CHARACTERISTICS OF TOWER LIGHTNING FLASHES IN A WINTER THUNDERSTORM AND RELATED METEOROLOGICAL OBSERVATIONS

Gerhard Diendorfer [1], Rudolf Kaltenböck[2], Martin Mair[3], Hannes Pichler[3]
[1] Austrian Electrotechnical Association (OVE), Vienna, Austria
[2] Austrocontrol Aviation Weather Service, Vienna Airport, Austria
[3] University of Technology, Vienna, Austria

1. INTRODUCTION

In the past a considerable number of papers on winter lightning in the costal area of the Sea of Japan has been published. But very limited information is available about winter lightning characteristics in other regions. Every year a few winter thunderstorms occur over the area of Austria. In this paper we present the analysis of one specific winter thunderstorm with special regard to meteorological aspects and lightning activity. The investigation is limited to the area of Salzburg where several flashes have been recorded at the instrumented tower on Gaisberg, which is located very nearby.

2. LIGHTNING DATA

During the night Feb. 12th/13th, 2005 a total of 20 flashes were recorded at the Gaisberg tower.

During that night in the area around the tower site (20 km distance range) only very little lightning activity was observed by the ALDIS lightning location system as shown in Figure 1.

Figure 1: Overall lightning stroke activity in the Salzburg area during the night 12th/13th February, 2005, reported by ALDIS

At Gaisberg tower the overall current waveforms are measured at the base of the air terminal installed on the top of the tower with a current viewing resistor of 0.25 mΩ having a bandwidth of 0 Hz to 3.2 MHz. A fiber optic link is used for transmission of the shunt output signal to a digital recorder installed in the building next to the tower. Two separate fiber optic channels of different sensitivity are used: ±2 kA to measure low amplitude currents like the initial continuing current (ICC) and ±40 kA to measure return stroke peak currents. The signals are recorded by an 8 bit digitizing board (upper frequency response 15 MHz sampling rate 20Ms/sec, record length 16MS) installed in a personal computer. The trigger threshold of the recording system is set to 200 A and a pre trigger recording time of 15 ms is used, whereas the total recording time is 800 ms. The lower measurement limit given by the 8 bit digitizer resolution is about 20 A. A digital filter with an upper frequency of 250 kHz and offset correction is applied to the current records before the lightning parameters (peak current, charge transfer, action integral) are determined. Using a current viewing resistor allows to determine directly the current parameters of lightning discharges.

As typical for elevated objects, more than 90% of the flashes to the tower are upward initiated. The upward leader bridges the gap between the grounded object and cloud and establishes an initial continuing current (ICC) with a duration of some hundreds of milliseconds and an amplitude of some tens to some thousands of amperes. In most cases current pulses are superimposed on the slowly varying continuing current. These pulses are often referred to as Initial Continuing Current pulses or α-pulses. After the cessations of the ICC, one or more downward leader/upward return stroke sequences may occur – the associated current pulses are called β-pulses. Typically α-pulses are relatively small, less than 10 kA, while β-pulses have peaks mostly in the range above 5 kA (Miki et al. 2005). A typical total record of the current measured at the tower is shown in Figure 2.

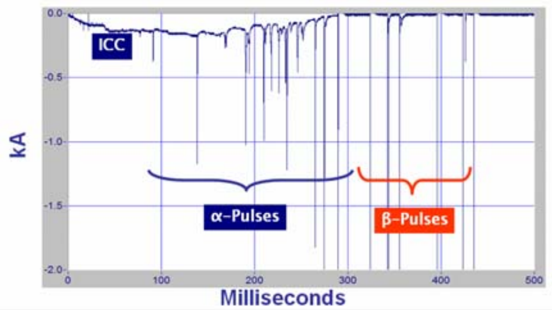

Figure 2: Typical current waveform of tower initiated lightning with its components

Table 1: Total charge and flash duration of the flashes recorded at the Gaisberg tower

Nr.	Date	Time (UTC)	Total Flash Charge [C]	Flash Duration [ms]
1	2005-02-12	22:36:25.7177557	385	720
2	2005-02-12	22:37:35.2847776	41 *)	800*)
3	2005-02-12	22:42:16.3270326	305 *)	800*)
4	2005-02-12	22:44:39.1948516	192	545
5	2005-02-12	22:45:13.0403521	44	180
6	2005-02-12	22:45:51.9393443	63	760
7	2005-02-12	22:47:02.7003477	87	425
8	2005-02-12	22:49:07.0143733	116	670
9	2005-02-12	22:50:05.2234882	12	120
10	2005-02-12	22:51:01.4220826	60	530
11	2005-02-12	22:53:37.7474034	51	665
12	2005-02-12	22:58:31.1188651	109 *)	800*)
13	2005-02-12	23:03:00.3350503	21	470
14	2005-02-12	23:17:26.3692610	34	590
15	2005-02-12	23:42:56.3492248	64	550
16	2005-02-12	23:53:10.5239686	69	420
17	2005-02-12	23:56:03.6235213	40	310
18	2005-02-13	00:00:26.8253293	60	580
19	2005-02-13	03:20:11.7672662	46	440
20	2005-02-13	03:21:50.9704771	14	300
		Total Charge [C]	**1 813**	

*) *Flash current lasted for more than 800 ms which is the maximum recording time*

Within about 5 hours a total charge of 1 813 C was transferred by the 20 flashes to the tower and to ground respectively. The maximum of the measured charge transferred to ground by an individual flash was 385 C. Flash duration of some flashes exceeded the maximum recording time of 800 ms and therefore the actual charge transfer is not known.

Berger et al. (1975) determined for downward negative flashes a charge median value of 7.5 C per flash. Therefore only the tower recorded upward flashes represent a charge equivalent of about 300 downward flashes in this winter thunderstorm.

Peak current values of the α-pulses and β-pulses are summarized in Table 2. We have set a minimum peak current of 1 kA for pulses superimposed on the ICC to be considered in this data analysis. It is interesting to note that the current pulse with the maximum peak current of -30 kA was an α-pulse, whereas the median with -2.8 kA is smaller for α-pulses as typical for tower initiated lightning. All recorded pulses and ICC currents have negative polarity.

Table 2: Peak current values of α- and β-pulses

	α-pulses	β-pulses
Number	164	28
Median	-2.8 kA*)	-11.5 kA
Maximum	-30 kA	-26 kA
Located by ALDIS	62	26

*) This value strongly depends on the setting of the minimum peak current (1kA) of pulses

3. METEOROLOGICAL OBSERVATIONS

3.1. Synoptic analysis

On February 12th, 2005, a rapid cyclogenesis developed over Northern Europe.

At 12UTC, the associated cold front extended from northern Spain to Denmark and moved fast over Western Europe leading to strong advection of cold air from northwest. A split front was formed due to dry air aloft which “overran” the shallow most air at lower levels. During the following night, this front passed Austria from northwest to southeast. The satellite image at midnight is shown in Fig. 3. About one hour earlier, the largest amount of total flash charge was recorded at the Gaisberg tower.

Such kind of intense cold front passages from the north are typical for the winter season. Enhanced by orographical lifting processes along the northern Alpine slopes, these fronts may lead to strong winter thunderstorms in the vicinity of Gaisberg tower.

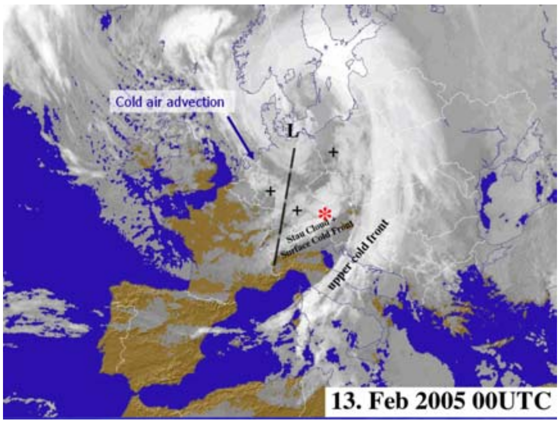

Figure 3: Meteosat infrared satellite image for February 13th, 2005 at 00 UTC: Indicated are the location of the center of the pressure low, fronts, and the trough axis over Middle Europe. Areas with high potential vorticity advection are indicated as plus (+). The location of Gaisberg tower is marked with a star(*).

However, for the case investigated in this study, the upward motions of synoptic forcing was strong enough to produce lightning in the low level cold front, even without orographic lifting.

The synoptic forcing resulted from strong cold air advection aloft and behind the front (at 5 km ASL the temperature decrease was 20°C within 12 hours and at 2 km ASL only 10°C), strong potential vorticity advection due to the cyclonic flow (Fig.4) and upward motions in the left exit region of the upper-level jet.

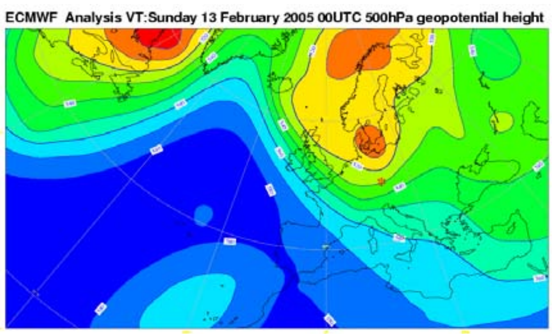

Figure 4: Analysis of the geopotential height at 500 hPa of the ECMWF model valid for 00 UTC 13 February 2005.

The low level cold front was associated with strong vertical wind shear (Fig.5). Before the front passed the location, the storm relative helicity (Moller et al., 1994) enhanced to values of more than 400 m²/s², a shear structure, which is favourable for severe storms in this area (e.g. Kaltenböck 2004). The descent of the tropopause from 12 km to 8.5 km ASL limited the vertical extent of convective activity and led to a shallow moist layer below 6 km ASL. Consequently, the layer of charge-separation processes was close to the surface, especially in mountainous areas. The -25°C isotherm was located at 5 km ASL and the level of -10°C was approximately at 3 km ASL. The temperatures profile in Fig. 5, taken from the sounding of Munich at 23 UTC, illustrates the situation at about one hour after the front had passed Gaisberg. According to Kitagawa and Michimoto (1994) the last one is higher than 1.8km and subsequent the clouds exhibit relatively strong lightning activity.

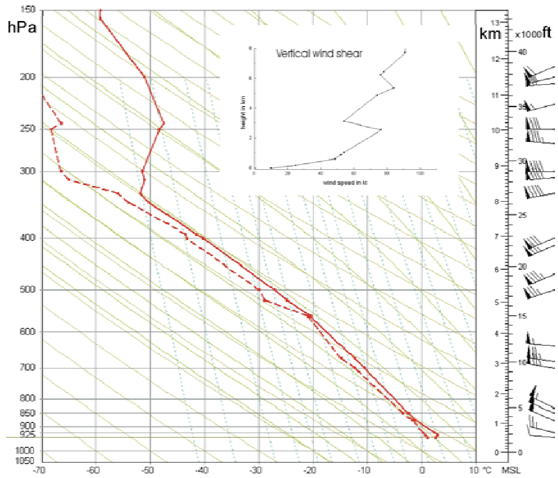

Figure 5: Sounding for 23 UTC 12 February 2005 representing the vertical structure of temperature and humidity as well as the vertical shear in the vicinity of the cold front.

During this frontal event, synoptic weather stations over North-western and Central Europe reported thunderstorms and graupel showers. Over a widespread area of Central Europe, the most frequent lightning discharges to the ground were negative (polarity ratio pos/neg was 1:4,5), observed by the EUCLID-lightning detection network.

3.2 Doppler weather radar data analysis

3.2.1 Horizontal maximum projection

An overview of the frontal event based on CERAD (Central European Radar Composite) maximum projection images is shown in Fig.6. The rainband of the winter cold front, which was associated by lightning discharges, had a length of about 500 km and a width of 100 km.

These dimensions are estimated from radar reflectivity exceeding 20dBZ. Beside of these wide rainband, a narrow embedded frontal rainband can be identified, which is associated with line convection of weak intensity.

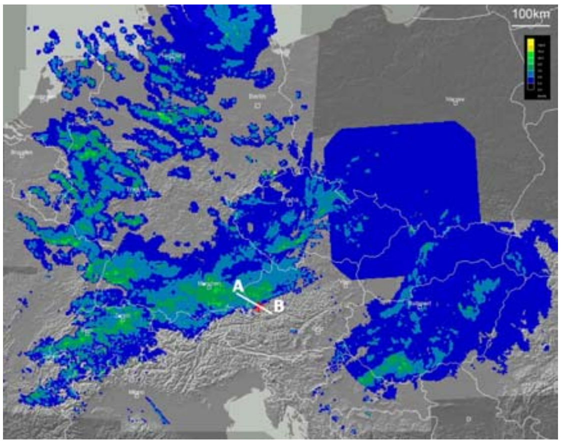

Figure 6: CERAD (Central European Radar Composite) horizontal maximum projection at 22:12 UTC 12 February 2005 (about half an hour before the first upward flashes had been recorded) shows the upper-level cold front southeast of Austria and the wide low level cold-front just northwest of Austria. The unstable Arctic air results in scattered convective cells over northern part of Germany. Gaisberg tower measurement site is marked by a star (*). Position of cross sections from Fig.9 along letters A/B.

Data from the operational Austrocontrol Weather Radar Network were analysed in order to investigate the thunderclouds of these event in detail. The network consists of four C-band Doppler radars, which operate at a wavelength of 5.3 cm and have a maximum range of 230 km. Volume scans are performed at every 5 minutes and at 16 levels. For three-dimensional visualisation the observations are transformed to a Cartesian coordinate system with a spatial resolution of 1x1x1 km. The minimum detectable signal of the radar is 11.8 dBZ. The closest radar site is 30 km north of Gaisberg tower.

Figure 7 shows a maximum projection of reflectivity. The “bright band” around the radar location, north of Gaisberg, at the lowest measuring level is indicated by higher radar reflectivity values. It occurs, when the temperatures are close to 0°C and falling graupel particles or large snow start to be come liquid due to melting.

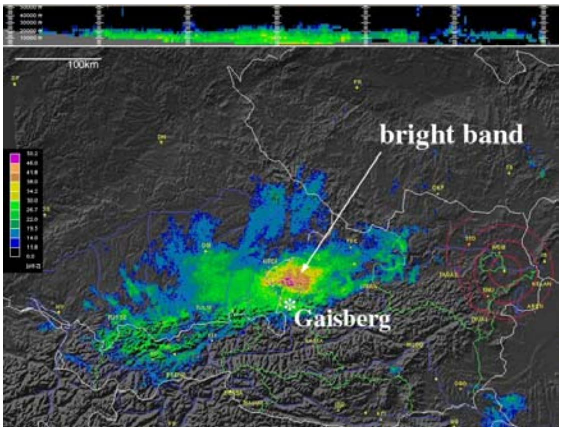

Figure 7: Horizontal and vertical maximum projection of radar reflectivity from the Austrocontrol Weather Radar Network at 22:30 UTC 12 February 2005. The cold frontal rainband with the bright band around the radar site can be seen.

First lightning records are seen along the frontal (southern) edge of the rainband, when radar reflectivity exceeds 30 dBZ (see additional Fig. 8 and 9).

3.2.2 Time-height cross sections

Figure 8 shows the temporal evolution of vertical radar reflectivity which has been interpolated to the location of Gaisberg tower. The corresponding lightning discharges from Table 1 are indicated at the bottom of the figure. From 22:30 to 22:35 UTC, radar reflectivities rapidly increase leading to echoes of 20 to 30 dBZ.

The first intense upward flashes are observed few minutes after the 20dBZ reflectivity echo has exceeded the -20°C temperature level at 4.5 km ASL. These results seem to be similar to observations along the Japan sea coast from Michimoto (1991, 1993) and Kitagawa and Michimoto (1994). About five minutes later, echoes >14 dBZ have reached an altitude of 7 km ASL, where the temperature is -40°C. This indicates the important role of ice crystals in the mechanism of charge generation of thunderstorms during the developing and late mature stages, when the positive charge is carried by ice crystals and snow flakes (Michimoto, 1993). The second peak of lightning discharge at 22:40 UTC is accompanied by enhanced backscattering of 30dBZ at lower levels due to graupel particles (i.e, big drops start to freeze and rime) that carry the main negative charge as well for a short period, the lower positive charge at levels below -10°C close to the surface by falling graupel (Kitagawa and Michimoto, 1994).

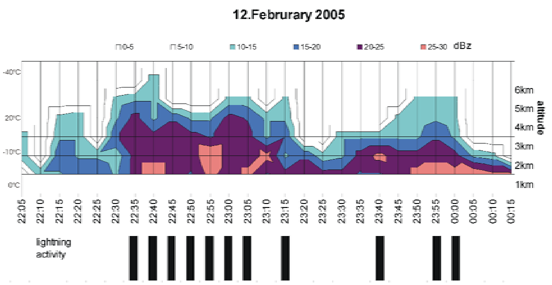

Figure 8: Time-height cross section of radar reflectivity at the location of Gaisberg tower. Lightning activity from Table 1 is shown as black columns.

The following strong lightning activity (e.g. at 2258 UTC) corresponds again to high radar tops (up to 6 km ASL with temperature of -32°C) and 20 dBZ values, which reach heights up to 5 km ASL (-25°C). During this period, a fast increase of radar reflectivity could not be observed.

3.2.3 Cross sections along flow direction and vertical wind shear

The spatial cross sections in Fig. 9 show the life cycle and the detailed structure of individual convective cells. They illustrate the strong influence of vertical wind shear on the evolution of the thunderstorm clouds.

The realisation of one volume scan takes about four minutes. Due to the strong vertical increase of horizontal wind speed (vertical wind shear) of about 30 kt within the lowest 5 km (Fig. 5), the estimated horizontal displacement of clouds during one volume scan is 3 to 4 km.

Subsequent the corrected downshear tilt (to east) of the convective cell which approached the measurement site from west northwest (from left to right in Fig.9 at 22:25 UTC) is approximately 3 km up to the cloud top at 6 km.

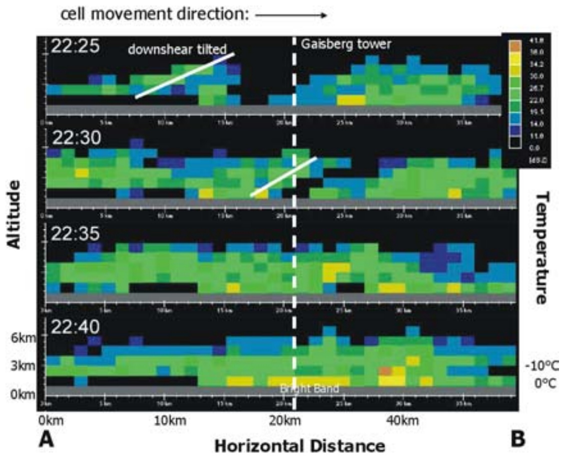

Figure 9: Vertical cross-sections of radar reflectivity from west-northwest to east-southeast, in the direction of cell movement (and low level wind direction) through the measurement site. The line A-B in Fig.5 indicates the position of the cross-sections. The dashed line indicates the location of Gaisberg tower.

During the developing stage of this tilted cell core, positive charge is spread in the upper portion of the clouds, when 25dBZ reached temperature level of -25°C and the negative charge being distributed below (-20°C till -10°C). Within this period the electric charge structure in the cloud seems to be a normal dipole (after Kitagawa and Michimoto 1994). At 22:25 UTC the first narrow rain band passed the site without lightning activity.

Stronger radar reflectivity (34dBZ) at the lowest measuring level and about 5 km east (right) of Gaisberg tower shows the melting layer (bright band).

At 22:30 UTC a new downshear tilted convective cell approached the tower site from west. The cloud top of 20 dBZ reached heights of 6 km with temperatures of -32°C. Echoes from ice crystals are enhanced six minutes before the first lightning stroke is observed. This is in agreement with findings from Maekawa et al. (1993). Due to the tilted cell core, the upper part of cloud had already passed the measurement site followed by enhanced radar backscattering from the bright band at the lowest levels.

Later, at 22:35 UTC and 22:40UTC, when upward flashes were recorded, radar reflectivity of 35 dBZ are observed up to 4 km

(-16°C) and just east (right) of the measurement location. In this event, high radar echoes were observed up to 7 km (as mentioned before in Fig.6) and a maximal reflectivity of 40 dBZ (between 2 and 3km) was measured. Additional, enhanced reflectivities at lowest levels reveal the bright band with graupel and melting snow flakes. This situation describes the mature stage of the convective system, when, after Kitagawa and Michimoto (1994), the lower positive charge, occurring below the temperature level of -10°C, is carried by graupel particles which are falling close to the ground.

4. REFERENCES

Berger, K., R. B. Anderson and H. Kroeninger, 1975: Parameters of Lightning Flashes, Electra, No. 41, 23-37

Kaltenböck, R., 2004: The outbreak of severe storms along convergence lines northeast of the Alps. Case study of the 3 August 2001 mesoscale convective system with a pronounced bow echo. Atmos. Res. 70, 55-75

Kitagawa, N., and K. Michimoto, 1994: Meteorological and electrical aspects of winter thunderclouds. J- Geophys. Res. 99, 10713-10721

Maekawa, Y., S. Fukao, Sonoi, Y., and F. Yoshino, 1993: Distribution of ice particles in wintertime thunderclouds detected by a C band dual polarization radar: A case study. J- Geophys. Res. 98, 16613-16622

Michimoto, K., 1991: A study of Radar echoes and their relation to lightning discharge of thunderclouds in the Hokuriku District, Part I: Observation and analysis of thunder-clouds in summer and winter. J. Meteor. Soc. Japan 69, 327-336

Michimoto, K., 1993: A study of the charge distribution in winter thunderclouds by means of network recording of surface electric fields and radar observation of clouds structure in the Hokuriku District. J. Atmos. Electr. 13, 33-46

Miki M., V. A. Rakov, T. Shindo, G. Diendorfer, M. Mair, F. Heidler, W. Zischank, M. A. Uman, R. Thottappillil, D. Wang, 2005: Initial stage in lightning initiated from tall objects and in rocket-triggered lightning, J. Geophys. Res., 110, D02109, doi: 10.1029/2003JD004474

Miyake, K., T. Suzuki, K. Shinjou, 1992: Characteristics of winter lightning current on Japan Sea Coast. IEEE Transactions on Power Delivery, vol.7, no.3, pp.1450-1457.

Moller, A.R., C.A. Doswell III, M.P. Foster, G.R. Woodall, 1994: The operational recognition of supercell thunderstom environments and storm structures. Weather Forecast. 9, 327-347

5. CONCLUSIONS

Typically one or a few flashes are recorded during a single storm at the Gaisberg tower. 20 flashes to the tower within a 5 hour period is unique up to now and some of the discharges showed unusual features, like a transferred charge of 385 As in a single flash and an ICC pulse of -30 kA, which was actually the largest pulse measured at the tower during that storm.

The meteorological conditions leading to a formation of such lightning event were the rapid passage of an intense cold front accompanied by strong vertical wind shear and strong advection of cold Atlantic air.

Radar data analyses reveal similar striking features as winter storms in the coastal area of Japan. These characteristics are downshear tilted cell cores due to low level vertical wind shear, shallow storms associated by echo tops up to 7 km ASL , the maximum of reflectivity is 40dBZ and the first lightning appear six minutes after 25dBZ exceeds -20°C level. The peak of lightning activity is observed when graupel and ice crystals in sufficient quantities occur. Subsequently enhanced backscattering can be observed at lower levels and echo tops grow up to temperature levels of -30°C, isolated till -40°C.