ANALYSIS OF LIGHTNING ACTIVITY DURING THUNDERSTORMS WITH THE OVERSHOOTING TOPS

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I. INTRODUCTION

Thunderstorms' updraft area, frequently manifested by the appearance of the overshooting tops (OT), is linked to the electric activity of the storm, in a way that updraft surges coincide with an increase in flash rate (e.g. Wiens et al. 2005). Due to significant correlation between OTs and severe weather conditions (Mikuš and Strelec Mahović, 2013; Bedka, 2010), OT detection has become more important in operational nowcasting. Objective OT detection methods is usually satellite based (e.g. Mikuš and Strelec Mahović, 2013; Bedka et al., 2010; Rosenfeld at al., 2008), but recognition and detection of OTs in satellite imagery are strongly dependent on the spatial and temporal resolution of the satellite instruments and also, in case of visible satellite imagery, possible only during the day time. Specific behavior of lightning discharges during the thunderstorms with the OTs was found during several investigations (e.g. Elliot et al., 2012), suggesting that analysis of lightning activity and using of lightning data can improve detection of OTs.

The basic vertical electrical structure of mature convective updraft is composed of four charge regions (e.g. Stolzenburg et al., 1998). The main dipole of the cloud is composed of main negative and upper positive charge regions, which are situated between the lower relatively weak positive charge region and upper shallow area of negative charge. According to previous investigations, the increasing in lightning production rate could be due to very rapid vertical storm growth. Large updraft magnitudes bring midlevel negative charge close to midlevel positive charge, what increases electric field magnitude in the convective cloud (e.g. Emersic et al., 2011). Close proximity of oppositely charged regions caused by strong updraft are more favorable for intracloud (IC) flashes. Consequently, cloud-to-ground (CG) lightning production is decreased in the region of strong updraft.

The number, spatial, temporal and monthly distributions of lightning discharges in general, but also atmospheric discharges in penetrative convective clouds are presented here. Number, type and amplitudes of the lightning strokes in convective clouds with OTs are analyzed on several cases over the study domain.

II. DATA AND METHODS

In this study the focus was on the warm part of the year (May-September) during 2009 and 2010. The study area covers region from approximately 41.5°N 8.5°E to 49.5°N 20.5°E (FIG.1).

Analysis of lightning activity in the thunderstorms with the OTs is done using the lightning data provided by the LINET (International Lightning Detection Network in Europe) network. This system covers a wide area, from approximately 30°N 10°W to 65°N 35°E and detects total lightning discharge, but it also separately detects cloud-to-ground (CG), intra-cloud (IC) and cloud-to-cloud (CC) strokes (e.g. Betz et al., 2009; Mikuš et al., 2012). The LINET sensors have a satisfactory sensitivity, the minimum detectable signal is in the range of 1–2 kA, and the discharge locations are detected with the accuracy of ± 100 m. But, the sensitivity of the sensors decreases as the distances of the lightning discharges from the LINET sensors increase (Höller et al., 2009).

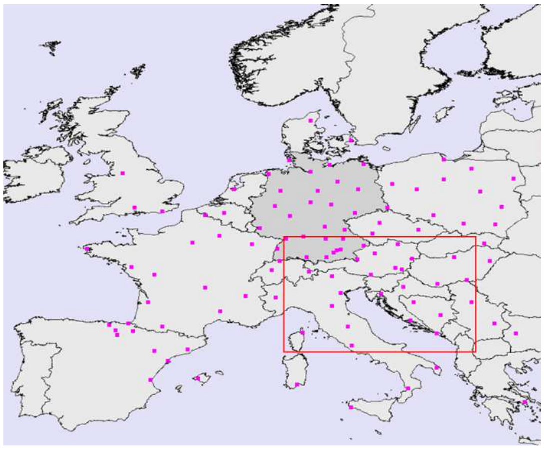

FIG. 1: Map of LINET sensors (magenta) (source: *https://www.nowcast.de/en/produkte-und-vorteile/linet-data.html*). Study area is outlined with the red box.

Deep convective clouds with OT were detected from the Meteosat 9, SEVIRI data with spatial resolution of 3 km/pixel, using a so called COMB method (Mikuš and Strelec Mahović, 2013). The mentioned OT detection method is based on the infrared window (IRW, 10.8 μm) channel and the absorption channels of water vapor (WV, 6.2 μm) and ozone (O_3, 9.7 μm) in form of brightness temperature differences (BTD). COMB method combines the criteria for the IRW brightness temperature and the criteria for two BTDs, WV-IRW and O_3-IRW. All pixels with O_3-IRW BTD larger than 13 K in the region where IRW brightness temperature is lower than 215 K and WV-IRW BTD larger than 4 K are characterized as OTs. Additionally, the COMB BTD method is strongly dependent upon the spatial resolution of the satellite instruments, which implies that some of the OTs can be recognized in the 1 km/pixel HRV imagery, but cannot be detected using BTD method based on SEVIRI data with spatial resolution of 3 km/pixel.

III. RESULTS

For the warm seasons of 2009 and 2010 the largest numbers of lightning strokes were detected in the western Hungary, southeastern Germany, northern Adriatic and northeastern Slovenia. The minimum lightning activity occures over the highest tops of the Alps and Dinaric Alps, as well as over the Adriatic sea (FIG. 2b). This generally agrees with the previous study about lightning activity in Croatia during the warm seasons 2006-2009 reported by Mikuš et al. (2011), who noted that the minimum lightning activity belongs to the mountainous areas, while over the sea, lightning often appears close to the coastline.

Analysis of total monthly distribution of lightning activity shows spatial variations by months. The highest lightning occurrence over the continental part of the studied region is recorded during July 2009 and 2010, while convective activity over the sea is more pronounced in the autumn (FIGs not shown), what is a consequence of an increase in mid-latitude cyclone activity. That is in agreement with the previous studies of lightning activity over the Europe (e.g. Mikuš and Strelec Mahović, 2013; Christian et al., 2003; Schulz et al., 2005).

The significant number of OTs using COMB BTD satellite–based detection method is found at the slopes of the Alps, in the south-eastern Austria and Germany, as well in the northern Italy (FIG 2a). The maximum number of OTs during the analyzed warm seasons is detected in central Hungary.

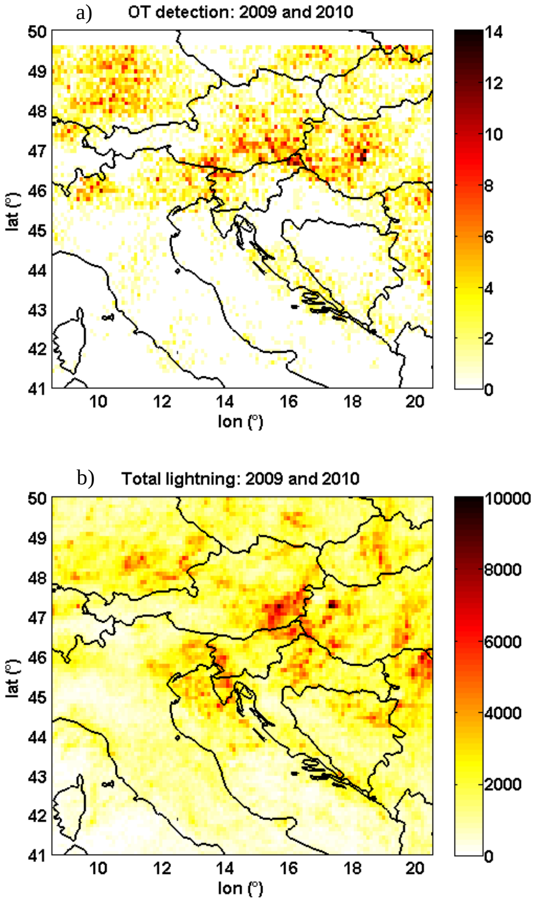

FIG. 2: **a)** Number of OT detections using COMB method computed over 0.1° x 0.1° grid boxes, **b)** Number of lightning strokes computed over 0.1° x 0.1° grid boxes from May to September 2009 and 2010.

Comparing figure 2a and 2b the areas of maximum lightning activity (FIG 2b) coincide well with the locations of maximum number of detected OTs (FIG 2a). Figure 3 displays the number of lightning strokes 5 min before and after the time of the scan within the range of 0.1° from the OT position, which shows that the significant number of lightning strokes in the vicinity of the OTs is registered in western Hungary, eastern Austria and northern Adriatic region. Maximum number of about 2598 lightning strokes was detected in eastern Austria. Also, in the southern Adriatic coastal region at the slopes of the Dinaric Alps the significant number of lightning activity is detected during the thunderstorms with the OTs.

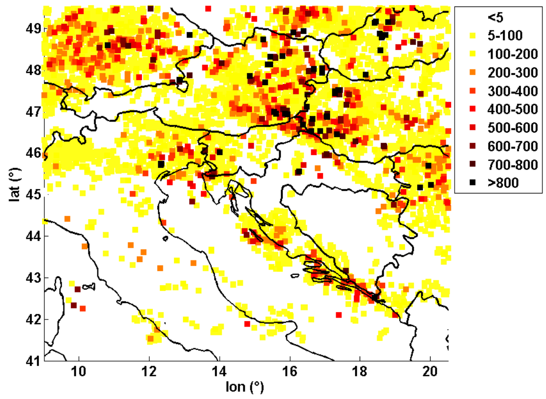

FIG. 3: Number of lightning strokes 5 min before and after the time of the scan within the range of 0.1° from the OT position.

OTs are more frequently detected during the daytime, from 09 AM to 09 PM LST (Local Standard Time; UTC +2 h), than during the night-time, from 09 PM to 09 AM LST (FIG 4b), especially near the slopes of the mountains, which agrees well with the results described by Bedka (2010). In general, the largest number of OTs occurs during the afternoon and early evening, with a well pronounced peak around 17 UTC (FIG 4b).

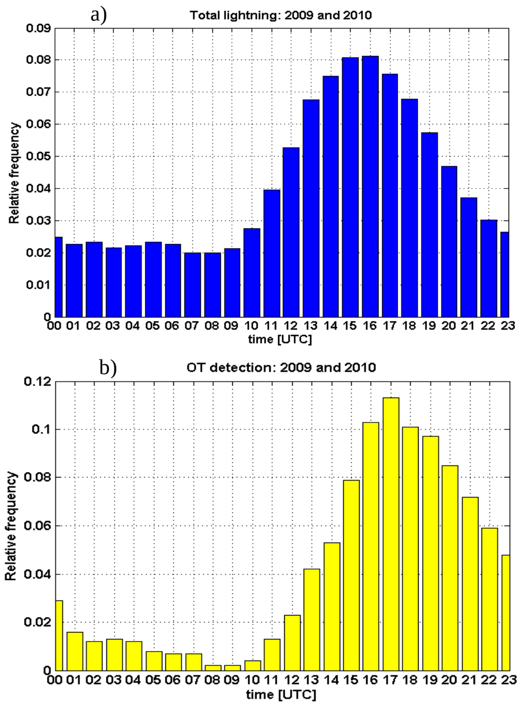

FIG. 4: Relative frequency of **a)** lightning discharges and **b)** OTs, detected using COMB method, within given hour.

Relative frequency of detected OTs within given hour is well correlated with temporal analysis of the occurrence of lightning discharges (FIG 4a), which shows that the largest number of lightning strokes for the study area during analyzed warm seasons occurs usually from 13 to 18 UTC. Between 06 and 10 UTC, OT detections as well as lightning discharges, as well as OT detections are rather rare.

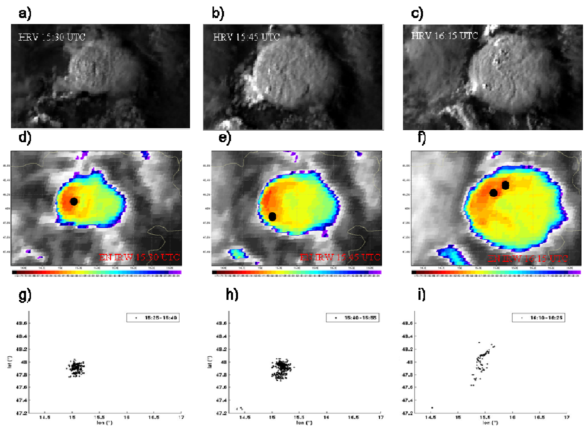

FIG. 5: Meteosat 9 HRV channel imagery on 23 August 2010 at a) 15:30, b) 15:45, c) 16:15 UTC, and color–enhanced (EN) Meteosat 9 10.8 (IRW) µm imagery at d) 15:30, e) 15:45, f) 16:15 UTC. Locations of the OTs detected by the COMB method are marked with black dots. Map of total lightning activity (IC + CG) above 12 km on 23 August 2010 g) 15:25 – 15:40 h) 15:40 – 15:55 and i) 16:10 – 16::25 UTC for the analyzed convective storm region.

Characteristic of lightning activity during the thunderstorms with the OTs are shown on an example of a convective storm on 23 August 2010 (FIG 5). The OTs are well pronounced on the HRV satellite imagery in the period between 15:15 UTC and 16:15 UTC, and also detected using the COMB BTD detection method (locations of detected OT are marked with black dots on FIGs 5d, 5e, 5f). The cold ring structure is also visible on enhanced IR 10.8 µm satellite images. Sharp increase of lightning activity (FIG 6) and larger values of the electric current (FIG 7) are evident at the time of OT detections. Also, lightnings occur well above the 12 km height (FIGs 5g, 5h, 5i), what is the height of the tropopause, estimated from the soundings of three closest radiosounding stations: Vienna, Budapest and Zagreb (not shown). The spatial distribution of these lightning discharges shows very good correlation with locations of the OTs observed on HRV images (FIGs 5a, 5b, 5c).

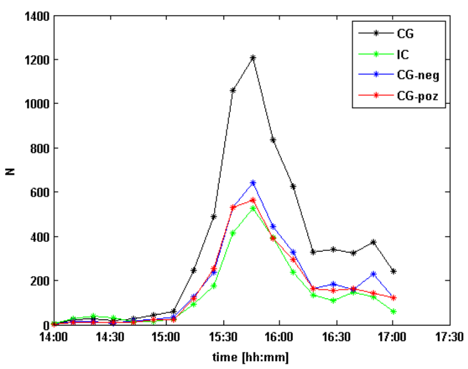

FIG. 6: Temporal distribution of a) lightning discharges (cloud to ground (CG), intra cloud (IC), CG positive (CG-poz) and CG negative (CG-neg)) on 23 August 2010 from 14 to 17 UTC.

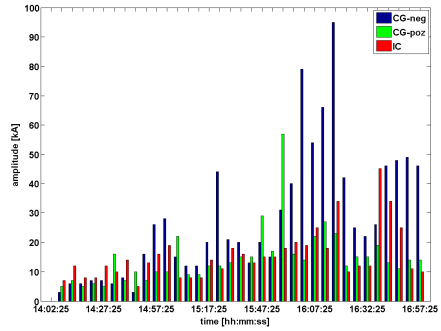

FIG. 7: Temporal distribution of maximum 5-min lightning current of CG-neg (blue), CG-pos(green) and IC (red) lightning discharges on 23 August 2010 from 14 to 17 UTC.

IV. CONCLUDING REMARKS

Characteristics of lightning activity, detected using LINET network, were analyzed in the vicinity of the OTs during warm season of 2009 and 2010. For the studied warm seasons the OTs were detected using COMB BTD method. Spatial distribution of lightning activity coincides well with the spatial distribution of detected OTs. The largest numbers of lightning strokes, as well as OTs were detected in the central and western Hungary and at the slopes of the Alps. The largest number of OTs, as well as lightning discharges are detected between 13 and 18 UTC, while from 06 to 10 UTC OT detections and lightning discharges are rather rare.

An example showed that lightning activity greatly enhances at the times of the overshootings. Lightnings occur well above the tropopause, therefore are clearly related to the OT parts of the Cb cloud. Sharp increase of lightning activity and larger values of the electric current are evident at the time of the OT detections.

V. ACKNOWLEDGMENTS

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VI. REFERENCES

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