CORRELATING OVERSHOOTING TOPS AND SEVERE WEATHER

Petra Mikuš[1], Nataša Strelec Mahović[2]

[1]EUMeTrain Project, Meteorological and Hydrological Service, Grič 3, Zagreb, Croatia, petra.mikus@cirus.dhz.hr
[2]Meteorological and Hydrological Service, Grič 3, Zagreb, Croatia, natasa.strelec.mahovic@cirus.dhz.hr

I. INTRODUCTION

An overshooting convective cloud top (OT) is a dome-like protrusion above a cumulonimbus anvil, often penetrating into the lower stratosphere. It is a manifestation of a very strong updraft in the convective cloud. An OT forms when a thunderstorm's updraft, due to momentum from rapid ascent and strength of lifting, protrudes its equilibrium level (the point where the surrounding air is about the same temperature or even warmer) near the tropopause region and penetrates into the lower stratosphere. This can occur within any cumulonimbus cloud when instability is high. An OT exists for less than 30 minutes and has a maximum diameter of ~15 km (e.g. Fujita, 1992; Brunner et al., 2007). According to some investigations, deep convective storms with OTs often produce hazardous weather conditions such as heavy rainfall, damaging winds, large hail, cloud-to-ground lightning and tornadoes (e.g. Brunner et al., 2007; Bedka, 2010). The OTs also generate gravity waves which can produce significant turbulence (e.g. Wang, 2003, 2004). These events can cause considerable property damages, influence everyday activities and even endanger the human lives.

II. PRESENTATION OF RESEARCH –DATA AND METHODS

The main focus of this study was to establish the relationship between the appearance of the OTs, detected from the satellite data, and the occurrence of sudden extreme changes in weather elements, such as wind, precipitation, temperature and humidity, measured by the instruments on the ground. Schmetz et al. (1997) found that the OTs can be detected using the combination of the infrared (10.5 – 12.5 µm) and the water vapor (5.7 – 7.1 µm) satellite data. They stated that the brightness temperature differences greater than 0 K are related to convective clouds with high vertical extension and suggested that positive brightness temperature differences are only possible when deep convective cloud penetrates through the tropopause, moistening the stratosphere. The brightness temperature in the WV channel can be larger than the one in the IR channel by as much as 6 to 8 K. One of the most commonly used methods for detecting the OTs using Meteosat Second Generation data is based on brightness temperature difference between the water vapour (WV) 6.2 µm and the infrared (IR) 10.8 µm channel.

In our research the OTs are detected from Meteosat 9 data, using a method that combines the criteria for the IR 10.8 µm brightness temperature and the criteria for brightness temperature difference (WV 6.2 µm - IR 10.8 µm). All pixels with IR 10.8 µm brightness temperature lower than 215 K and brightness temperature difference larger than 4 K are considered to be connected with the OTs.

Locations and times of the appearance of the detected OTs are compared with the occurrence of the wind gusts, temperature drop, humidity increase and precipitation measured by the automatic stations. Additionally, hailpad measurements are used to determine the relationship between the occurrence of the OTs and large hail.

When comparing satellite data with the data from the automatic ground weather stations, parallax shift of the cloud pixels had to be taken into account. Since the OTs are considered to have a height similar to the height of the tropopause, mean tropopause height was derived from the radiosonde data representative for the studied regions. Parallax correction was then estimated using tables from http://www.convectionwg.org/parallax.php, taking the mean tropopause height as the OT cloud-top height. To avoid shifting each cloud pixel, locations of the automatic stations and hailpads were shifted north-eastwards for the amount of the parallax correction in the given region.

The analysis of the correlation between the appearance of the OTs and the occurrence of the wind gusts, temperature drop, relative humidity increase and precipitation has been performed for the period May-September 2010. 15 minutes Meteosat 9 data have been used for OT detections. Coordinates of each pixel meeting the criteria for the brightness temperature and brightness temperature difference (215 and 4 K, respectively) have been compared to the parallax corrected coordinates of the automatic stations. All OTs detected within the range of 0.1 deg from the automatic station have been taken for the analysis. More than 900 matching pairs of OT detections and available nearby automatic station data were found. For the analysis of the correlation between the occurrence of the OTs and hail, detected OTs were compared with measurements on 558 hailpads placed in the continental part of Croatia. This analysis was done for all OTs detected within the range of 0.2 deg from the hailpad for the period May-September 2010.

III. RESULTS

Comparison of the OTs with mentioned automatic station data showed that in more than 50% of cases detected OTs are connected to some sort of extreme weather situation. The best correspondence is found for precipitation, being correlated with the OTs in 77 % of cases. Very good correlation (62%) is found between wind gusts and OT occurrence, whereas temperature drop and relative humidity increase are found in the vicinity of the OTs in 54 and 53 %, respectively (Table I).

In association with OTs severe wind gusts can be produced by downward transfer of high momentum air or by downdrafts induced by melting of small hail in the vicinity of the OT (e.g. Dotzek and Friedrich, 2009; Bedka, 2010). In order to analyze the intensity of wind gusts correlated to OT appearances more closely, we defined three categories of wind-gust speed: moderate (5 to 10.8 m/s), strong (10.8 to 17.2 m/s) and gale (>17.2 m/s). Out of the 62 % of the wind gusts correlated with the OTs the largest portion fall into the category of strong wind gusts (Table II). Considerable number of gale force wind gusts was also observed, some of them reaching the maximum wind speed stronger than 30 m/s.

Type of automatic station data	Number of detected OTs in the vicinity of the station	Number of OTs matching data extremes	(%)
wind gust	938	579	62
precipitation	915	707	77
rel. humidity	929	491	53
temperature	929	504	54

TABLE I: Total number of the OTs detected within 0,1 deg radius from the automatic stations measuring mentioned parameters, compared to the number of OTs matching the measured extremes. Correlation between the OTs and each measured parameter is given in the last column.

Wind gusts matching OT detections				
	5 to 10.8 m/s	10.8 to 17.2 m/s	>17.2 m/s	total
Apsolute frequency	174	261	144	579
Relative frequency (%)	30	45	25	

TABLE II: Portions of different wind-gust intensities matching the OT detections

Generally, rain events in convective clouds can be associated with wind gusts due to the fact that precipitation from a cloud cell, in almost every case, produces a downward airflow (e.g. Cotton and Anthes, 1989). Precipitation loading and negative buoyancy, caused by cooling associated with evaporation or melting of the hydrometeors, can be considered as the processes which favour convective wind gusts (Doswell, 1993). As already mentioned before, very good correlation between wind gusts and location of OTs was found, but usually in such cases precipitation was also observed.

Precipitation matching OT detections				
	0-5mm	5-10mm	>10mm	total
Apsolute frequency	468	145	76	689
Relative frequency (%)	68	21	11	

TABLE III: Portions of different 10 min precipitation quantities matching the OT detections

Table III shows 10-min precipitation amounts correlated with the OTs (77%, Table I) divided into three categories. In 11% of the observed precipitation events correlated with OTs, more than 10 mm per 10 min were recorded by certain automatic station. In 21% events, 5 to 10 mm per 10 min were recorded.

Temperature change matching OT detections					
	2 to 4 °C	4 to 6 °C	6 to 8 °C	> 8°C	total
Apsolute frequency	156	153	105	81	495
Relative frequency (%)	32	31	21	16	

TABLE IV: Portions of different intervals of temperature drop matching the OT detections

Besides wind gusts and precipitation, in 54% of the analyzed OT cases nearby automatic stations recorded the temperature drop (Table I). The temperature decrease larger than 4°C was observed in 68% of the cases matching the OT detections (Table IV), whereas in considerable number of cases (16%) temperature drop of more than 8°C is found.

In order to scenically present the correspondence between an OT and the occurrence of the wind gusts, temperature drop, humidity increase and precipitation measured by an automatic station, an example of a convective storm on 13 July 2010 is taken. The OT, detected by the WV-IR brightness temperature difference method (Fig.1) appeared in the vicinity of the automatic station Weiz in Austria.

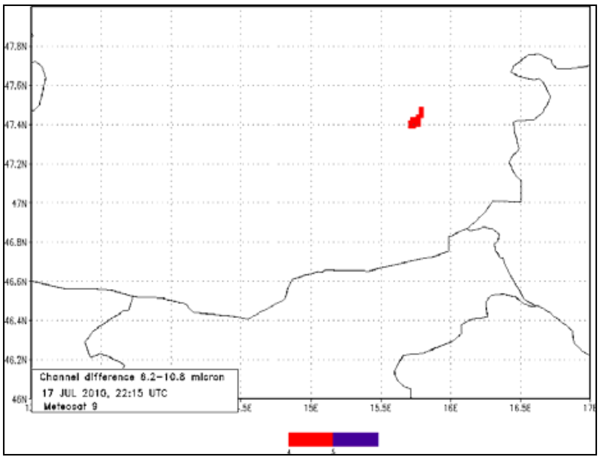

FIG. 1: Brightness temperature difference (BTD) between 6.2 and 10.8 μm channel, 13 July 2010, 22:15 UTC. BTD larger than 4 K (red) stand for OT. Location of the automatic station Weiz is shown.

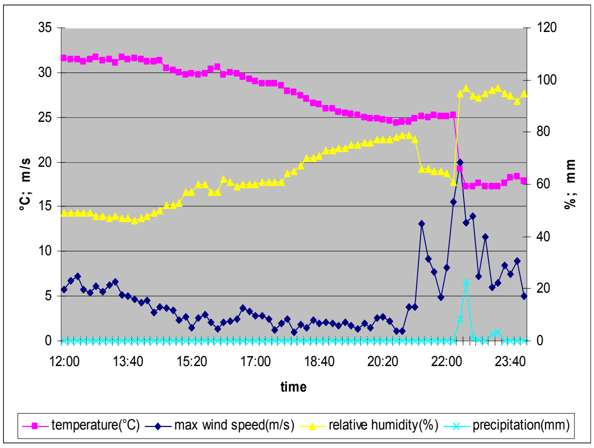

FIG. 2: Maximum wind speed, temperature, humidity and precipitation measured by the automatic station Weiz, Austria on 13 July 2010, 12:00-24:00 UTC. Extreme changes of all elements are seen between 22:10 and 22:30 UTC.

The automatic station recorded extreme weather situation with gale wind gusts and shower. Maximum wind speed, shown by a dark blue line in Fig. 2, was 20 m/s at 22:20 UTC. 10 minutes later precipitation started. In 10 minutes 22.5 mm of precipitation was recorded (light blue line in Fig.2). The event was also accompanied by significant temperature drop and relative humidity increase. In only 10 minutes temperature decreased by about 10 °C and relative humidity increased to almost 100%.

Besides automatic station measurements, hailpad measurements are used to determine the relationship between the occurrence of the OTs and large hail. The correspondence between OT and hail is found in 38 % of the cases. Fig. 3 shows the convective storm with detected OT on 13 August 2010, which produced very large hail. One of the hailpads recorded hail with diameter larger than 3 cm (Fig. 3, blue dot) at the time of detected overshooting. On that day the hail was recorded on 28 hailpads in the vicinity of detected OTs.

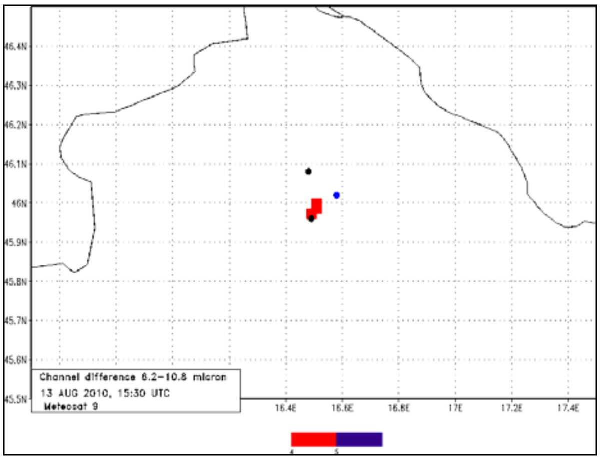

FIG. 3: Brightness temperature difference (BTD) between 6.2 and 10.8 µm channel, 13 August 2010, 1530 UTC. BTD larger than 4 K (red) stand for OT. Locations of the observed hail (dot) within the range of 0.2 deg from the detected OT are shown. Blue dot represents hail with diameter larger than 3 cm.

IV. CONCLUSION

The study of the correlation between the appearance of the overshooting on the tops of the convective clouds, detected from the satellite data, and the occurrence of severe weather conditions, represented by the abrupt changes in weather elements measured by the automatic ground weather stations, is significant. The best correspondence is found for precipitation, which appears close to detected OT in 77% of the analyzed cases. Wind gusts, correlated with OTs in 62% of the cases, mostly fall in the category strong (5 to 10.8 m/s), but about 25% of the wind gusts correlated with OTs have gale wind speed (>17.2 m/s), making them potentially dangerous, especially to aviation. In about 50% of OT cases temperature drop and relative humidity increase is observed by the closest automatic stations. The results showed that in 16% of the cases temperature can drop for more than 8°C in the vicinity of the OT.

This study is still in progress. It is planned to analyze the data for a 5-years period, which would make the statistics more reliable. It is envisaged that OT detections could be used by the operational meteorologists as a parameter suggesting the severity of the storm and its potential to produce severe weather conditions.

V. ACKNOWLEDGMENTS

The authors would like to thank meteorological services of Austria, Slovenia and Slovakia for the automatic station data used in the analysis. The work was partly performed under the international project EUMeTrain, co-sponsored by EUMETSAT. We also thank the Ministry of Science, Education and Sports of the Republic of Croatia for the support under Project "Storms and natural disasters in Croatia".

VI. REFERENCES

Bedka, K. M., 2010: Overshooting cloud top detections using MSG SEVIRI Infrared brightness temperatures and their relationship to severe weather over Europe. *Atmos. Res.,* doi:10.1016/j.atmosres.2010.10.001.

Bedka, K. M., Brunner, J., Dworak, R., Feltz, W., Otkin, J., Greenwald, T., 2010: Objective Satellite–Based Detection of Overshooting Tops Using Infrared Window Channel Brightness Temperature Gradients. *J. Appl. Meteor. Climatol.,* 49 181 – 202.

Brunner, J. C., Ackerman, S. A., Bachmeier, R. M., 2007: A quantitative analysis of the enhanced–V feature in relation to severe weather. *Wea. Forecasting,* 22 853 – 872.

Cotton, W. R., Richard, A.A., 1989: Storm and Cloud Dynamics. Academic Press, London, 883 pp.

Doswell, C. A., 1993: Severe Convective Weather and Associated Disasters in North America. *Proceedings, International Workshop on Observations/Forecasting of Meso-scale Severe Weather and Technology of Reduction of Relevant Disasters*, Tokyo, Japan, 22-26 February 1993, 21-28.

Dotzek, N., Friedrich, K., 2009: Downburst-producing thunderstorms in southern Germany: radar analysis and predictability. *Atmos. Res*., 93 457–473.

Fujita,T. T., 1992: Memoirs of an effort to unlock the mystery of severe storms. WRL Research Paper 239, University of Chicago Wind Research Lab, 298 pp.

Machado, L. A. T., Lima, W. F. A., Pinto, O., Morales, C. A., 2009: Relationship between cloud-to-ground discharge and penetrative clouds: a multi-channel satellite application. *Atmos. Res.*, 93 304–309.

Schmetz, J., Tjemkes, S. A., Gube, M., van de Berg, L., (1997): Monitoring deep convection and convective overshooting with METEOSAT. *Adv. Space Res*., 19 433–441.

Wang, P. K., 2003: Moisture plumes above thunderstorm anvils and their contributions to cross-tropopause transport of water vapor in midlatitudes. *J.Geophys. Res*., 108, 4194, doi:10.1029/2002JD002581.

Wang, P. K., 2004: A cloud model interpretation of jumping cirrus above storm top. *Geophys. Res. Lett*., 31, L18106, doi:10.1029/2004GL020787.

Wang, P. K., 2007: The thermodynamic structure atop a penetrating convective thunderstorm. *Atmos. Res.*, 83 254-262.