 31. Space collocations between particular CG clusters and radar reflectivity/precipitation cores are indicated by arrows.
Fig. 30. Brzuchania radar data and lightning detections after tornado incident; description of radar reflectivity and altitude of radar echo scale is given in Fig. 31. Space collocations between particular CG clusters and radar reflectivity/precipitation cores are indicated by arrows.

Fig. 31. Brzuchania radar data with overlapping lightning CG detections during 10 minute interval covering the tornado incident; single negative CG lightning flash detected by the SAFIR/PERUN system that was located very close to the tornado trace (shown as a black bar) is indicated as small black open circle; its estimated return stroke lightning current was equal to −47.1 kA.
Fig. 32. Brzuchania radar data and lightning detections at the beginning of the second hail event; description of radar reflectivity and altitude of radar echo scale is given in Fig. 31. Space collocations between particular CG clusters and radar reflectivity/precipitation cores are indicated by arrows.

Fig. 33. The example of PPI and V CUT radar scans taken from Brzuchania site which displaying the supercell region with hook echo; black bar on the left side picture denotes the direction of performed V C U T which is presented on the right panel.
The first time relationship may be caused by the occurrence in that time of some downdrafts which were increasing the supercell IC strokes activity during the second hail episode. On the other hand, the second time relation can agree with a scenario presented by Rust *et al.* (1981) and showing typical location of to-ground channels for different polarity of CG flashes relative to supercell storm dynamic structure driven by strong updraft associated with mesocyclone wind field pattern and when total CG flash activity is not dominated by RS, strokes. Also MacGorman and Nielsen (1991) reported the case when RS flash rates were larger than RS, ones throughout a storm that produced a strong tornado and was classified as a supercell for an hour.

6.1.3 **Lightning current distribution of CG flashes during the observed supercell event**

Discrimination of CG flashes that are allowed and processed by algorithm procedures of the SAFIR/PERUN system implemented in the Polish network enables us to obtain their estimated lightning current distribution as such shown in Fig. 34 and with discarding all return strokes having lightning current less than 3 kA. Hence, we can note that during the whole life time of the considered supercell, its CG flashes activity was dominated by weak negative return strokes having the bin peak lightning current of −10 kA for 6200 strokes. On the other hand, positive return strokes were considerably less numerous than negative ones, and had the bin peak lightning current of 10 kA for 400 strokes.

Fig. 34. Histogram of the estimated peak value of positive and negative return strokes of CG flashes detected by SAFIR/PERUN system during supercell event in Poland on 20 July 2007.
7. Conclusions and summarizing remarks

The development of convective situation over south Poland on July 20, 2007, was conditioned in the synoptic scale by a degradation of the Polar Front and dissipation of the combined polar and tropical jet streams, with a characteristic inflow of cold polar mass (an active upper cold front) over warm and humid tropical air masses. A process of this type generates the so-called conditional potential instability and releases a strong convection. The macro synoptic situation favorable for the development of a strong convection over south Poland was realized through the lee cyclogenesis in the shade of the Moravian Gate (hence an increase of vorticity in the lower layer) and a strong increase of temperature enhancing the instability and accumulation of the available potential energy (CAPE), which initiated the convection. The convective system was analyzed and stages of development and mature were determined. The time moment was defined in which the huge right convective complex collided with a gigantic cumulonimbus cloud with positive vorticity spin. Once the two cells merge, a supercell is formed with right-moving (most probably dominant at the moment, but with tendency to vanish) macro circulations and the inner mesocyclone rotating to the left. The mesocyclone can be noticed in the mature development phase of the supercell development on the visible light satellite photo. The relatively weak tornado thus formed was short-lived, and the supercell circulation, already deprived of the characteristic near-ground whirl, was entirely left moving. The behavior of thunderstorm activity was analyzed and characteristic traits of the discharges accompanying the tornado onset were determined, with a supposed eventful influence of thunderstorm electricity on the fusion of thunderstorm cells making up the supercell and tornado.

The increasing number of huge disasters over the world caused by severe weather phenomena, such as tropic storms and tornados, which are sometimes connected with violent floods has focused the efforts of atmospheric research community on more scrutinized post-time examination of such incidents taking into account a possible mutual interaction mechanism between their dynamic development and associated lightning activity. And so, for example, the last issue of Atmospheric Research journal published in July 2009 (No. 1-3) is almost completely devoted to presentation of recent reports and considerations on that subject. Here, the most important thing is to answer the basic question to what extent the observed lightning activity accompanying severe hail/supercell or MCS (Mesoscale Convective System) complexes may be used as a good proxy of their dynamic development. As for now, we do not see any straight way which will be directed to achieve full and wide understanding of that hot problem. Nevertheless, further experimental and theoretical studies are strongly needed to get deeper knowledge about the relationship between lightning behavior and evolution of severe weather conditions that would help us to enhance the warning decision tree and improve short term forecasting of approaching dangerous storm hazards. Moreover, such studies are also crucial for gaining the greatest benefit from the modern advanced lightning detection and location technologies, i.e., 3D lightning mapping ground-based networks which should be more widespread and satellites which should have the capability to measuring total lightning flash rates and bringing that data online. Due to such research action more information on lightning discharges in severe supercell thunderstorms will be collected and analyzed.
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