SATELLITE-BASED OVERSHOOTING TOPS DETECTION METHODS – COMPARISON AND VALIDATION

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I. INTRODUCTION

Detection and possible nowcasting of severe convective storms is one of the most challenging tasks for operational forecasters. Several studies showed that severe thunderstorms show specific signatures or shapes in the thunderstorm cloud tops, such as cold rings and cold-U/V signatures (e.g. Setvak et al., 2008; Brunner et al., 2007) as well as the overshooting tops (OT) (Bedka, 2010; Bedka et al., 2010). Since OTs in significant number of cases indicate some type of severe weather conditions (Bedka et al., 2010; Mikus and Strelec Mahovic, 2011), we tried to develop a satellite-based OT detection method which can be used as a tool for nowcasting severe thunderstorms.

OTs can be most easily identified in the high-resolution visible channel imagery as the lumpy textured appearance, however only during day-time. In the 10.8 μm infra-red window (IRW) channel, available during both day and night, a small cluster of very cold brightness temperatures can indicate that an OT is present. Other studies have combined IRW channel temperatures with those from the 6.2 μm water vapor (WV) absorption channel to identify OTs. Both IRW-only and WV-IRW techniques have shown some disadvantages when used alone, so it is important to evaluate the information provided by other spectral channels in an effort to improve objective OT detection. Here we use data from the SEVIRI imager on-board the Meteosat Second Generation (MSG) satellites to test four OT detection methods that use combinations of SEVIRI channels in the form of channel differences.

II. SATELLITE-BASED OT DETECTION METHODS

Satellite based methods for the detection of convective clouds and the heights of their tops are usually based on IRW measurements. Different objective satellite based OT detection methods using multi-spectral satellite data are presented in several studies, such as Berendes et al., 2008, Lindsey and Grasso, 2008, Rosenfeld et al., 2008, Schmetz et al., 1997 and Setvak et al., 2007. The techniques which use combinations of visible and near-IR satellite channels perform well only during the day time (e.g. Berendes et al.; 2008, Lindsey and Grasso, 2008; Rosenfeld et al., 2008). Therefore, we have tested the methods that use channels which can be used 24 hours a day. One of the most commonly used methods for detecting OTs is based on the brightness temperature difference (BTD) between the 6.2 μm and 10.8 μm (WV-IRW) channels. This technique is appropriate for day/night OT detection (e.g. Schmetz et al., 1997; Setvak et al., 2007). WV-IRW BTD greater that 0 K indicates presence of deep convective clouds and OTs. The brightness temperature in WV channel is greater in such cases than the one in the IRW channel, because of the presence of the water vapor above the cloud top. Contribution of the water vapor is included in the emission from the water vapor band. Because 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). According to Kwon et al. (2010) BTD of the ozone channel (9.7 μm) and the IRW channel also shows positive signature for the cloud tops above 11 km. They pointed out that the signal of BTD between ozone and IRW channel is even more significant than BTD WV-IRW near the tropopause suggesting that it could be a better indicator for the deep convective activity than BTD of WV and IRW channels. Additionally, BTD of carbon dioxide (13.4 μm) and IRW 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 CO2 gets smaller, making the BTD of the CO2 and IRW channel close to 0 or positive, in case of very deep convective clouds.

A more complex method, called IRW-texture, includes a combination of infrared channel brightness temperatures and their spatial gradients, a numerical weather prediction model tropopause temperature forecast and OT size criteria (Bedka, 2010) to identify OTs during both day and night at their proper spatial scale. Pixels with an IRW BT ≤ 215 K and near to or colder than the NWP tropopause are considered candidate OT pixels. A maximum OT diameter of 15 km and maximum anvil cloud IRW BT of 225 K are assumed based upon detailed analysis of OT signatures in satellite imagery. The anvil is sampled at a ~8 km radius from a candidate OT pixel in 16 directions to compute the mean anvil IRW BT. A candidate OT pixel that is 6.5 K colder than the surrounding anvil is considered an OT. Validation of GOES and/or SEVIRI OT detections against ground and space-based radar observations of OTs indicates a mean false alarm ratio of ~ 15%.

III. COMPARISON OF THE METHODS

The aim of this investigation is to compare the results of several different satellite–based OT detection methods and to validate their ability to locate very deep convective clouds and possible overshooting. All methods presented in our study include two criteria: one for the IRW brightness temperature and the other for BTD (Tab. 1). The COMB BTD method, a combination of BTD O3-IRW and WV-IRW includes IR brightness temperature criteria and the criteria for both BTDs. Bedka (2010) and Martin et al. (2008) used IRW brightness temperature ≤ 215 K as a threshold for very cold pixels within convective clouds. Setvak et al. (2007), using 1 km MODIS data, determined WV-IRW BTD in the range of 4 to 7K in the overshooting above the coldest cloud tops.

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

TABLE I: The IRW brightness temperature and the BTD thresholds for the WV-IRW, CO2-IRW, O3-IRW and COMB BTD method.

In order to present and compare the studied BTD methods we analyzed the convective system over Italy on 4 July 2009 at 17:00 UTC (Fig. 1). A red rectangle shows the area that will be used for the visualisation of the satellite-based OT detection methods in Figs. 2 and 3.

Fig. 1A shows the color-enhanced Meteosat 9 10.8 µm IRW channel image at 17:00 UTC on 4 July 2009. A region of deep convective clouds is located in northwestern Italy, near Swiss border. The IRW BT of the coldest cloud tops is lower than 210 K (red in Fig. 1A) meeting the mentioned BT criteria for the BTD methods in Table 1 and IRW-texture method. In HRV satellite image (Fig. 1B) the OT structure is located on the area of the coldest cloud pixels in the storm.

A)

B)

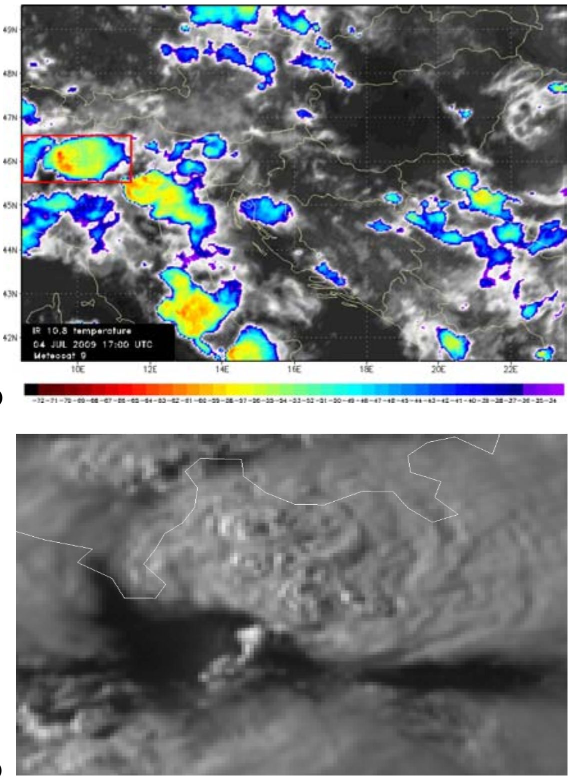

FIG. 1: A) Color-enhanced Meteosat 9 10.8 µm image at 17:00 UTC, 4 July 2009. Color scale from -33°C (purple) to -72°C (dark red). B) Meteosat 9 HRV channel image for the region outlined by the red box in panel A.

The BTD values of different channels for studied case are shown in Fig. 2. The WV-IRW BTD (Fig. 2A) and CO2-IRW BTD (Fig. 2B) values greater than 4K and 3.5K, respectively, are generally located within the region of the most intense convection in the IR and HRV satellite images (Fig. 3). However, although these values correspond well with deep convective clouds, they occupy too large area to exclusively represent OTs. This is even more evident in Fig. 2C which shows pixels detected as OTs by the O3-IRW BTD method. It has been noted that the regions of BTD values O3-IRW > 13K are too large compared to the expected size of the OT mostly in May and June. It is known that the concentration of ozone has the seasonal variation with the highest values in spring and the lowest in autumn over the mid-latitudes. In this case values > 14K (Fig. 2C) seem to be located within the region of the most intense convection, better corresponding to the pixels detected by the other BTD methods, suggesting that we might have to determine a threshold for this BTD method for each month separately.

A)

B)

C)

D)

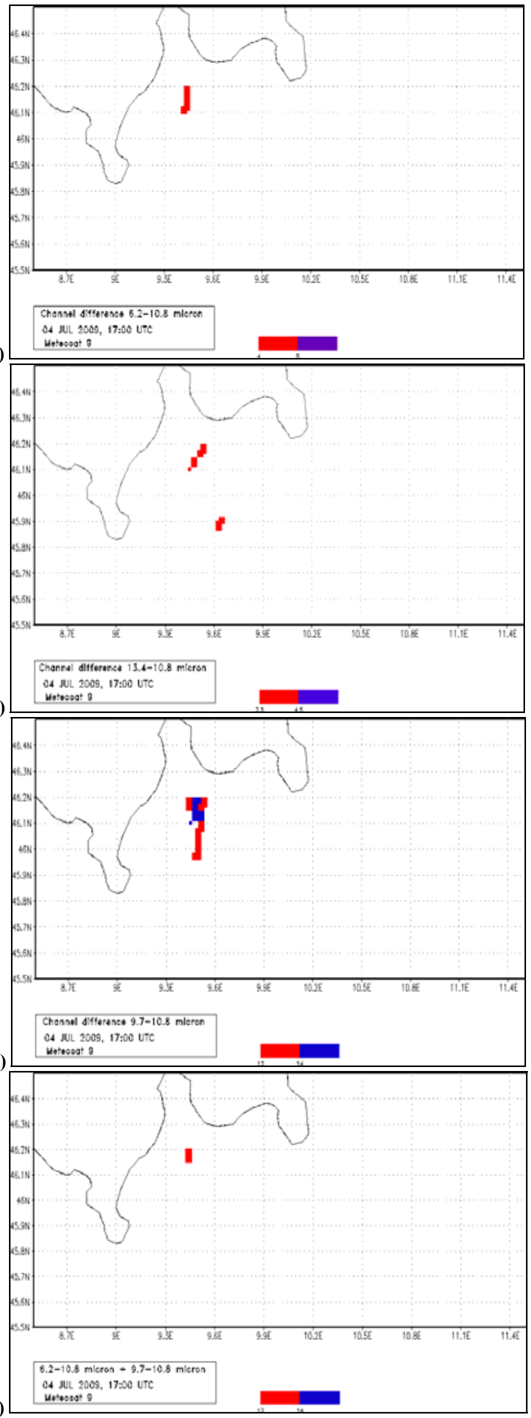

FIG. 2: Pixels meeting the criteria for the brightness temperature and BTD, detected using A) WV–IRW, B) CO2–IRW, C) O3-IRW and D) COMB BTD method for the selected area (red rectangle) shown in Fig. 1 at 17:00 UTC, 4 July 2009.

The COMB BTD method is developed (Fig. 2D) in order to use the ability of both WV and O3 channel data to identify significant cloud tops. The regions of most intense convection and possible OTs correspond to O3-IRW BTD values > 13 K in the region where the IRW BT < 215 K and WV-IRW BTD > 4 K. All presented BTD methods indicate the deep convection and OT on location of IRW-texture OT detection (black dot, Fig. 3).

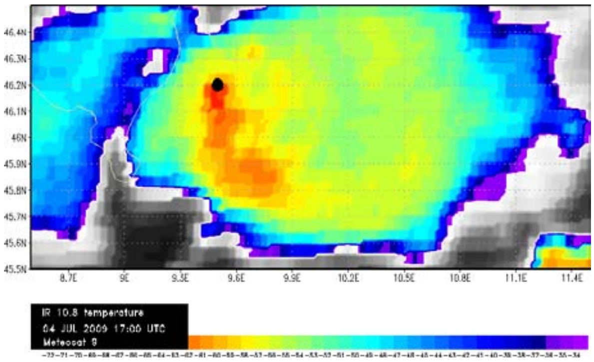

FIG. 3: Location of OT detected using IRW-texture (black dot)

IV. CONCLUDING REMARKS

We can conclude that all four investigated BTD methods indicate deep and very intense convection but not necessarily the OTs. In most cases pixels meeting defined criteria are too widely dispersed to exclusively represent OTs (Fig. 2). This suggests the need to adapt the criteria especially in case of O3-IRW BTD method which should have criteria depending on the seasonal variation of the ozone concentration. The work is still in progress. The results of detection for all five satellite based OT detection methods will be compared with the High Resolution Visible (HRV) satellite images during day-time in order to validate each method.

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