

Severe storm over Hungary on 10 June 2013

Deflecting above anvil ice-plume

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On 10 June 2013 large hail (diameter up to 3 cm) were reported from several locations of Hungary falling from several convective clouds. We studied one storm of them, causing large hail around 14:50 UTC in four neighboring settlements (see Fig. 1 for their locations).

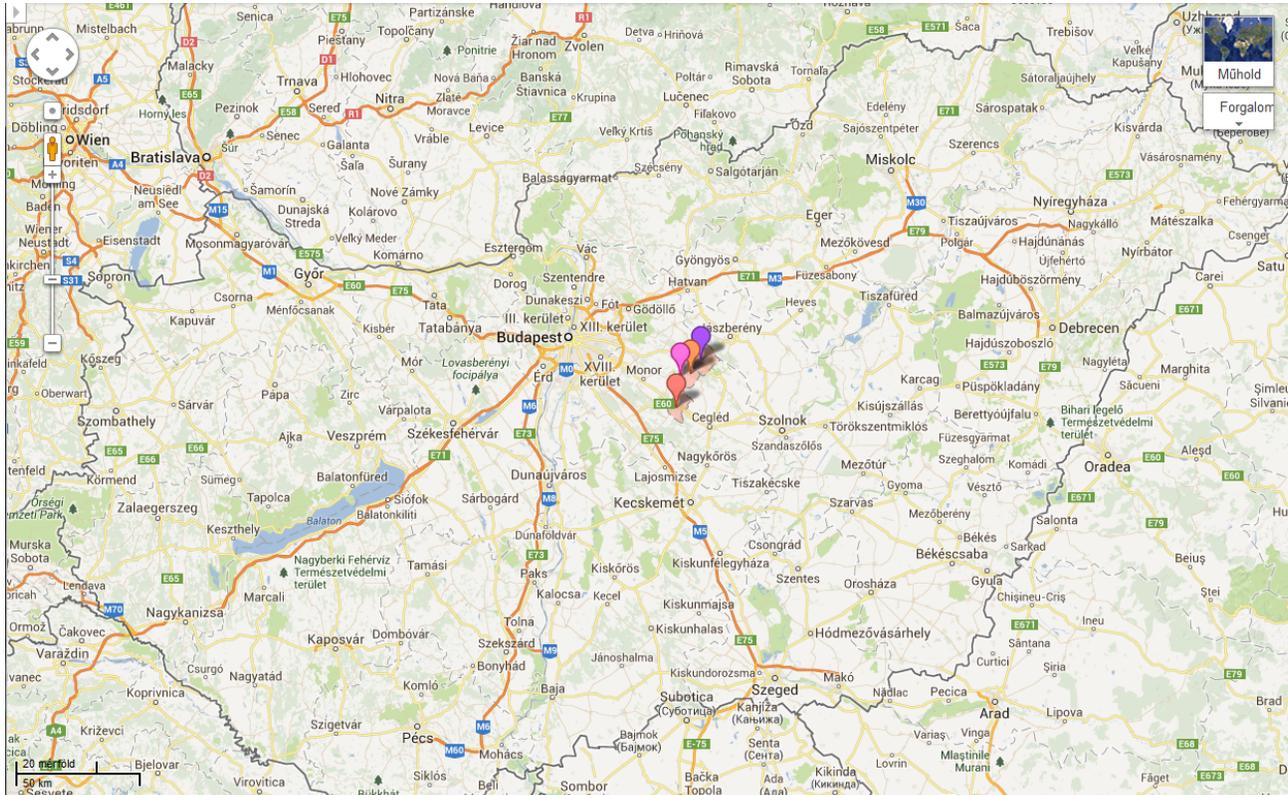


Fig. 1. The colored bubbles indicate the locations of the settlements reporting large hail around 14:50 UTC on 10 June 2013.

5-minute Meteosat SEVIRI images and 5-minute radar data of the Hungarian radar network were used to study this event. In Figs. 2 and 3 one can see four panels: HRV cloud RGB image (top left), IR10.8 image (top right), radar column maximum reflectivity ($\log Z$) image overlaid on HRV image (bottom left) and HRV/IR10.8 blended image (bottom right) at 14:55 and 15:35 UTC. A purple arrow indicates the studied cell in the radar panel of Fig. 2.

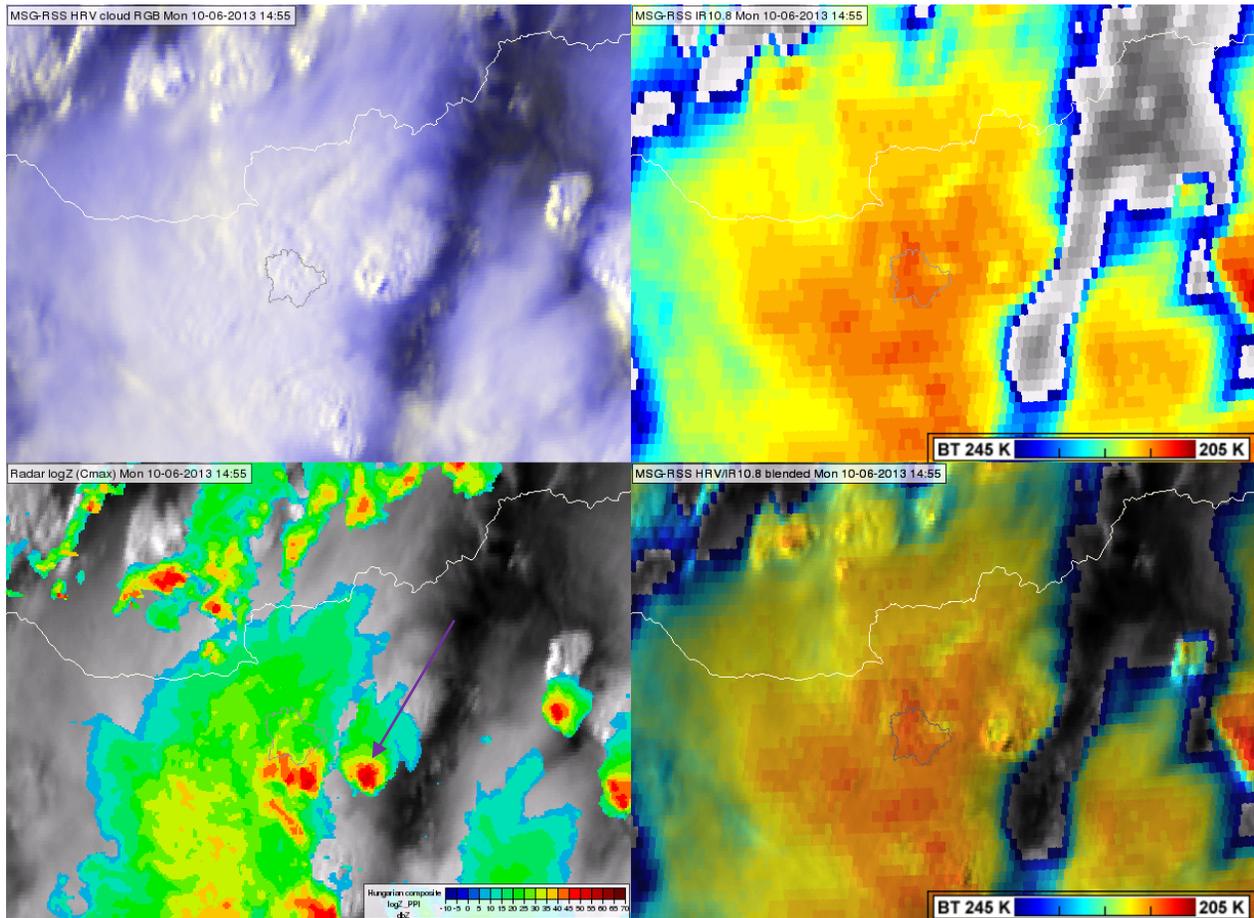


Fig 2 Radar and Meteosat SEVIRI images: HRV cloud RGB image (top left), IR10.8 image (top right), radar column maximum reflectivity ($\log Z$) image overlaid on HRV image (bottom left) and HRV/IR10.8 blended image (bottom right) at 14:55 UTC. The purple arrow indicates the studied cell. Budapest, the capital of Hungary is indicated by grey contour.

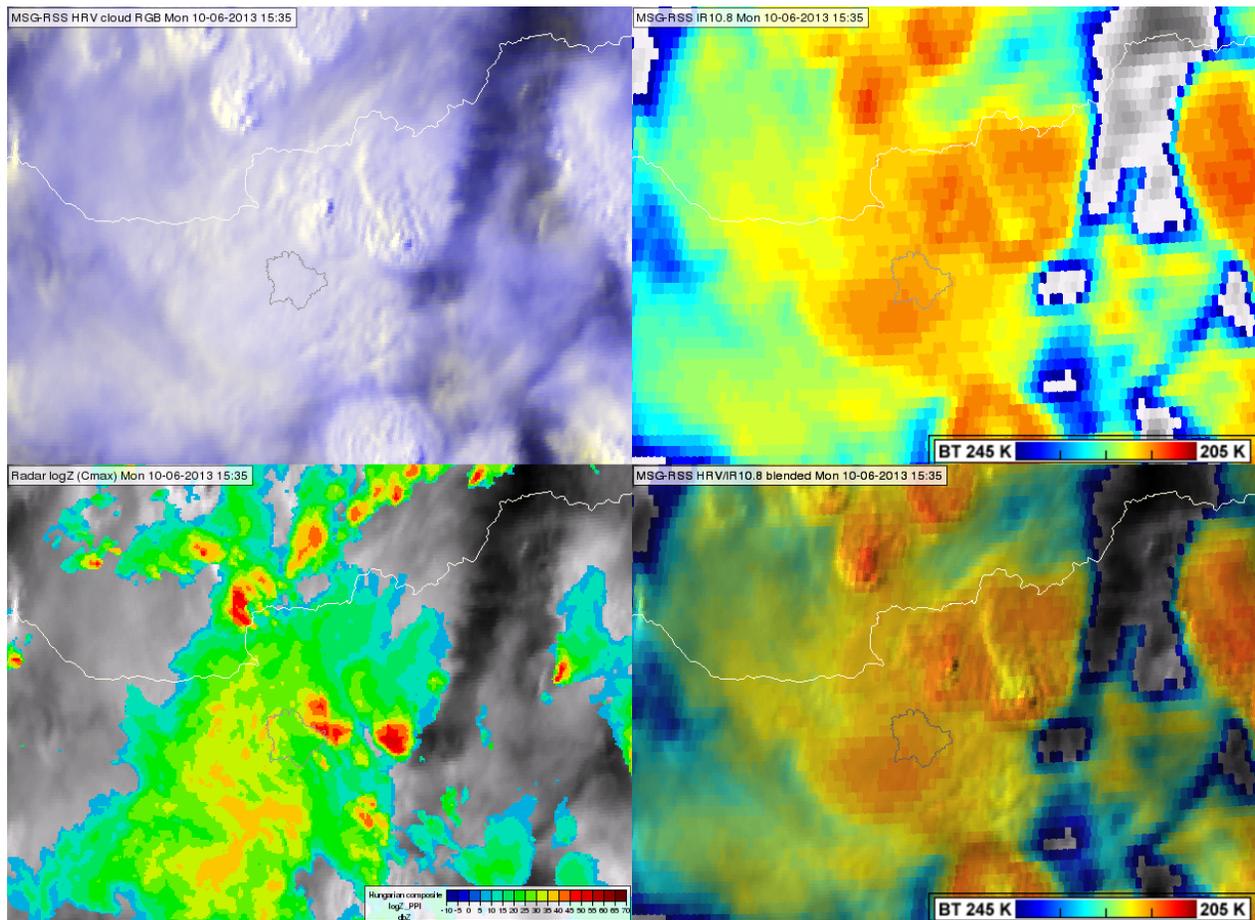


Fig. 3. Same as Fig. 2, but for 15:35 UTC. In the satellite images an ice-plume is seen above the studied storm.

Many convective clouds on this day including the studied one showed cold ring feature on their top. The evolution of the storm can be followed in the [HRV/IR10.8 blended image animation](#) between 14:00 and 16:30 UTC, and in the [4-panel image sequence](#) between 14:00 and 17:00 UTC.

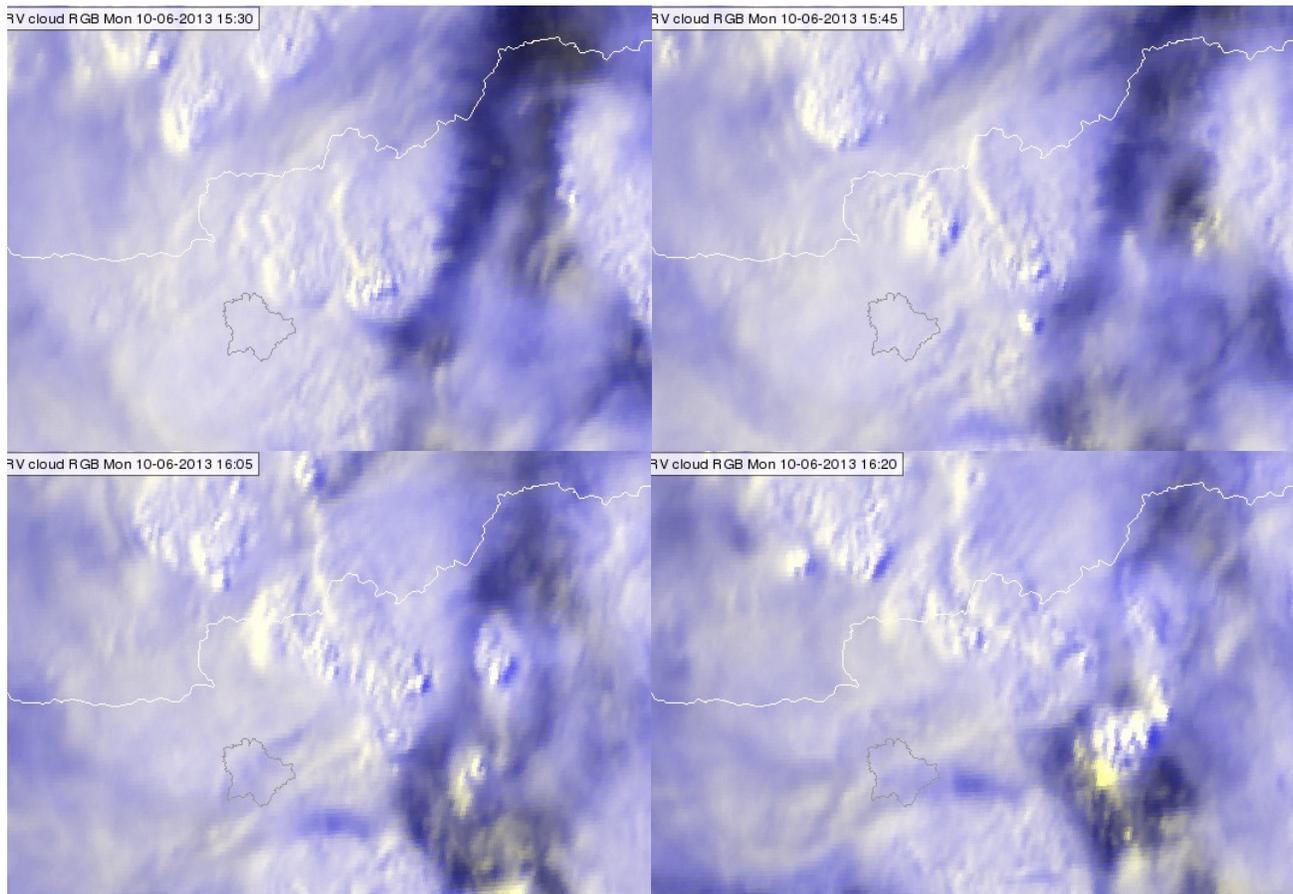


Fig. 4. Meteosat SEVIRI HRV cloud RGB images from 15:30, 15:45, 16:05 and 16:20 UTC

An ice-plume is seen above the studied cell between 15:25 and 16:25 UTC (see also the 4-panel image sequence and Fig. 4). The cell mostly propagated in southwest-northeast direction and the winds at the tropopause were southerly-southwesterly (according to ECMWF forecasts and the nearest soundings).

It is interesting that the orientation of this ice-plume turns to left with respect to the wind at over the tropopause and it changes its orientation as it propagates farther away from the storm's top. **We studied why the ice-plume orientation turns.**

As the orientation of the ice-plume is determined by the *storm related wind vector* at the height of the overshooting tops, we checked which one was modified in this time period: the storm motion vector or the environmental wind vector at the overshooting top height or both.

First we checked the storm motion vector. Based on the [satellite image animation](#) one has the feeling that it was moving to the right in its late development stage, after around 16 UTC. In the radar images this is more obvious. Fig. 5 shows a composite radar image, taking the maxima of the 5-minute column maximum LogZ data during 12 hours, from 06 to 18 UTC. The tracks of the most intense precipitation are well seen in such a figure. For the studied storm this track **deflects to right**. At the beginning it moved towards NE (track indicated by black arrow), and then it deflects more to east (track indicated by purple arrow). From the location where the track begin to band to right one can see a weaker track to left as well (indicated by blue arrow), giving us the suspicion that the studied storm might be splitted here into a right and a left moving storm pair. To check this suspicion we looked at the radar images more thoroughly.

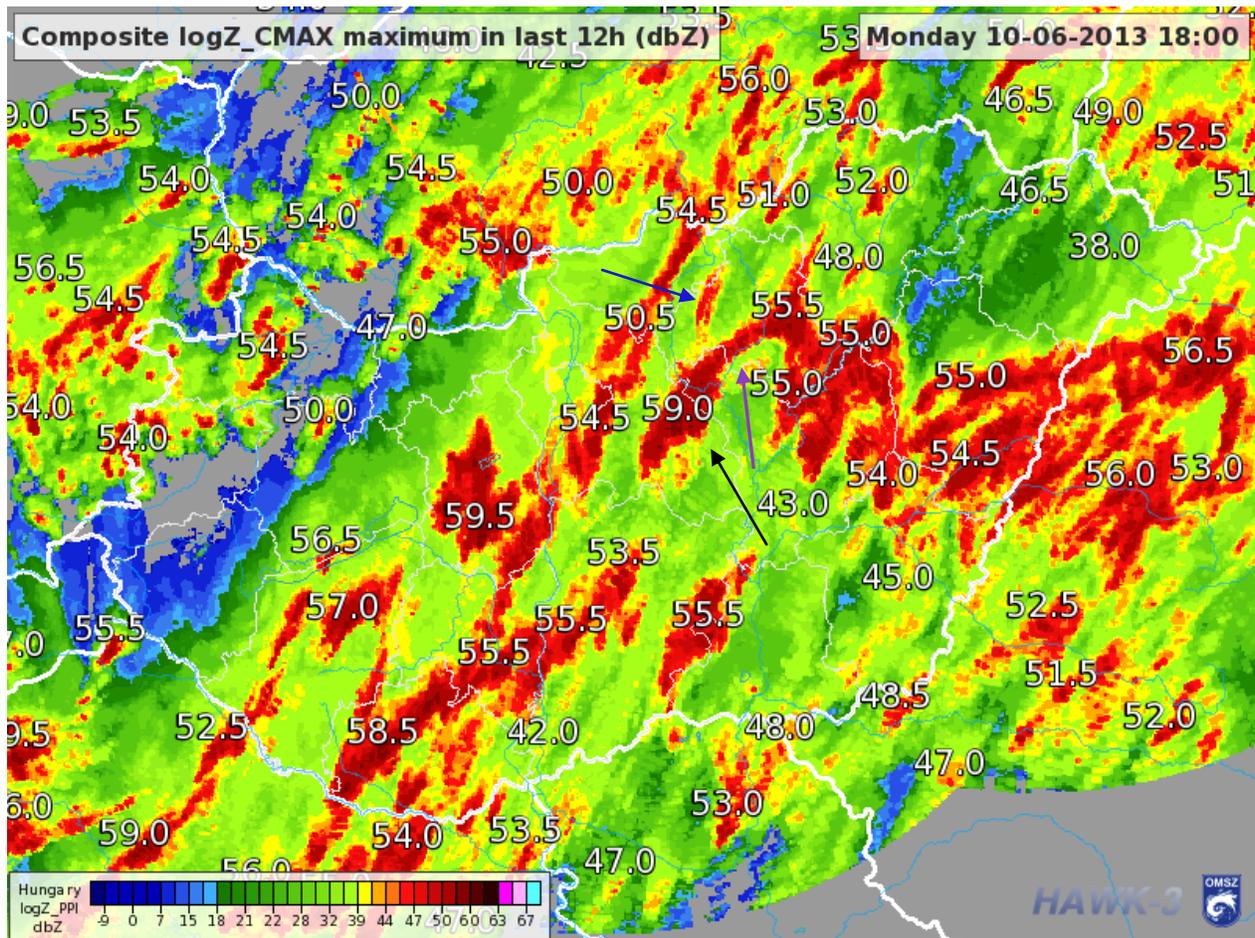


Fig. 5. Composite radar image, taking the maxima of the 5-minute column maximum LogZ data during 12 hours, from 06 to 18 UTC.

Looking at the [radar animation](#) from 15:00 to 17:10 UTC, one can well see the studied cell splitting into two parts one turning to right, one turning to left (the latter had a shorter life time). The storm splitted around 16:00 UTC. Fig. 6 shows 5-minute radar column maximum LogZ images for 4 time steps. The arrows in the upper panels indicate the studied storm before and around splitting, while in the lower panel the black arrow pairs indicate the splitted cells.

The white and black wind barbs (both in Fig. 6 and in the radar animation) show the so called ‘Bunkers Storm Motion Vectors’ related to the right and the left moving cells. The ‘Bunkers’ method estimates the supercell motion (both the right-moving and the left-moving cells): if a supercell forms in the particular environment what will its motion be like. The ‘Bunkers Storm Motion Vectors’ were retrieved from ECMWF forecasts. Note, that the movement of the splitted cells and the ECMWF derived Bunkers Storm Motion Vectors fit quit well, (see the animation).

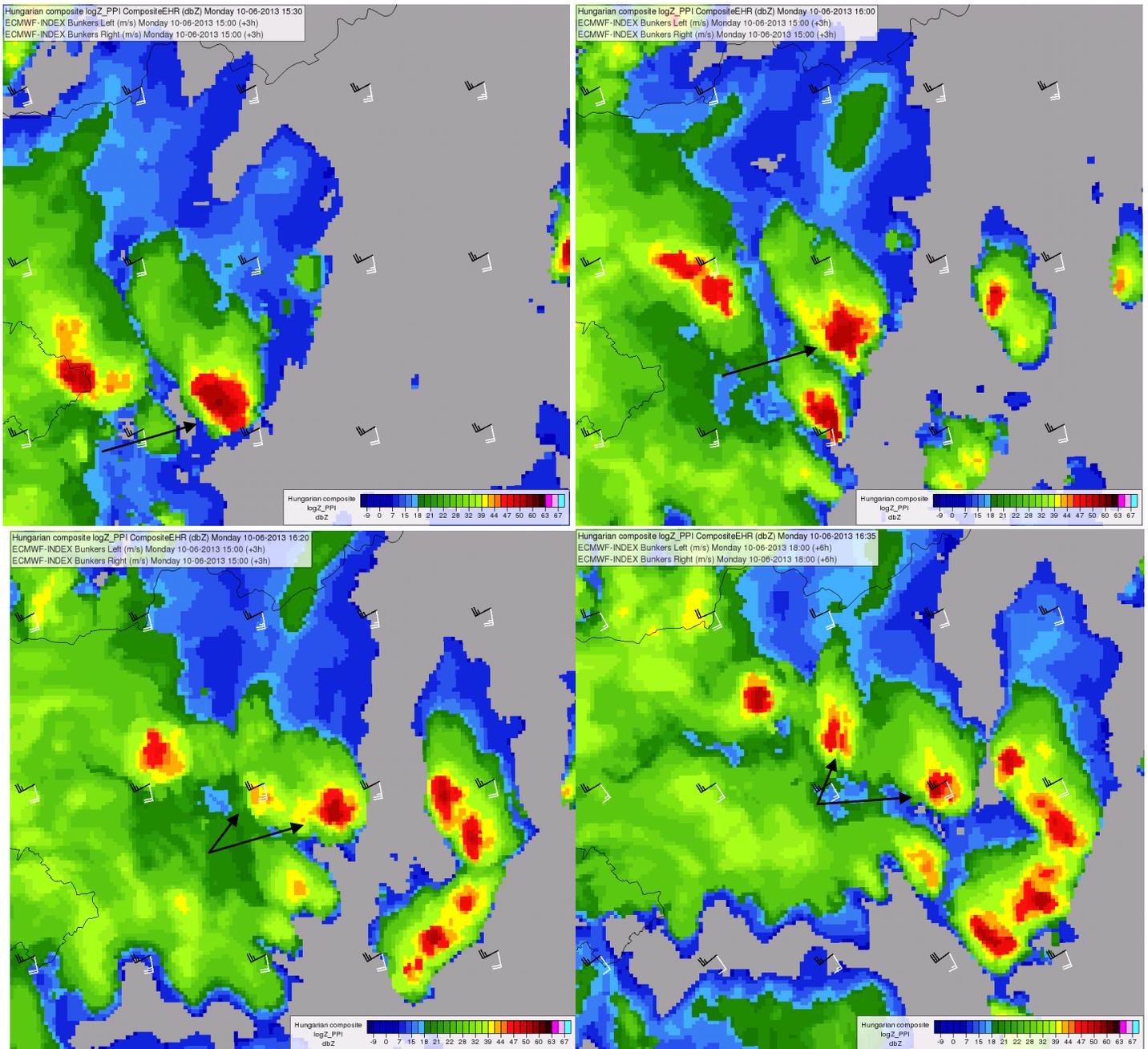


Fig. 6. 5-minute radar column maximum LogZ images overlaid by the ‘Bunkers Storm Motion Vectors’ related to the right and the left moving cells (indicated by white and black wind barbs). The ‘Bunkers Storm Motion Vectors’ were retrieved from ECMWF forecasts. The arrows in the upper panels indicate the studied storm before and around splitting, while in the lower panel the splitted cells. The panels correspond to 15:30, 16:00, 16:20 and 16:35 UTC. Budapest is indicated by grey contour.

We can conclude that the storm motion vector was not constant during the life-time of the ice-plume. The ice-plume was detectable from 15:25 to 16:25 UTC. The storm splitted during this time period, at around 16:00 UTC. Note that after splitting the ice-plume was detectable above the right moving cell.

We checked also the environmental wind vector at the overshooting top height to see if it was constant during the life-time of the ice-plume. According to the Radar Echotop (cloud top height) measurements the storm height was about 10.8-11.8 km (storm top pressure ~200-250 hPa). We analyzed the wind directions around and

above the tropopause at the nearby radiosonde stations and in the NWP forecasts, and looked at the cirrus patterns on the satellite images.

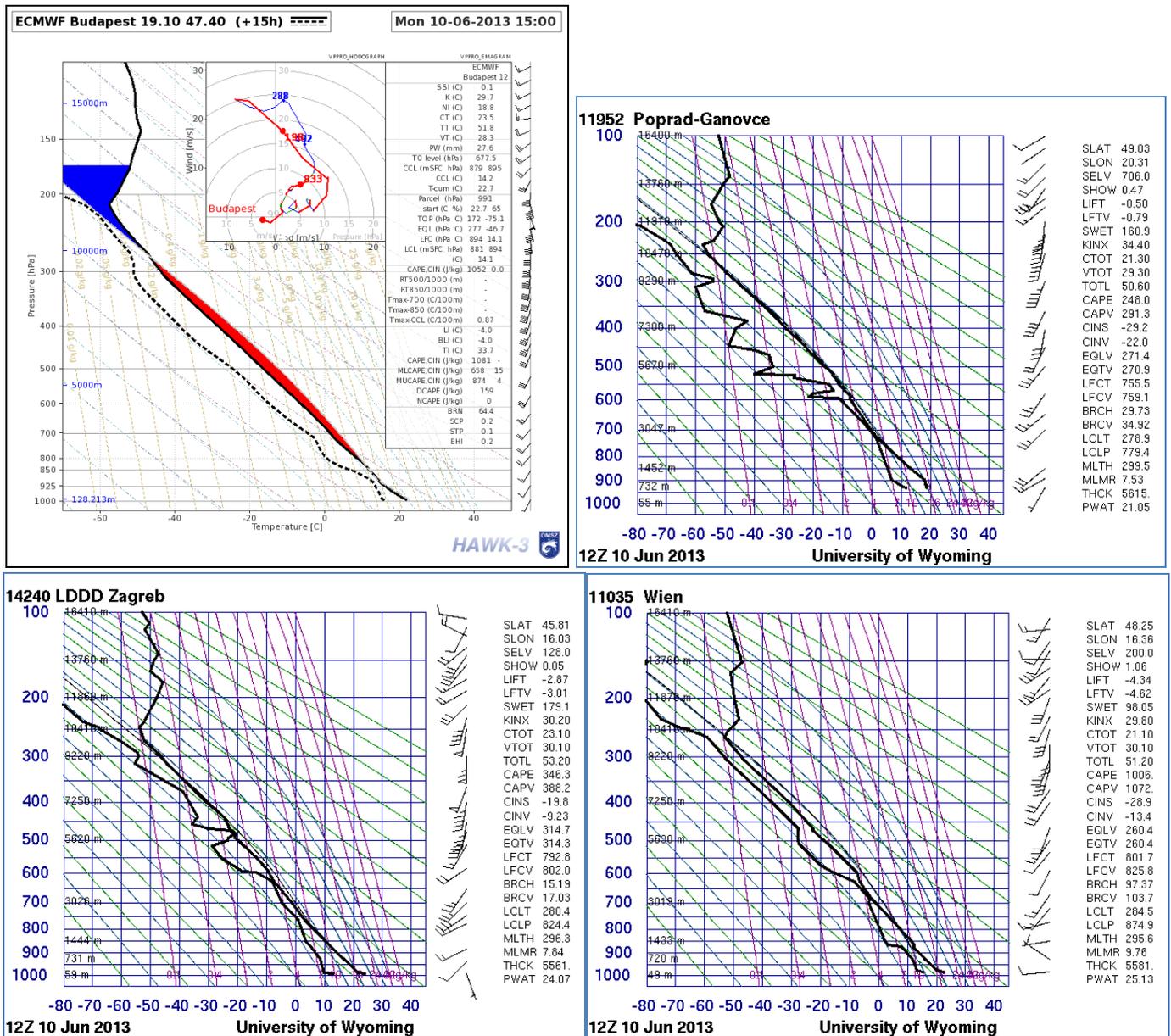


Fig. 7. ECMWF pseudo-TEMP for Budapest forecasted to 15:00 UTC (top left) and radiosonde measurements at 12 UTC at Poprad-Ganovce in Slovakia (top right), Zagreb in Croatia (below left) and at Wien in Austria (bottom right).

Fig. 7 shows the 12 UTC radiosonde measurements in the surrounding countries. For Budapest unfortunately there was no midday radiosonde measurement, instead we show ECMWF pseudo-TEMP forecasted for 15 UTC. The wind shear was rather strong above the tropopause around 200-250 hPa.

Fig. 8 shows the spatial distribution of the 200 and 250 hPa ECMWF wind forecasted for 15 hour. One can see that along the storm track the environmental wind direction changed.

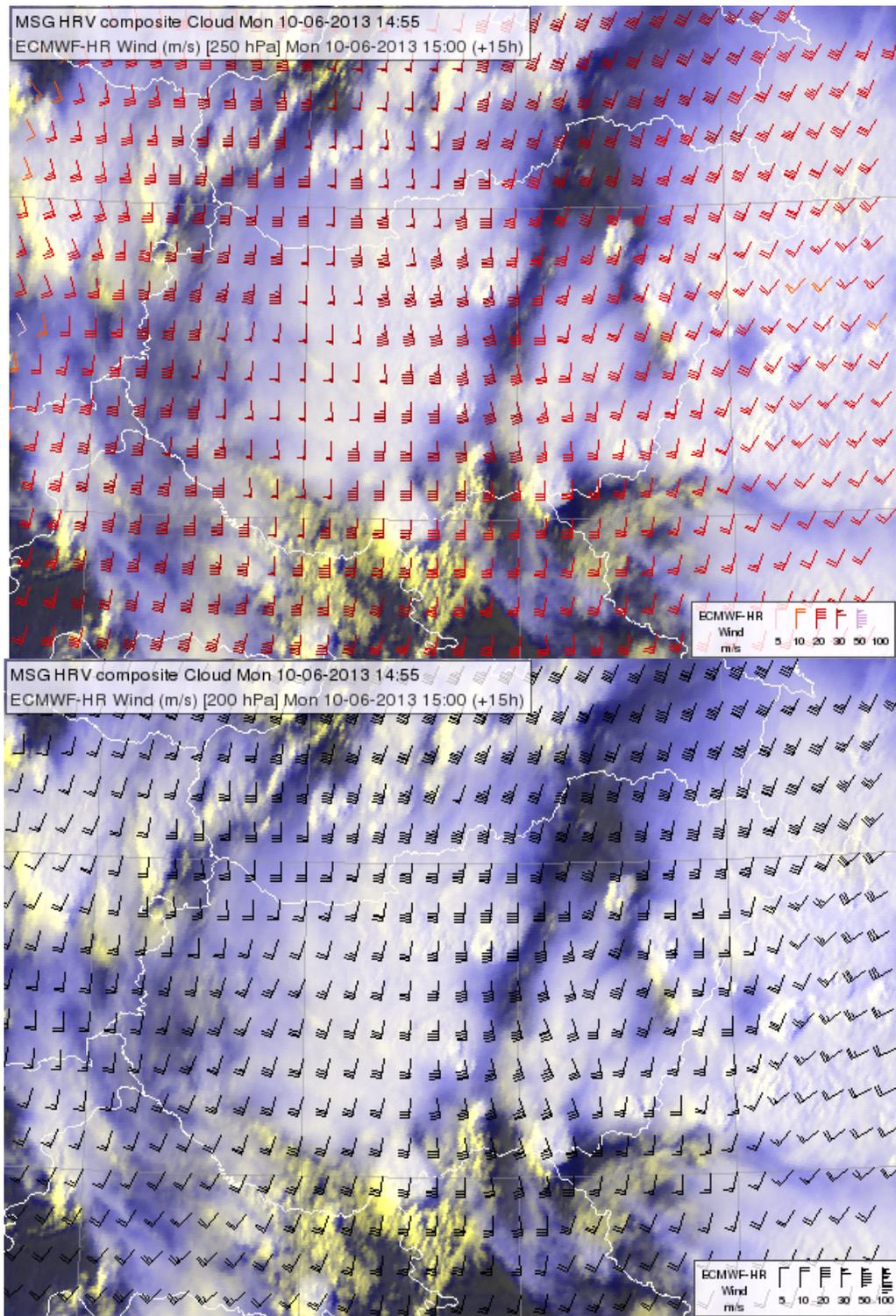


Fig. 8. 200 and 250 hPa ECMWF wind forecasted for 15 hour overlaid on HRV cloud RGB image taken at 14:55 UTC.

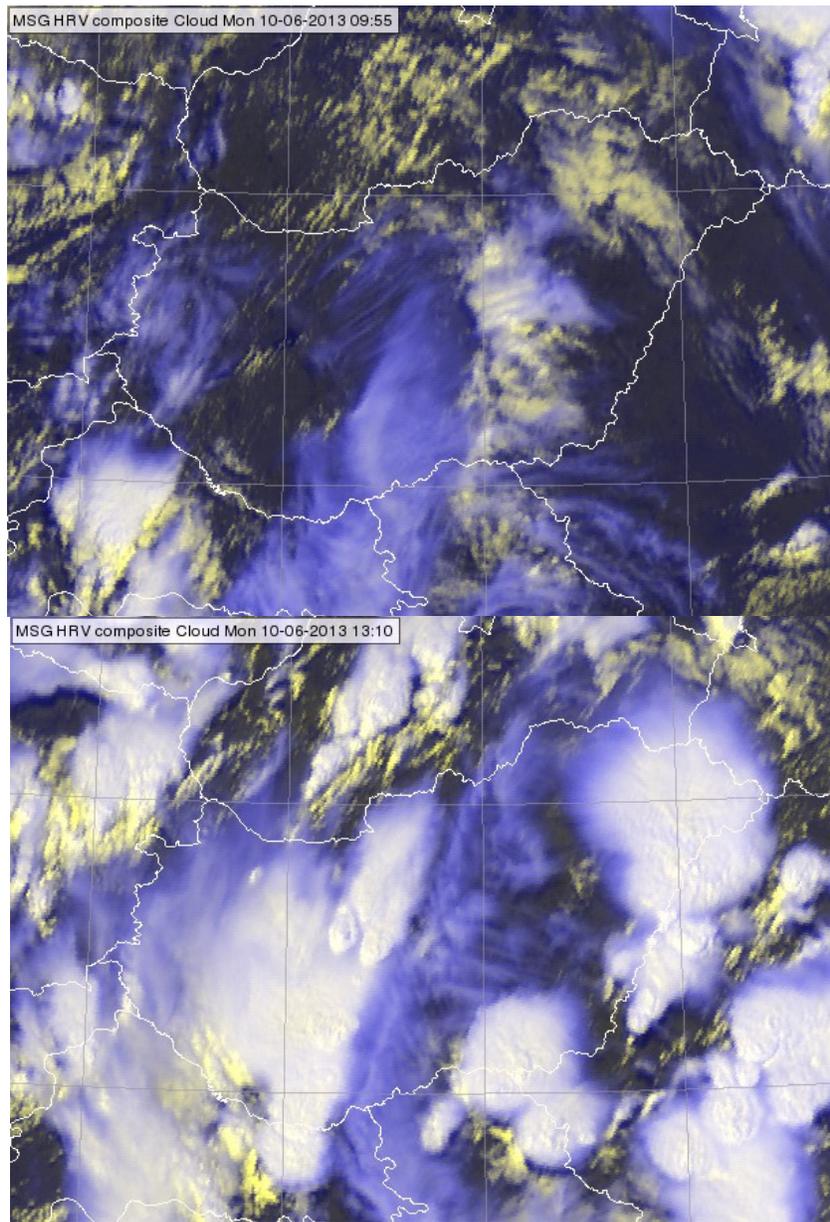


Fig. 9. HRV cloud RGB images from 9:55 and 13:10 UTC

The cirrus cloud patterns in the satellite images also support that the direction of high level wind was not uniform (see Fig. 9).

Concluding, both the storm motion vector and the high level environmental wind vector changed along the storm track during the life-time of the ice-plume. This might have caused a deflection of the ice-plume orientation. The storm-relative wind vectors were calculated and visualized in Fig. 10. The storm-relative wind vectors (red arrows) were calculated by subtracting the storm motion vector (derived from radar reflectivity images) from the 200 hPa ECMWF forecasted wind vectors (black arrows). The left and right images correspond to 15 and 18 UTC, respectively. One can see that the orientation of the storm relative wind vector really deflected to the left, at least about 20 degree. We managed to confirm that the storm relative vector turned considerably into the observed direction. Based on the satellite images, the turn of the plume orientation was even stronger. However, we should not forget, that the wind above the storm might depend on several local effects. The thunderstorm might modify the wind field within, around and above itself. In our calculation, for example, the divergent flow at the storm top is not taken into account. There is also some uncertainty in the

precision of the model wind forecast at the tropopause (note that the ECMWF 00 UTC run predicts the wind direction to be rather southerly; in the ECMWF 12 UTC run the 200 hPa wind turns more into the southwesterly direction).

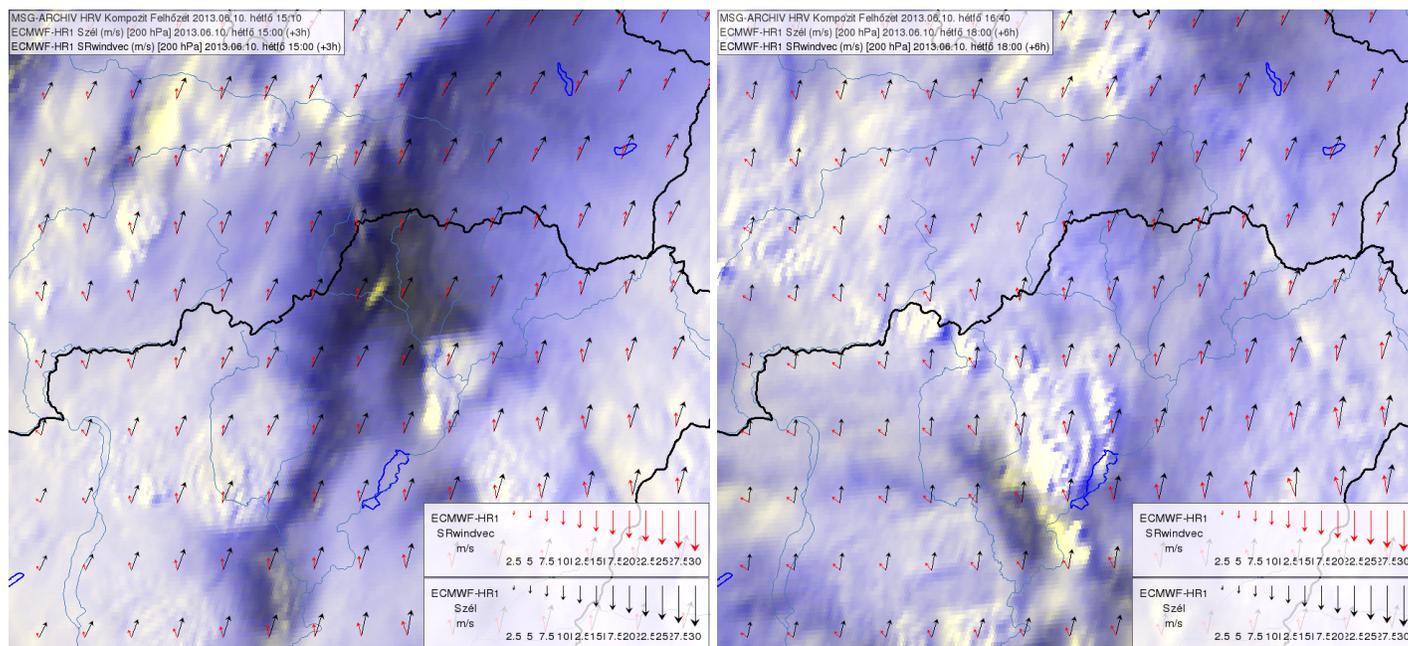


Fig. 10. HRV cloud RGB images overlaid by ECMWF forecasted 200 hPa wind vectors (black arrows) and storm-relative wind vectors (red arrows) at 15:00 (left) and 18:00 UTC (right).