THE ANALYSIS OF THE ENHANCED-V STRUCTURES ATOP TORNADIC STORMS ACROSS ROMANIA

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ABSTRACT:
Enhanced-V is a structure that appears at the top of a storm and it is often associated with severe weather, especially hail and tornadoes (*McCann 1983, Adler et al., 1985*). These structures can be observed through satellite images provided by satellites such as Meteosat Second Generation, due to the spectral, time and space resolution the satellite has. The objective of this article is to determine the details of the enhanced-V type structures that have appeared in the upper structure of tornadic storms across Romania. All the cases of tornadoes that have been reported in Romania have been selected from the European Severe Weather Database (ESWD) and for each case a series of analysis were made to determine first if such structures were present and secondly, to find specific parameters of these structures. Analyzing the most clearly defined type of enhanced-V structures was the last step in determining which the best defined enhance-V structure was.

Keywords: *Enhanced-V, satellite images, tornadic storms, Romania, analysis.*

1. INTRODUCTION

Upper structure of storms has been studied since the 1980s from many perspectives (*Negri 1982, Heymsfield et al. 1983, 1983b, McCann 1983, Adler et al. 1985, Heymsfield and Blackmer 1988*) and many specific structures could have been observed, including the enhanced-V and cold-ring shape, in which the coupling between an area with higher temperatures and an area with lower temperatures close to one and another is specific. An indispensable tool in studying these features is the enhanced satellite images in infrared bands of long wavelength, about 11 mm.

In this article the interest is directed towards enhanced-V type structures. This structure is characterized by the following component areas (*Fujita, 1982, Negri, 1983, McCann, 1983, Heymsfield, Blackmer 1988*):

- Cold Area - the area with the lowest temperatures in the upper layers of the storm, which usually overlaps with the storms main updraft (**Fig. 1a**);
- Close-in Warm Area - the area with the higher temperatures located 20-40 km downwind (*McCann, 1983*) of the Cold Area (**Fig. 1b**)
- Distant Warm Area - the area with higher temperatures, located at distances of 40-120 km downwind from the Cold Area (**Fig. 1c**). This area is not always present in the enhanced-V structures and the temperature is usually smaller then the close-in warm area (*Heymsfield, Blackmer 1988*).

The genesis of this structure is due to penetration of the upper level winds by the strong storm ascending current, the updraft. The updraft acts to block the strong upper level winds and forces the flow to divert around it (*Fujita, 1978*). Having lower temperatures, the updraft's upper parts are eroded by the upper level winds and are carried in the downwind side. Thus in the infrared channels of the satellite images the “V” shape area stands out (**Fig. 1d**).

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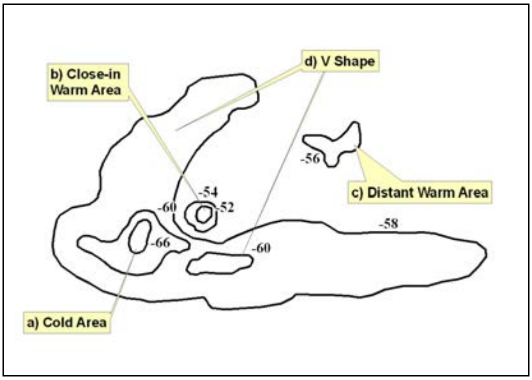

Fig. 1 Enhanced-V Structure
a) Cold Area, b) Close-in Warm Area, c) Distant Warm Area, d) „V" Shape
Adapted from Heymsfield and Blackmer 1988

The Cold Area appears due to adiabatic expansion associated with the rise of air in the troposphere above the storm updraft (*Alder, Mack, 1986, Heymsfield, Blackmer, 1988*).

Explanation of the Close Warm Area has several theories. Negri 1982, Heymsfield et al. 1983, Schlesinger 1984, believe that the emergence of this region is a result of subsidence of cold air, which is characterized by negative buoyancy, downwind of the updraft. Another theory states that stratospheric cirrus clouds, generated at the peak of overshooting tops are sinking in the storm anvil. Being located above the anvil in a warmer environment, these clouds appear warmer on infrared satellite images (*Wang et al., 2002 Setvak et al., 2005*).

The first part of the name "enhanced-V" has derived from the fact that it is necessary to do an enhancement to the infrared satellite images to identify the structure. The second part of the name is given by the "V" shape. Since this structure is not always a perfect "V" shape, there are many discussions on what name it should have. Some authors (*Setvak et al., 2010*) prefer to make a differentiation of names. Structures with the "U" shape are called "cold U shape" and the structures with "V" shape are called "cold V shape". Further on we will refer only to the name "enhanced-V" because the main references of this article use this name.

The main objective of this study is the analysis of the top structure of the storms that have generated tornadoes according to the database held by the European Severe Weather Database - ESWD.

The second part of the article describes the data we have used and its processing. In the third part of the article the methodology is described. It includes a first stage that shows how the enhance-V structures were identified and a second part showing how the parameters of the enhanced-V structure are extracted (*Brunner et al,. 2004*). Part four contains the analysis of these structures and a comparison between the enhanced-V cases found in Romania and those found in the United States.

2. SOURCES OF DATA AND THEIR PROCESSING

Satellites are the best tools that can make repeated observations of the upper structure of storms and processes that are taking place in this area. For the Romanian territory, the geostationary satellite Meteosat Second Generation - MSG provides the satellite images used for this study. It has a spectral resolution between 0.6 µm and 13.4 µm, divided in 12 spectral bands, a time resolution of 15 minutes, 11 of the bands with a spatial resolution of 3 km and one band in the visible range of 1 km spatial resolution (Source: Navigator Product EUMETSAT). All these data are freely available in the Earth Observation Portal application on the EUMETSAT organization website.

The temporal limitations of this study are defined by data availability. As mentioned, information without which this study could not be made is the infrared satellite images. The MSG satellite (Meteosat 8) and MSG 2 satellite (Meteosat 9) have began transmitting images of 19 January 2004, the date representing the starting point for our study. Before that date, the first generation Meteosat satellites were in order but they have inferior spectral and spatial resolution: 5 km, and 3 bands (Source: Navigator Product EUMETSAT). We have considered that it would not have been appropriate for our study to use data with different characteristics.

In Romania, according to the ESWD, there were reported a total of 65 cases of tornadoes from 2003 to the present day. Since only from 2004 there is a continuity of satellite images with the same characteristics, we can not consider the three cases of tornadoes reported in 2003.

To study the upper structure of storms the 10.8 µm infrared satellite images are used. For a better analysis of satellite products, which initially are in a gray scale scheme, an enhancement for certain ranges of values is needed. For the pixels that have a value included in the range between 200 and 240 on the satellite imagery a colored scheme is applied to help with an easier identification on the structures in the images (**Fig. 2**).

Processing of satellite images was done with MSG SEVIRI Image Processing and Visualization Software - MSG View, a free software created by Aydin Ertürk from the Turkish State Meteorological Service (TSMS). The software has a default setting that allows the viewing of enhanced 10.8 µm IR satellite images and the equivalent blackbody temperature from the upper surface of the storm (**Fig. 2**).

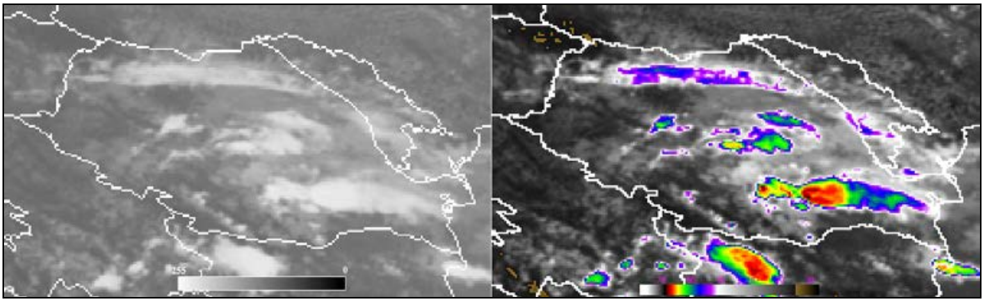

Fig. 2 Comparison of 10.8 µm IR satellite image without enhancement on the right and a enhanced satellite image in MSG View on the left

3. METHODOLOGY

The only database that contains information about tornadoes that were observed in Romania is the European Severe Weather Database. It contains information primarily from newspaper articles, but a contribution is also added from scientific articles or by trained personnel in the field of meteorology throughout Europe.

3.1 Identification of enhanced-V structures

A first selection of the cases was made by confirming on the High Resolution Visible - HRV satellite images that at the place and time noted in ESWD database there were specific structures associated with storms. Using the criteria suggested by Bader et all. 1995 to identify on satellite imagery thunderstorms we have analyzed all of the 62 cases. The purpose of this filtering was to eliminate mistakes in reporting tornadoes in the ESWD. Following this first step 11 cases have not pass the criteria mentioned above.

The remaining 51 cases were analyzed using enhanced 10.8 IR satellite images. Using Figure 1 as a model for each of the 51 cases we have chosen one representative satellite image, in which the specific features of the enhanced-V structure are searched, features that are described below:

- The existence of specific elements of an enhanced-V structure: the “V” or “U” shapes, cold area, close-in warm area, distant warm area (*Heymsfield, Blackmer, 1988*);
- The distance between the cold and the close-in warm area should be of 20-40 km (*McCann, 1983*);
- The cold area should overlap the storms main updraft;
- An area with lower temperatures to form a “V” or “U” shape which should have the tip overlapping or near the cold area and contain the close-in warm area;

Nine cases from the initial 51 had an enhanced-V structure that met the conditions mentioned above. Only these nine cases were analyzed further.

3.2 Identification of the specific parameters of the enhanced-V structures

To perform various quantitative and qualitative analyses between different cases, Brunner et al. 2007 proposed a series of seven parameters, which can provide more information for each case of enhanced-V:

- Minimum temperature (TMIN) is the lowest temperature of the top structure of the storm. It almost always coincides with the overshooting of the storm (Adler and Mack 1986, Heymsfield and Blackmer 1988).
- Maximum temperature (TMAX) is the highest temperature of the upper structure of the storm and it is located in the close-in warm area downwind of the cold area, surrounded by the “V” structure. In the figure 3 a), the location of TMIN and TMAX can be seen, having values of -60,4 ºC respectively -56,68 ºC.
- The difference between maximum and minimum temperature (TDIFF) is the next parameter and forms a temperature couple (*Negri, 1982, Fujita, 1982, Heymsfield et al. 1983, 1983b, McCann, 1983*);
- The distance between minimum temperature and maximum temperature (DIST) is the length of the segment connecting the center of the minimum temperature area with the center of the maximum temperature area. TDIFF and DIST are represented in figure 3 b) with values of 4,14 ºC, respectively 17,5 km.
- The “V”‘s arms length (DISTARMS) is given by the average of the two arms length. The length of an arm is measured from the tip of the “V” structure, which often overlaps with the point of minimum temperature to the point where temperature increases with more than 10% compared to the minimum

temperature (*Brunner et al. 2004*). **Fig. 3c** shows how to determine the enhanced-V structure arms length.

- -Angle arms (ANGLEARMS) is the angle between the two arms of the "V" (**Fig. 3c**), for this example case with a value of 55 º.
- Orientation (ORIENTATION) of the structure is defined according to four quadrants of 90 degrees each. The south direction has the value 0, and the first quadrant is between 0º and 90º to the south-west, quadrant two is between 90 º and 180 º, to the north-west, quadrant three is between 180º and 270º to the north-east and quadrant four between 270 º and 360 º to the south-east. The quadrant that contains most of the angle between the two arms (ANGLEARMS) gets the orientation of the enhanced-V.

How to determine the orientation is shown in **Fig. 3d**, and for this case the orientation is in the third quadrant.

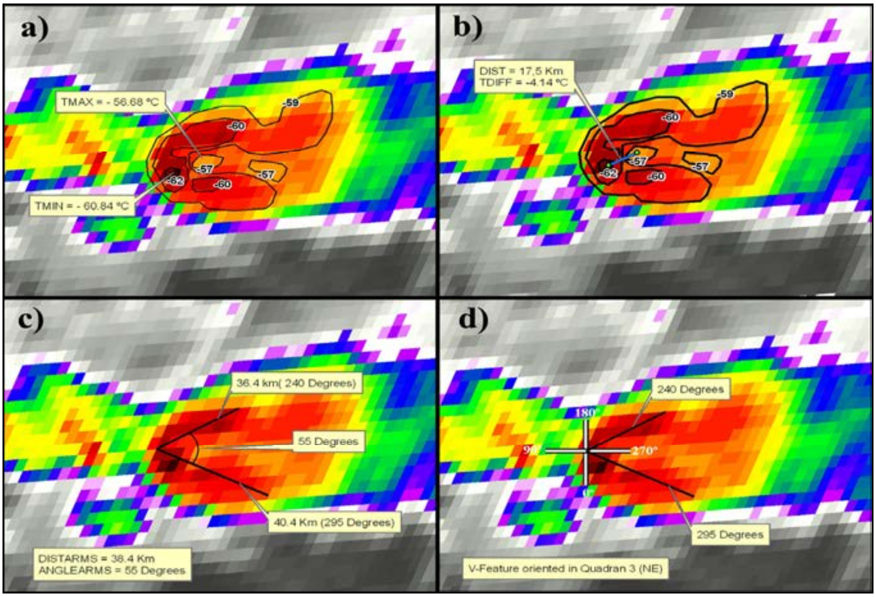

Fig. 3 10.8 µm IR satellite image from 27th of June 2005 12:57 UTC from Dambovita County The specific parameters of the enhanced-V structure: a) Location of TMIN and TMAX, b) Determination of TDIFF and DIFF, c) Measurement of ANGLEARMS and DISTARMS, d) Determining the enhanced-V structure quadrant. Adapted by *Brunner V et al. 2007*

4. ENHANCED-V STRUCTURAL ANALYSIS

4.1 Analysis of enhanced-V shape structures

Although the nine cases identified are those where the "V" structure is observable, not all correspond in detail with the model proposed by Heymsfield and Blackmer 1988 due to weather conditions that make the evolution of each storm to be different. The most important among these atmospheric conditions is the upper level wind direction and speed (*Fujita 1978*).

For example, the warm distant area can not be identified in all nine cases. The storm on the 31st of May 2007 in Galati County (**Fig. 4d**) does not have a warm distant area due to proximity of the structures arms. Similarly, the storm from the 22nd of May 2008 from Buzau (F**ig. 4f**), has a better close-in warm area highlighted, because temperatures gradually decreases from the close-in warm area outward, without further highlighting another warm area.

Depending on the interaction of strong ascending currents in the updraft and the upper level strong winds not all the times the ideal form of "V" can be observed. As mentioned in the introduction, the structure can sometimes take a "U" shape as seen with the storms of 27th June 2005 (**Fig. 4a**), 19th July 2005 (**Fig. 4c**), 31st May 2007 (**Fig. 4d**), and 22nd May 2008 (**Fig. 4f**). Other interesting developments can be seen in the storm of 31st May 2007 (**Fig. 4d**) where another updraft interacts with the "U" shape structure and makes the arm on the south-vest part to be better individualized than the other one. A lower cloud equivalent blackbody temperature can be observed at the south-vest arm. Also, the storm of 2nd July 2005, the "V" shape is not complete because the eastern arm, which is only half developed into normal direction, the other half is developed at an angle of almost 90 from the first half (**Fig. 4b**).

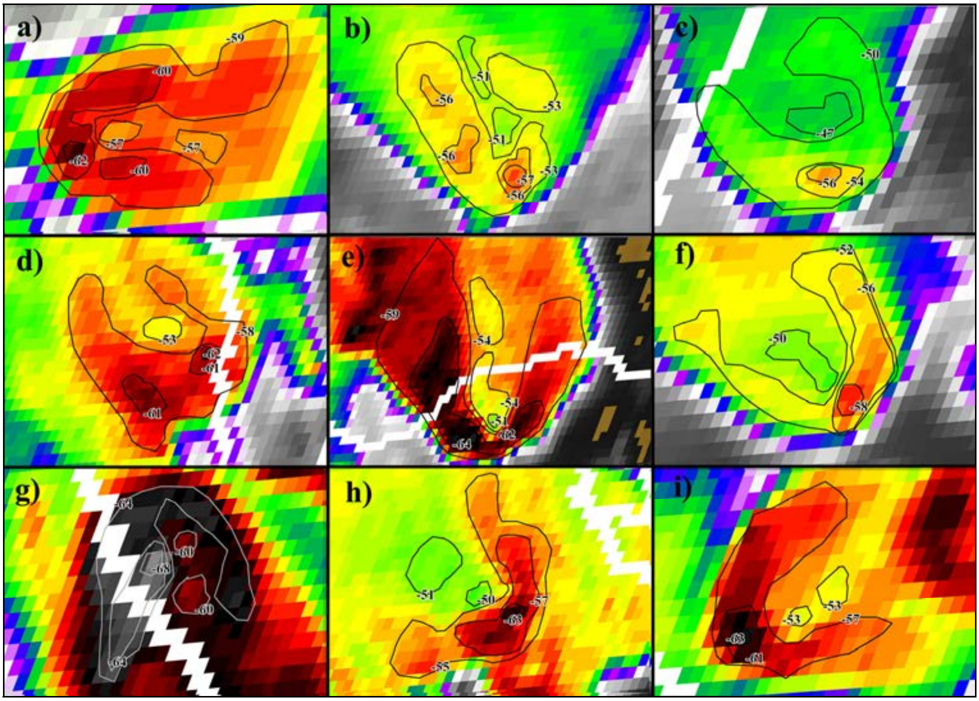

Fig. 4 Enhanced-V structures of tornadic storms identified from the ESWD
a) 27thJune 2005 12:57 UTC Dambovita County, b) 2ndJuly 2005 09:42 UTC Olt County,
c) 19th July 2005 13:42 p.m. UTC Arad County, d) 31st May 2007 14:42 UTC Galaţi County,
e) 22nd April 2008 13:57 UTC Constanta County, f) 22nd May 2008 14:42 UTC Buzau County,
g)12th May 2009 13:12 UTC Iasi County, h) 25th June 2009 12:57 UTC Constanta County,
i) 16th June 2010 15:12 UTC Caras-Severin County

4.2 Analysis of enhanced-V structure specific parameters

Firstly, having information about the specific parameters of each enhanced-v structure, we can compare the nine cases to see which has the best individualized structure from the storm that developed in Romania. Secondly we will make a comparison with the parameters obtained by Heymsfield and Blackmer 1988, in a quantitative analysis study carried out in the United States for a number of 209 enhanced-V structures from 4th May to 5th July 2004.

4.2.1 Comparison of the enhanced-V cases from Romania

The result of more detailed analysis of each enhanced-V structure is represented in the charts from figure 5, which contains all the specific parameters listed in subchapter 3.2 of this article.

The storm on 12th May 2009, which according ESWD had a tornado that hit the settlement of Bivolari from Iasi County, has the lowest value of TMIN, of -65.3 °C (**Fig. 5a**). TDIFF has a value of only 4.1 °C (**Fig. 5c**), the lowest of all cases, TMAX has the highest value of the nine cases of -61.5 °C (**Fig. 5b**). Given the above values and that the enhanced-V structure of the storm (**Fig. 4g**) has some irregularities, TMIN is on one of arms of “V” feature, we can assume that it’s not the best individualized case, even if it has the lowest TMIN value. These issues tend to lead to the conclusion that the “V” shape is not specific to the enhanced-V process, and it can be due to a coincidence of form.

On 19th July 2005, in Arad County, a total of three tornadoes were reported in the settlements Socodor, Cermei and Chişineu-Cris. The storm that produced these three tornadoes had the highest minimum temperature of all the cases we have analyzed, -56.3 °C (**Fig. 5a**), TMAX was - 47.7 °C (**Fig. 5b**) and the TDIFF parameter had a value of 8.6 °C (**Fig. 5c**). Storm structure tends more towards a “U” shape but it is well individualized (**Fig. 4c**). Even if the upper structure has higher temperatures, there are indicators that show that this storm was a storm with all specific enhanced-V features.

TDIFF parameter can sometimes provide information about the severity of a storm. A bigger value of this parameter indicates that the storm has a strong updraft, which manages to reach higher altitudes, thus have low equivalent blackbody temperatures and can block strong winds from the altitude. This will lead to the appearance of a close-in warm area with a big difference from the temperature of the cold area (*Fujita, 1978, Negri, 1982, Heymsfield et al., 1983, 1983b, McCann, 1983, Adler et al., 1985, Heymsfield, Blackmer 1988*).

According ESWD, on the 22nd April 2008, a supercell storm led to the formation of several tornadoes that hit more than 5 localities in Romania and Bulgaria. This storm is the case that has the highest value of the parameter TDIFF, 12, 6 ºC (Fig. 5 c), TMIN with -64,4 °C (**Fig. 5a**) and TMAX -51,8 °C (**Fig. 5b**). The parameter that provides information about length of the arms structure has also the highest value, 83,4 km (**Fig. 5e**), showing a difference of more than 20 km from the next value of this parameter. These values and the form almost identical to the structure proposed in **Fig. 1** enhanced-V, make us conclude that this storm is the best individual of all analyzed.

Another TDIFF parameter value that stands out is from the storm on 25th June 2009, with a value of 12,4 °C (**Fig. 5c**). This storm is also notable because the angle formed by two arms of the structure is the largest of all cases with a value of 85 º C (**Fig. 5f**). These issues may be due to a strong updraft, leading both to create differences between the cold and warm area near the structure, and block the wind from high altitude and angle between arms creating a structure (*Fujita 1978*).

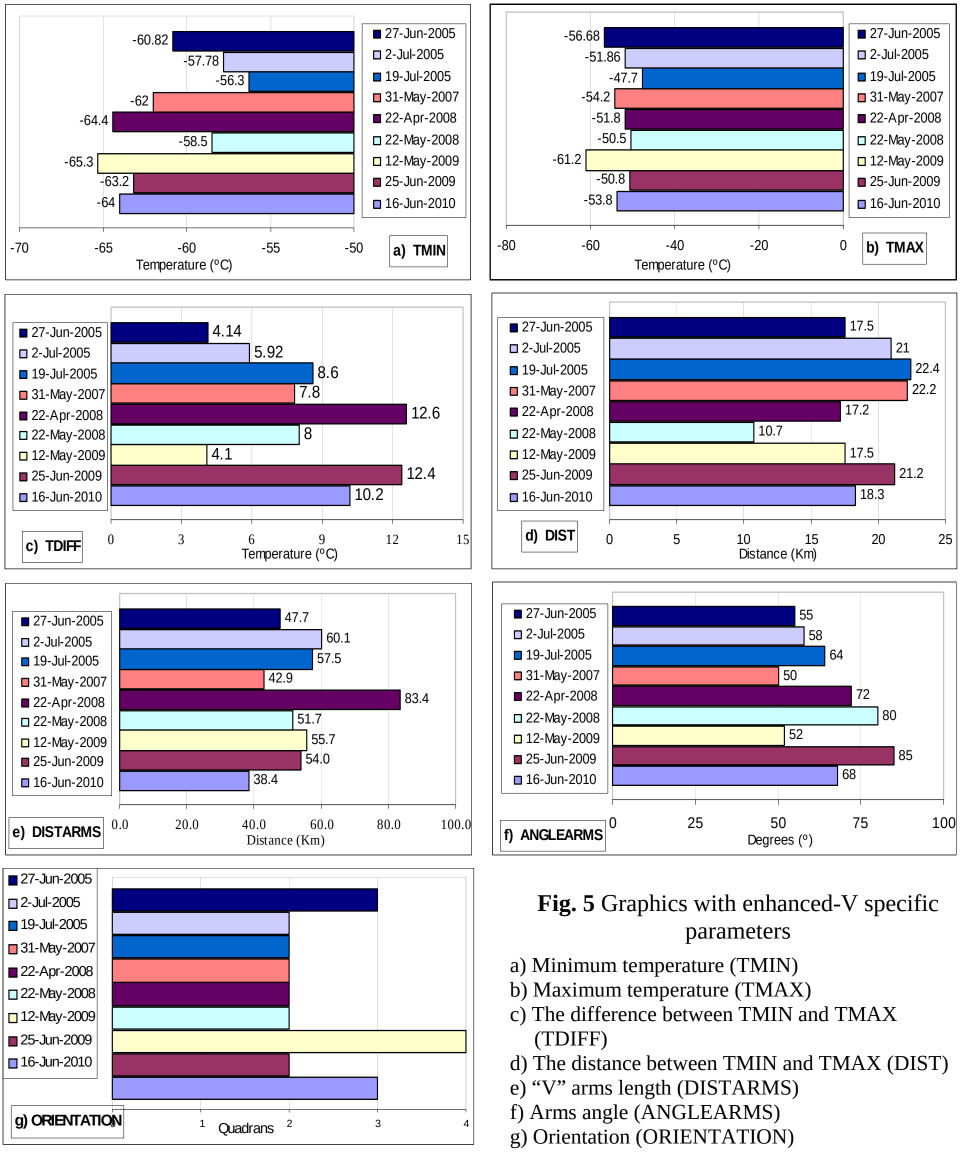

Fig. 5 Graphics with enhanced-V specific parameters

a) Minimum temperature (TMIN)
b) Maximum temperature (TMAX)
c) The difference between TMIN and TMAX (TDIFF)
d) The distance between TMIN and TMAX (DIST)
e) "V" arms length (DISTARMS)
f) Arms angle (ANGLEARMS)
g) Orientation (ORIENTATION)

The parameter that determines the orientation of enhanced-V structures, ORIENTATION, can provide us information about the upper level wind direction. Most cases, six out of nine, had the orientation in the north-western quadrant, two cases had orientation in the third quadrant, to the north-east, and one case had an south-east orientation, to the fourth quadrant. The small number of cases doesn't allow us to draw a conclusion about the dominant wind direction in which most storms with enhanced-V signatures occur.

4.2.2 Comparison cases of enhanced-V U.S.

Considering numerical and climatic considerations, one can say that won't be appropriate to compare mean, maximum and minimum values of the specific parameters of enhanced-V structures that have been observed in Romania with those from the United States. We will still do this comparison to see that differences can we find between the two situations. Figure 6 has this comparison represented in a graphical form.

Between the average values of TMIN and TMAX it can be seen that there is not a big difference, 9 °C respectively 3 °C. The United States have smaller values for TMIN -72 °C (**Fig. 6a**), respectively -56 °C (Fig. 6 b), while the cases from Romania have values of -61 ºC for TMIN (**Fig. 6a**) and -53 °C for TMAX (**Fig. 6b**). The TDIFF parameter has a bigger difference between mean values. Cases in the United States have an average of 16 ºC (**Fig. 6c**), while the average of the Romanian cases is only 8 °C (**Fig. 6c**).

Regarding the parameters that cover the spatial aspects DIST, DISTARMS and ANGLEARMS the mean values are close to one another. For the parameters mentioned above the values are 10 km (**Fig. 6d**), 41 km (**Fig. 6e**) and 75 º (**Fig. 6f**) for the United States cases and for the Romanian cases the same parameters have values of 19 km (Fig. 6 d), 55 km (**Fig. 6e**), 65 º (**Fig. 6**).

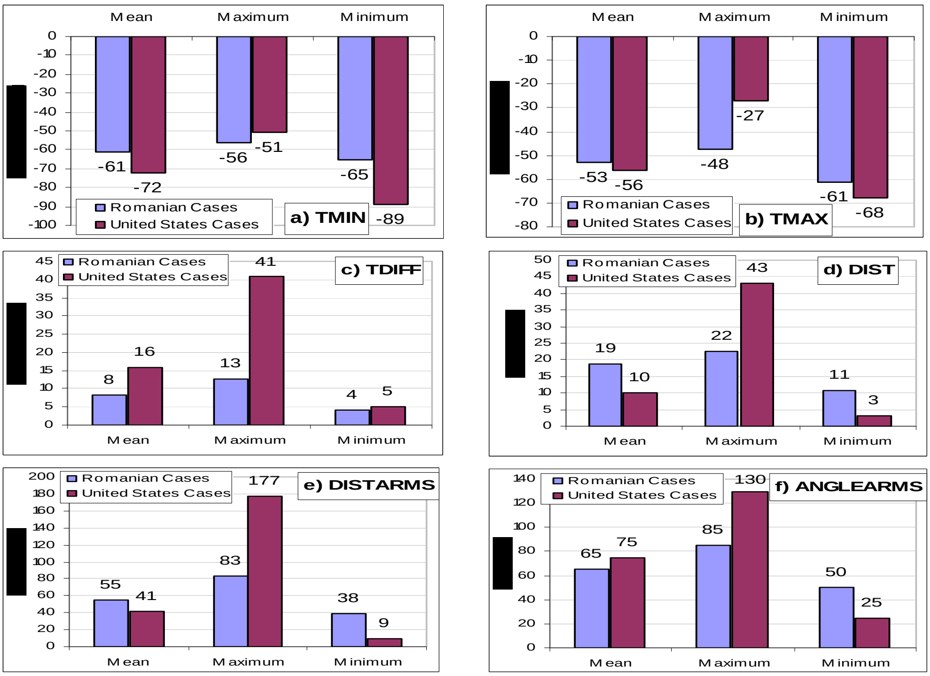

Fig. 6 Comparison of the mean, maximum and minimum enhanced-V specific parameters values that have been found in cases from Romanian and those found by Brunner et al. 2007 in cases from the United States

a) Minimum temperature (TMIN)
b) Maximum temperature (TMAX)
c) The difference between TMIN and TMAX (TDIFF)
d) The distance between TMIN and TMAX (DIST)
e) "V"'s arms length (DISTARMS)
f) Arm angle (ANGLEARMS)

Differences between maximum and minimum enhanced-V structures specific parameters may vary greatly. This can be attributed to the fact that there were considered more cases from the United States, and the chances are greater for unusual situations to arise and thus to appear extreme values of parameters.

From these values we can conclude a very well known fact: the North American continent storms are more severe than those in Romania.

5. CONCLUSIONS

Starting from the European Severe Weather Database, the only source of information about tornadoes that affected Romania, we have determined whether the storms that produced tornadoes had enhanced-V feature in their upper level structure. Such structures are generally associated with severe meteorological phenomena and it could be considered a validation from the satellite imagery perspective of this database.

Using High Resolution Imagery in visible spectrum and infrared images of 10.8 µm, from the Meteosat Second Generation satellite, there we have determined which cases had an enhanced-v structure. Enhancing the infrared satellite images whit MSG View helped us to find our first result: nine cases of storms that have enhanced-V structures. Finding the values of the specific parameters for the nine cases led to the determination of a number of unique features both in terms of structure and in terms of equivalent blackbody temperature values. Another set of results was obtained from the analysis of both points of view mentioned above. He could see that every storm evolves differently depending on weather conditions, particularly on the strong upper level winds. As an example, the storms such the one in the 27th June 2005, 22nd April 2008 and 16th June 2010 have a structure very similar to the model proposed by Heymsfield and Blackmer 1988, while the storm from the 12th May 2009 only resembled an enhanced-V structure. By comparing the nine cases, using the values of the temperatures recorded in the upper structure of the storms, the storms from 22nd April 2008 and 27th June 2005 had values close to the specific values of the enhanced-V structures (*Brunner et al. 2004*).

Emphasizing both structural analysis and temperatures in conjunction with the fact that the storm from 22nd April 2008 and 27th June 2005 had a series of tornadoes that hit more then five settlements in the county of Constanta and for the second case three settlements in the county of Arad, we can concluded that these situations were the most severe storms that occurred in Romania from the point of view of enhanced satellite images, more specifically enhanced-V structures.

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