CORRELATING LOCATIONS OF THE OVERSHOOTING TOPS WITH THE OCCURENCE OF SEVERE WEATHER ON THE GROUND

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

[1] Meteorological and Hydrological Service, Grič 3, 10000 Zagreb, Croatia
[2] EUMeTrain project, Meteorological and Hydrological Service, Grič 3, 10000 Zagreb, Croatia

Abstract

Storms with overshooting tops often produce severe weather conditions such as heavy rainfall, strong winds, hail, lightning and tornadoes. According to some investigations the relationship between the overshooting tops and severe weather over Europe is rather strong, especially for large hail and severe wind. Overshooting cloud tops can be detected from the satellite, using brightness temperature differences between the water vapour (6.2 µm), ozone (9.7 µm) or carbon-dioxide (13.4 µm) and the infrared (10.8 µm) channel. The aim of this investigation is to establish the relationship between the occurrence of the overshooting tops and the onset of severe weather phenomena over the Central Europe. Locations and times of appearance of the overshooting tops, derived from the Meteosat 9 data, are compared with the occurrence of strong wind and wind gusts, temperature and humidity change and precipitation, measured by the automatic stations.

INTRODUCTION

In satellite images severe thunderstorms show specific features in their cloud tops, such as cold rings or cold-U/V signatures (e.g. Setvak et al., 2008; Brunner et al., 2007) and the overshooting tops (OT) (e.g. Bedka, 2010; Bedka et al., 2010). Overshooting convective cloud tops (OT), dome-like protrusions above a cumulonimbus anvil, are a sign of very strong updraft in the convective cloud. An OT forms when a thunderstorm's updraft protrudes its equilibrium level near the tropopause region and penetrates into the lower stratosphere. This can occur within any cumulonimbus cloud when instability is high. OTs are short-living phenomena, with 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. Bedka, 2010; Brunner et al., 2007). The OTs also generate gravity waves which can produce significant turbulence (e.g. Wang, 2003, 2004). Therefore, in this work, several satellite-based OT detection methods will be tested. The detected OTs will be compared with the simultaneous measurement data in order to asses the correlation between the appearance of the overshooting top and the occurrence of severe weather on the ground.

SATELLITE-BASED OT DETECTION METHODS

Different objective satellite based OT detection methods using multi-spectral satellite data are presented in several studies (e.g. Schmetz et al., 1997; Setvak et al., 2007). Since the techniques which use combinations with visible and near-IR satellite channels perform well only during the daytime (e.g. Berendes et al.; 2008, Lindsey and Grasso, 2008; Rosenfeld et al., 2008), we have tested the methods that use channels applicable 24 hours a day. One of the most commonly used method for detecting the OTs is based on the brightness temperature difference (BTD) between the 6.2 µm and 10.8 µm (WV-IR) channels. Since the OT often protrudes into the lower stratosphere, the area of increasing temperature with height, the water vapor at that height has warmer temperature than the cloud top, which makes the BTD positive (Setvak et al., 2007). Therefore WV-IR BTD greater that 0K can indicate the presence of deep convective clouds and OTs. According to Kwon et al. (2009) BTD of the ozone channel (9.7 µm) and the IR channel also shows positive signature for the cloud tops above 11 km. They pointed out that the signal of BTD between ozone and IR channel is even more significant than the BTD WV-IR near the tropopause, suggesting that it could be a better indicator for the deep convective activity. Additionally, BTD of carbon dioxide (13.4 μm) and IR channel can also be used for determining the height of the opaque clouds. The reason is that with higher cloud tops the absorption effect of CO_2 gets smaller, making the BTD of the CO_2 and IR channel close to 0 or positive, in case of very deep convective clouds. Finally, we also tested a combination of two BTDs: WV-IR and O_3-IR (COMB in further text).

To validate their ability to locate very deep convective clouds and possibly overshootings we compared the results of all mentioned satellite–based OT detection methods, each method including two criteria; one for the IRW brightness temperature and the other for BTD (Table 1). The thresholds were partially based on previous research, namely Bedka (2010) and Martin et al. (2008) used IRW brightness temperature ≤ 215 K as a threshold for very cold pixels within convective clouds and Setvak et al. (2007), using 1 km MODIS data, determined WV-IRW BTD in the range of 4 to 7K in the overshootings above the coldest cloud tops.

BTD	**Thresholds**	
WV-IR	IR brightness temperature < 215 K	> 4 K
CO2-IR		> 3.5 K
O3-IR		> 13 K
COMB		> 4 K & > 13 K

Table 1: **The IR brightness temperature and the BTD thresholds for the WV-IR, CO2-IR, O3-IR and COMB BTD method.**

In order to present and compare the studied BTD methods a convective system over North Italy is analyzed. Figure 1 shows a color-enhanced Meteosat-8 10.8 μm channel image at 17:05 UTC, on 6 July 2010 blended with HRV image. Region of deep convective clouds visible on IR image is located above North Italy and the overshootings are clearly visible due to their apperance in HRV image.

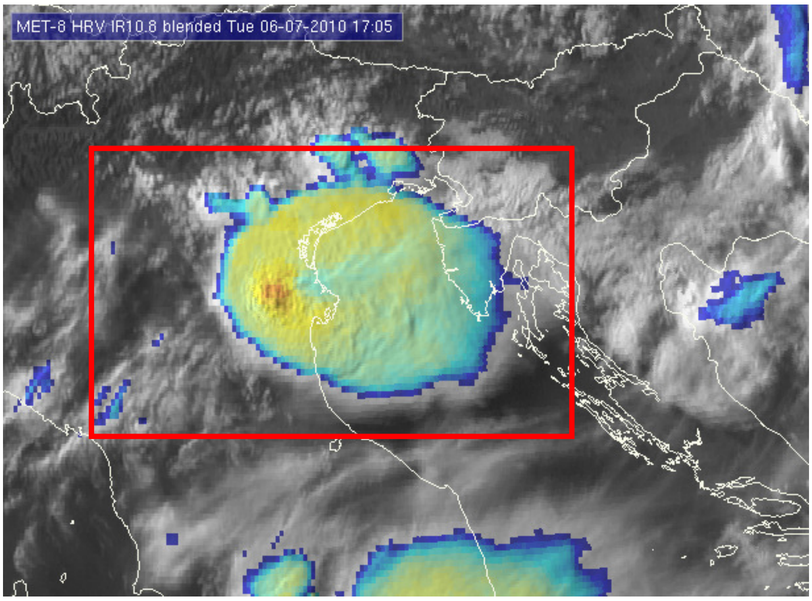

Figure 1: **Color-enhanced Meteosat 8 IR 10.8 μm image blended with HRV image at 17:05 UTC, 06 July 2010**

The BTD fields for studied case are shown in Figure 2. These fields generally correspond well with deep convective clouds, but in some methods occupy too large area to exclusively represent OTs, or show some false-alarm pixels. It has been noted, for example, that the field of O_3-IR BTD > 13K always occupy too large area during May and June. The reason for that seems to be a seasonal variation of the ozone concentration with the highest values in spring and the lowest in autumn over the mid-latitudes. Values > 14K in Figure 2b are generally located within the region of the most intense convection, suggesting that we might have to determined different threshold for this BTD method for each month. In order to determine more closely the location of the most intense convection and OT using the O_3-IR BTD method the COMB BTD method is developed (Figure 2c). This method takes into account both WV-IR and O_3-IR BTD and, as seen in Figure 2c, suggesting that only the O_3-IR BTD values > 13K in the region where the IR brightness temperature is < 215K and WV-IR BTD > 4K correspond with the regions of most intense convection and OTs. The CO_2-IR BTD (Fig. 2d) shows that values greater than 3.5K are generally located within the region of the most intense convection.

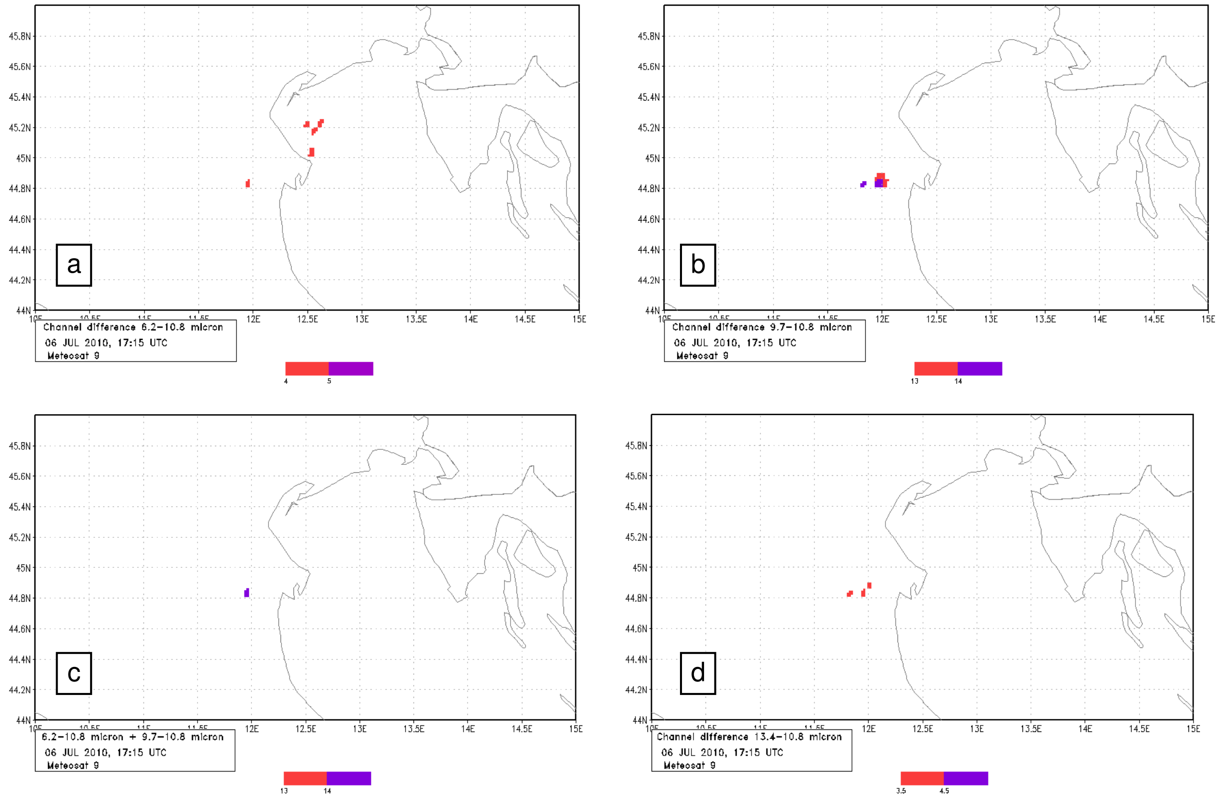

Figure 2: **Locations of the pixels meeting the criteria for brightness temperature and brightness temperature difference: A) WV–IR, B) O_3-IR, C) COMB BTD, D) CO_2–IR method for the selected area (red rectangle) on the image shown in Fig. 1.**

COMPARISON OF DETECTED OT WITH WEATHER ON THE AUTOMATIC STATIONS

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 the weather elements, such as wind, precipitation, temperature and humidity, measured by the instruments on the ground. The OTs are detected from Meteosat 9 data, using the WV-IR BTD with the criteria from Table 1. 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.

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 shift (°)						
	Croatia	Slovenia	Austria	Slovakia	Hungary	Bosnia and Herzegovina
N	0,14	0,14	0,15	0,16	0,15	0,14
E	0,08	0,07	0,08	0,12	0,11	0,08

Table 2: **Values of paralax shift northwards and eastwards applied to the locations of the automatic stations in different European countries**

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 were shifted north-eastwards for the amount of the parallax correction in the given region (Table 2).

The analysis of the correlation between the appearance of the OTs and the occurence of the abrupt changes in the weather elements has been performed for the period from May to September 2010. Meteosat-9 data have been used for OT detections. Coordinates of each pixel meeting the criteria for the brightness temperature and brightness temperature difference 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.

RESULTS

Comparison of the OTs with automatic station data showed that in more than 50% of the 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 3).

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 4). 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 3: **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 4: **Portions of different wind-gust intensities matching the OT detections**

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

Table 5**: Portions of different 10 min precipitation quantities matching the OT detections**

Table 5 shows correlation of 10-min precipitation amounts with the occurrence of the OTs (77%, Table 3) 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 (Table 5).

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 6*: 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. The temperature decrease larger than 4°C was observed in 68% of the cases matching the OT detections (Table 6), 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 appeared in the vicinity of the automatic station Karlovac in Croatia. The automatic station recorded extreme weather situation with gale wind gusts and shower. Maximum wind speed, shown by a dark blue line in Fig. 3c, was 17.4 m/s measured at 19:09 UTC. Recorded precipitation was 12.3 mm during 25 minutes (orange line in Fig. 3c).

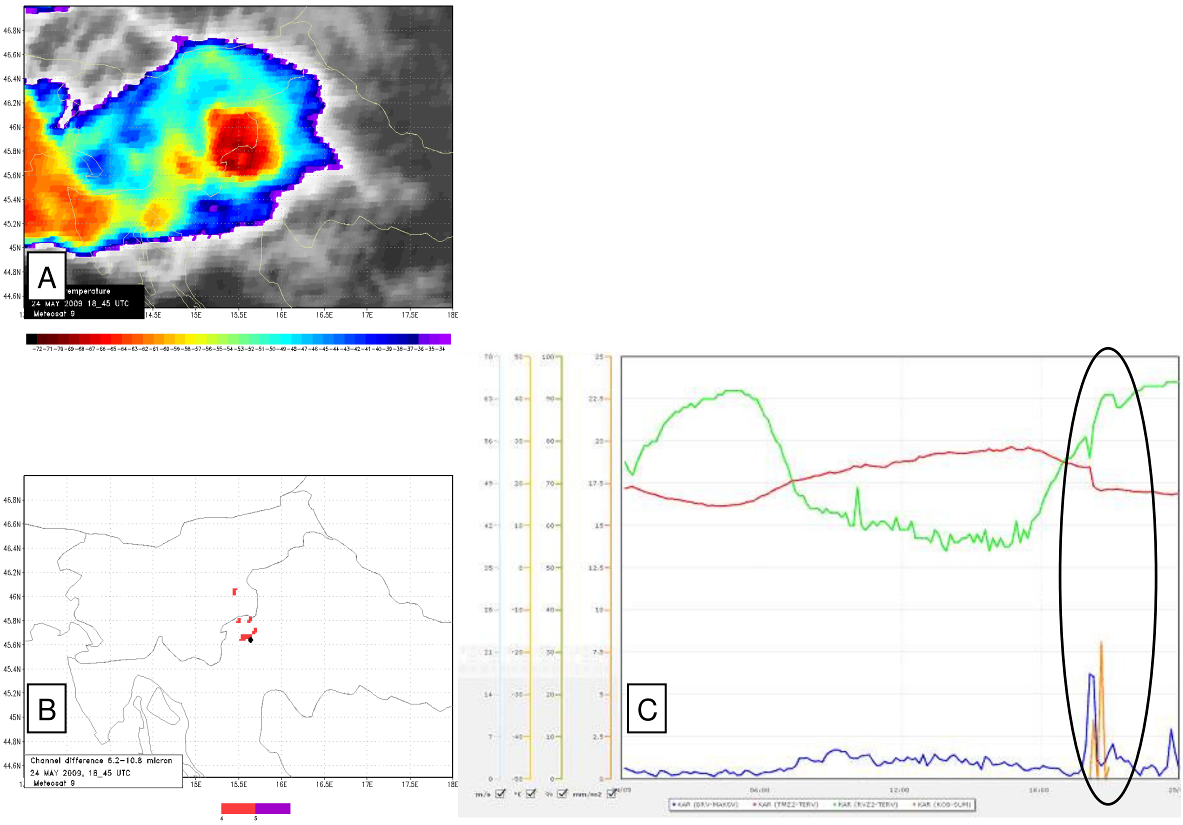

***Figure 3*: A) Color enhanced Meteosat 9 IR 10.8 µm image and B) brightness temperature difference (BTD) between 6.2 and 10.8 µm channel for 24 May 2009, 18:45 UTC. BTD larger than 4 K (red) is presumed to be connected with the OT. Location of the automatic station Karlovac is shown (black dot). C) Measurement data from the automatic station Karlovac: wind speed (blue), precipitation (orange), temperature (red) and humidity (green). Changes of the weather elements appearing at the time of the overshooting are circled.**

The event was also accompanied by significant temperature drop (red line) from 23.8°C at 19 UTC to 18.6 °C at 20 UTC, and relative humidity increase (green line).

CONCLUSION

This study showed significant correlation between the appearance of the overshootings 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. The best correspondence is found for precipitation, which appears close to detected OT in 77% of the analyzed cases. Wind gusts are correlated with OTs in 62% of the cases. Most of these are strong winds (5 to 10.8 m/s), but about 25% of the wind gusts correlated with OTs have gale wind speed (>17.2 m/s). Temperature drop and relative humidity increase is observed in about 50% of OT cases. 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.

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 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”.

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.

Berendes, T. A., Mecikalski, J. R., MacKenzie Jr., W. M., Bedka, K. M., Nair, U. S. (2008) Convective cloud identification and classification in daytime satellite imagery using standard deviation limited adaptive clustering. J. Geophys. Res., **113**, D20207, doi:10.1029/2008JD010287.

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.

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.

Kwon, E. H., Sohn, B. J., Schmetz, J., Watts, P. (2009) Use of ozone channel measurements for deep convective cloud height retrievals over the tropics. 16th Conference on Satellite Meteorology and Oceanography, 11-15 January, 2009, Phoenix, AZ, USA.

Lindsey, D. T., Grasso, L. (2008) An effective radius retrieval for thick ice clouds using GOES. J. Appl. Meteor. Climatol., **47**, 1222-1231.

Martin, D. W., Kohrs, R. A., Mosher, F. R., Medaglia, C. M., Adamo, C. (2008) Over-ocean validation of the Global Convective Diagnostic. J. Appl. Meteor. Climatol., **47**, 525-543.

Rosenfeld, D., Woodley, W. L., Lerner, A., Kelman, G., Lindsey, D. T. (2008) Satellite detection of severe convective storms by their retrieved vertical profiles of cloud particle effective radius and therodynamic phase. J. Geophys. Res., **113**, D04208, doi:10.1029/2007JD008600.

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

Setvak, M., Rabin, R. M., Wang, P. K. (2007) Contribution of the MODIS instrument to observations of deep convective storms and stratospheric moisture detection in GOES and MSG imagery. Atmos. Res., **83**, 505-518.

Setvak, M., Lindsey, D. T., Novak, P., Rabin, R. M., Wank, P. K., Kerkmann, J., Radova, M., Stastka, J. (2008) Cold-ring shaped storms in central Europe. Proc. 2008 EUMETSAT Meteorological Satellite Conf., Darmstadt, Germany, EUMETSAT.

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.