OBSERVATIONS OF INCREASED IR3.9 REFLECTIVITY AT THUNDERSTORM CLOUD TOPS

Mária Putsay, André Simon, Ildikó Szenyán and István Sebők
Hungarian Meteorological Service, Kitaibel Pál u. 1, H-1024 Budapest, Hungary

Abstract

An area of increased IR3.9 reflectivity in the daytime SEVIRI imagery can sometimes be observed on thunderstorm cloud tops, which indicates presence of small ice crystals. This can be caused by different mechanisms: e.g. by very strong updraft within the thunderstorm and/or presence of above anvil cirrus clouds, like plumes or pileus clouds. These phenomena are supposed to be possible indicators of the storm severity and its rapid development.

The purpose of the paper is to study possible reasons of the increased IR3.9 reflectivity and to evaluate existing hypothesis. For this we used measurements of the Hungarian and Slovak radar network and METEOSAT satellite imagery, as well as photographs and time-lapse movies of thunderstorm clouds.

Small ice crystals on the thunderstorm cloud top could be caused not only by strong updraft, but also by cold cloud base or high pollution.

INTRODUCTION

An area of increased IR3.9 reflectivity in the daytime SEVIRI imagery can sometimes be observed on thunderstorm cloud tops indicating presence of small ice crystals. This can be caused by different mechanisms: very strong updraft within the thunderstorm, or presence of above-anvil cirrus clouds, or cold cloud base or high pollution (e.g. PyroCb, or high dust load).

We studied some of the possible reasons of the increased IR3.9 reflectivity:

- Five severe storm cases were analyzed when the radar data indicated strong updraft: cases with WER (Weak Echo Region) or BWER (Bounded Weak Echo Region) echoes.
- Eight severe storm cases with above–anvil cirrus clouds were analyzed. In the ice-plume cases the presence of cirrus clouds were seen in the satellite imagery. Other type of above-anvil cirrus clouds were analyzed in simultaneous satellite images and surface photographs.

The presence of small ice crystals on the storm cloud top could be an indicator of storm severity (Lindsey et al., 2006). Small ice particles may be present on the cloud top due to cells with strong updrafts. In strong updrafts the small water particles forming at cloud base reach the cloud top quickly and have less time for interacting and growing (Lensky and Rosenfeld, 2006). However, the presence of small ice crystals could be not, or only indirectly related to the updraft strength.

DATA AND METHODOLOGY

The improved spectral resolution of the Meteosat Second Generation (MSG) satellite makes it possible to retrieve cloud top microphysical properties at high temporal resolution. 5-min satellite data were used when available.

The SEVIRI IR3.9 channel data provide information about the cloud top particle size. Daytime the IR3.9 radiance consists of solar reflected and thermal emitted components. The solar component (the
IR3.9 reflectivity) is sensitive to the particle size. Over the thunderstorm cloud tops (being very cold surfaces) the solar component is often dominant, unless the sun is too low.

In the following figures we visualize the IR3.9 brightness temperature (BT). Its local maximum in most of the cases coincides with the area of the local maximum of IR3.9 reflectivity, which in turn shows the local minimum of the cloud top particle effective radius (Reff). In case of low solar elevation the above statement was always checked with the ‘Rosenfeld and Lensky tool (MSG_RGBv2007)’ (Lensky and Rosenfeld, 2006). This tool was used also to retrieve the Reff values.

Blended images are presented merging the color enhanced IR10.8 or IR3.9 image with the HRV image to see together the cloud top morphology and the IR BT distribution. This method was developed by Martin Setvák (Setvák et al., 2009).

Vertical cross sections, CAPPI and column maximum radar products from the Hungarian and Slovak radar network were studied.

CASE STUDIES WITH STRONG UPDRAFT OBSERVED BY RADAR DATA

Five severe storm cases were studied when WER (Weak Echo Region) or BWER (Bounded Weak Echo Region) echoes was found in the radar data. These echoes are supposed to indicate strong updrafts. In all five cases (24 and 26 June 2008, 25 June 2007, 3 August 2009 and 19 July 2011) about the same time increased BT patches were found near to the overshooting top area, or all around the anvil top. Note that in the 19 July 2011 case above-anvil ice plume was also present. Fig 1 and 2 show two examples for simultaneous BWER/WER radar echoes and satellite images.

CASE STUDIES OF THUNDERSTORMS WITH ABOVE-ANVIL ICE PLUMES

The ice-plumes formation was successfully simulated by Wang (2007). On the top of severe storms ice plumes may form from the moisture injected above the thunderstorm top by the storm itself by gravity wave breaking mechanism. The ice particles of jumping cirrus may also contribute as ice plume material.

Four severe storm cases with above-anvil ice-plume were analyzed in the satellite images. An example is shown in figure 3, a thunderstorm over northern Italy. In this case increased IR3.9 BT area is seen around the ice plume region. It is interesting that the shape of the area of small ice crystals resembles rather the shape of the ship trail gravity wave crests, than the ice plume itself.
In the other three cases we found that the ice plume particles are not always smaller than the particles of the ‘background’ anvil. For example on 06 July 2010 afternoon a long living distinct ice plume was well seen in the HRV/IR10.8 blended image. However, in the IR3.9 channel the ice plume had no distinct contrast compared to the ‘background’ anvil. The ice plume particles were not smaller, than the anvil particles around it.

Figure 3: HRV/IR10.8 (left) and HRV/IR3.9 (right) blended images from 6 July 2010 06:00 UTC.

CASE STUDIES OF OTHER TYPE OF ABOVE ANVIL CIRRUS CLOUDS

Two cases were analyzed when pileus cloud was photographed. A pileus is a small, horizontal cloud that can appear above a cumulus or cumulonimbus cloud. They are formed by strong updrafts by lifting the moist layer above them. If the pileus cloud forms at high altitude – just below the tropopause – the water vapor will deposit directly to ice crystals. As there is not much moisture at high levels so the high-level pileus will consist of very small size ice crystals. Pilei tend to change shape rapidly.

Two cases were analyzed: from 25 and 27 May 2010. The 27 May 2010 case was analyzed in detail in a previous paper (Simon et al., 2010). The other case is shown in figure 4. Beside the photograph convection RGB images are presented. At the time the pileus cloud was photographed (over northwestern Hungary) a small yellow patch appeared on the convection RGB image. In this RGB type the yellow color represents cold cloud top covered with small ice crystals. In both cases the pileus appeared as short living small yellow patch in the convection RGB image and as small increased BT patch in the IR3.9 channel. It changed its shape rapidly.

Figure 4: Photograph (left, taken by Gyula Borbély stormchaser) from 25 May 2010 16:33 UTC. Convection RGB images from 16:23 and 16:33 UTC (middle and right). The photograph was taken from the direction of the arrow.

After this a very interesting feature appeared on the satellite imagery over southwestern Slovakia (see Fig 5). On the convection RGB images (first column) a yellow ‘arch’ appeared above the upwind side of the anvil of a very rapidly developing thunderstorm cell. This cell is a cold ring shape storm (see the HRV/IR10.8 images in the third column). In the day&night RGB images one can see an ‘arch-like’ semitransparent cloud ‘overhanging’ the thick anvil (in dark blue color). In the HRV/IR3.9 blended images (last column) one can see that the structure is smoother near the upwind anvil edge than in the middle of the cell.
Figure 5: Satellite images and surface photograph from 25 May 2010. Satellite images: convection RGB (first column), day&night RGB (second column), HRV/IR10.8 blended (third column) and HRV/IR3.9 blended (last column) images. The photograph was taken by a storm chaser at 17:35 UTC from the direction of the arrow.
From all these features one can conclude that an arch like thin cirrus cloud might be above the anvil. The surface photograph shows that such an above anvil cirrus cloud was really present. This arch like thin cirrus cloud could have been developed like a very huge pileus cloud.

Another very interesting case occurred on 12 May 2007. This case was well documented by photographs. Over the thunderstorm top huge extended cirrus cloud layer(s) were observed, very similar to the lenticularis clouds, which usually develop atop of high mountains in strong wind (figure 6). In this case the wind below the tropopause was really very strong (45 m/s according to both Budapest and Vienna TEMPs). The fact that the thunderstorm ‘acted’ like a mountain indicates that the updraft should have been very strong.

Figure 6: Photograph taken by Tamás Mirk stormchaser on 12 May 2007 16:26 UTC (left). To illustrate the similarity of the above anvil cirrus cloud to lenticularis clouds a photograph is presented on the right.

Figure 7: Satellite images and surface photograph from 12 May 2007 15:40 UTC. Satellite images: convection RGB image (upper left), HRV/IR3.9 blended images visualized with two different color scales (upper middle and right). The surface photo was taken by Tamás Mirk storm chaser. The arrow in the below left panel shows the direction the photograph was taken from.
Figure 8: Satellite images and surface photograph from 12 May 2007 16:25 UTC. Satellite images: convection RGB image (upper left), HRV/IR3.9 blended images visualized with two different color scale (upper middle and right). The arrow in the left panel shows the direction the photograph was taken from.

In the Figs. 7 and 8 simultaneous satellite and surface photographs are seen. The photos were taken about the same thunderstorm from two different directions. The second one was taken from up wind direction, while the first one from the ‘sideways’.

RETRIEVED EFFECTIVE RADIUS VALUES

The satellite images were analyzed also with the Rosenfeld-Lensky tool MSG_RGBv2007 (Lensky and Rosenfeld, 2006). Effective radius values were retrieved on the thunderstorm cloud top, in the regions of interest: around the overshooting tops in case of observed BWER/WER radar echoes or in the above anvil cirrus cloud area. Table 1 contains a summary of the cases: the fact whether an increased IR3.9 BT area was found in the region of interest and the minimum retrieved effective radius in these regions. The retrieved Reff values show a large range. Note, that this tool retrieves Reff value with the assumption the particles are spherical water droplets. The real Reff values of ice crystals are very likely even smaller.

In all five of BWER/WER echo cases increased IR3.9 BT patch(es) appeared at the overshooting top(s). The minimum Reff values varied from 22 to 39 microns. Note that even the first case was a severe storm, very likely a supercell.

Eight severe storm cases with above-anvil cirrus cloud were studied. In almost all cases increased IR3.9 BT values were found on the area of the above-anvil cirrus clouds, indicating smaller ice crystals in the cirrus cloud than on the ‘bare’ anvil top, except for two ice-plume cases, in these cases we did
not found a distinct contrast between the cirrus covered area and the ‘bare’ anvil top. The reason of this might be that during ice plume formation additional moisture is injected from inside the thunderstorm above the anvil. So the ice-plume forms not only from the pre-existing lower stratospheric moisture. Additionally, the anvil could be also covered by small ice crystals formed in regions of strong updraft and subsequently spread by outflow at the top of the thunderstorm. The retrieved Reff values were the lowest in the pileus, ‘arch-like’ cirrus and lenticularis cases. In these cases, the above anvil clouds might be formed only from the pre-existing humidity.

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<th>Feature</th>
<th>Date</th>
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Table 1: Summary of the studied cases: studied features (first column), dates (second column), minimum of retrieved effective radius (third column) and indication whether an increased IR3.9 BT patch(es) was found near the overshooting tops or on the above anvil cirrus cloud areas.

**DISCUSSION**

The presence of small ice crystals in/above the storm top may be an indicator of the storm severity and its rapid development. Strong updraft may generate small ice particles on the cloud top (direct effect). However, an above-anvil cirrus cloud can cover some part of the storm top. In case small ice crystals are found they can belong to the cirrus cloud and not to the thunderstorm top.

We have studied different types of above-anvil cirrus clouds. As their formation was related to strong updraft, the small ice crystals they consist of can serve as an (indirect) indicator of strong vertical motions, although the ice particles do not form directly within the updraft. The particle size and the thickness of the cirrus cloud depend not only on the updraft speed (e.g. speed of the environmental wind, moisture content above the thunderstorm).

It is important to keep in mind that small ice crystals on the thunderstorm cloud top could be caused not only by strong updraft, but also by cold cloud base or high pollution (e.g. dust load or PyroCb). Also the high level lee clouds typically consist of small particles.

**ACKNOWLEDGEMENTS**

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**REFERENCES**
