Hrvatski meteorološki časopis – Croatian Meteorological Journal, 41, 2006., 69–80.

UDK: 551.515.3
Stručni rad

TORNADOES AT NOVIGRAD, ISTRIA, ON AUGUST 14, 2006

Tornado kod Novigrada u Istri 14.8.2006.

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Prihvaćeno 10. siječnja 2007, u konačnom obliku 19. ožujka 2007.

Abstract: The study presents the case of two tornadoes observed on August 14, 2006, in the vicinity of Novigrad, on the Istrian peninsula. The descriptions of the tornado events are based –on visual observation and on photo-documentation. The synoptic and mesosynoptic conditions for thunderstorm generation have been analyzed by using EUMETSAT Meteosat Second Generation (MSG) satellite imagery and ALADIN numerical model outputs. The accessible data give evidence of non-supercellular tornadoes related to a narrow line of convective clouds that probably formed at the outflow boundary of an older convective system. It is shown that traits of intense convection could be detected in the evaluated case by using RGB composites of satellite channels. Streamwise vorticity has been diagnosed from parameters like Storm to Relative Environmental Helicity (SREH) and Energy Helicity Index (EHI), supposing that it had a support role in the formation of the tornadic thunderstorms. It is concluded that very high resolution data and more information about the mesosynoptic setting of tornadogenesis are needed for an operational recognition of potential hazards by similar events.

Key words: tornado, Istria, satellite, diagnostic parameters, non-supercellular

Sažetak: U radu je prikazan slučaj pojave dva tornada 14.8.2006. u okolici Novigrada u Istri. Opis pojave tornada temelji se na vizualnom opažanju i fotografijama. Sinoptički i mezoskalni uvjeti koji su pogodovali razvoju konvektivnog nevremena analizirani su korištenjem EUMETSAT-ovih slika "Meteosat Second Generation" (MSG) i rezultata numeričkog modela ALADIN. Prema raspoloživim podacima može se zaključiti da pojava tornada nije vezana uz superćelijski kumulonimbus, nego je posljedica postojanja tanke linije konvektivnih oblaka koja se razvila iz nekog prijašnjeg konvektivnog sistema. Satelitske slike nastale kombiniranjem 6 kanala MSG-a pokazuju postojanje niza kumulonimbusa duž linije. Vrijednosti parametara SREH i indeksa EHI upućuju na postojanje komponente vrtložnosti u smjeru strujanja koja pospješuje razvoj kumulonimbusa. Rezultati analize pokazuju da su za uspješnu prognozu pojave tornada potrebni precizniji podaci o mezoskalnoj situaciji vezanoj uz pojavu tornada.

Ključne riječi: tornado, Istra, satelit, dijagnostički parametri, ne superčelijski

1. INTRODUCTION

The detection of tornadoes and tornado climatology is a difficult task because of their small horizontal dimensions and short lifetime (usually a few minutes). The tornado rotation is only rarely detectable by meteorological radar. Such a task requires very high resolution scans from short distance, which is possible by certain specially designed mobile radars used for research purposes (Bluestein, 1999). However, this is mostly beyond the capabilities of the present operational radars. Hence, most of the tornado observations are purely visual and reported by people which are not professional meteorologists. For this reason, the problem of tornadoes has been underestimated in some European countries – claiming that such kind of phenomena belong entirely to the United States. This is not the case for Croatia, where tornadoes have been known already for a long time and where scientific works and articles about this phenomenon exist.

One of the oldest tornado descriptions was given by Mohorovičić (1894), of a tornado in Novska, in the continental part of Croatia. It is interesting that until the nineties of the last century more work was done on tornadoes in the continental parts. The greatest attention was given to the July 22, 1973 tornado in Zagreb. Čapka (1978) analyzed the mesoscale conditions leading to tornado occurrence and Jurčec (1978) used a mesoscale numerical model. A more recent case, the 30 August 2003 supercell development and tornadogenesis in northwestern Croatia was investigated by Stiperski (2005). Tornadoes at sea and in the coastal regions have been long known but more studies of this phenomenon have appeared only recently. Ivančan-Picek et al. (1995) analyzed tornado occurrence in the vicinity of Zadar, on August 18, 1994. It was caused by a storm that originated in a moving cold front. The tornado formed over the sea and heated the land, damaging houses and other property. The same paper gives the climatology of tornadoes in coastal regions. Poje (2004) gave a more thorough climatology of tornadoes in coastal regions, based on observations at the main meteorological stations. It is interesting that tornadoes are more frequent in the cold part of the year, with the greatest frequencies in September and December. A climatology of tornadoes, based on descriptions in the media, was done by Ivančan-Picek and Jurčec (2005). In the period 2000–2003, there were about 4 days with tornadoes every year in the coastal regions. In the continental parts of Croatia, the number of tornadoes kept growing from just one in 2000 to six in 2003. It is hard to say if this growth was due to the growing interest of the media in tornadoes or whether it was a real natural phenomenon. Although the climatology of tornadoes in Croatia is incomplete, it is clear that each year there are several tornadoes both in coastal and continental Croatia. It is not known which mechanisms are responsible for tornado occurrences in Croatia. Available data have allowed only studies of the synoptic and mesoscale conditions leading to tornado occurrences. Further investigations are needed, both observational and theoretical.

These last years, the overall use of digital cameras, mobile phones and the internet has resulted, in Europe, in an increasing number of reports and photographs of severe weather phenomena, among which there are also photographs and videos of tornadoes (Šálek et al., 2002). These reports are sometimes provided by foreigners, as was the case of the two tornadoes in the vicinity of Novigrad, observed by Slovak tourists on holiday.

This article gives the English transcription of the observation report (section 2), the description of the synoptic situation (section 3) and of the mesosynoptic conditions (section 4) using satellite observations and NWP diagnostics. The possible causes of thunderstorm and tornado development are discussed in Section 5.

2. OBSERVATIONS

A detailed description and photographs of two tornadoes were given by Mr. Kvetoslav Jansík, who was one of the witnesses to the event: “The tornadoes were observed on August 14, 2006, from the Busuja peninsula, situated 5.5–5.6 km south of the town of Novigrad (Fig. 1). That morning, the air temperature was about 24–25°C. Several showers and thunderstorms occurred over the sea at 5–15 km from the observation point and propagated northeastwards. Precipitation occurred at Novigrad, which was confirmed by other tourists in the area. Around 1040 local time (LST), another shower passed by. It seems that the rain was intense and thunder was heard (lightning was not observed). Precipitation was probably located far from the observation point, because the rain at Novigrad was not so intense. When the rain reached the coast, we observed, around 1048 LST, a dark rotating funnel extending westerly from the cloud towards the shower (Fig. 2).

Figure 1. Map showing the place of tornadoes occurrence on 14 August, 2006. Istria peninsula is shown zoomed in the upper right corner. The arrow points to the observation point at Busuja peninsula. Tornadoes occurred close to Novigrad (highlighted by small disk).

Slika 1. Geografska karta na kojoj se vidi mjesto gdje se pojavio tornado 14.8.2006. Istra je prikazana u gornjem desnom kutu. Strelicom je prikazano mjesto, na poluotočiću Busuja, s kojeg je tornado opažen. Tornadi su bili blizu Novigrada (označeno kružićem).

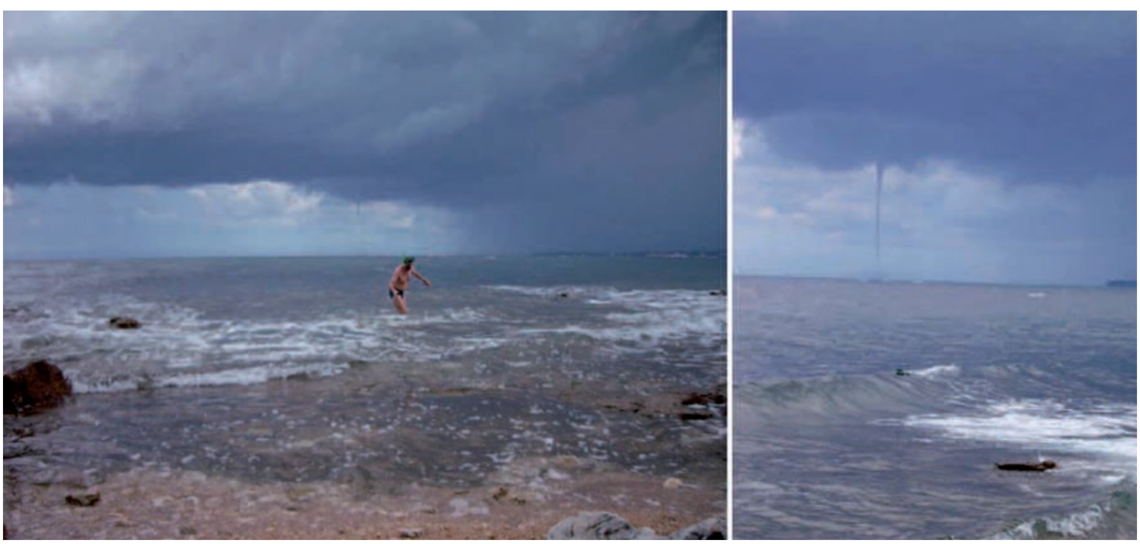

Figure 2. First tornado observed at Novigrad, approximately at 1049 LST (left) and 1050 LST (right). The view is directed towards north (at azimuth nearly 340 degrees). Novigrad is at right side of both figures (courtesy Kvetoslav Jansík).

Slika 2. Prvi tornado uočen kod Novigrada u 1049 po lokalnom vremenu (lijevo) i u 1050 (desno). Slika prikazuje pogled prema sjeveru (azimut 340). Na obje slike Novigrad se nalazi desno (autor slika Kvetoslav Jansík).

The rotation of the funnel was probably clockwise and it seemed that it was propagating southwards. The base of the clouds was approximately 900–1000 m above ground. A few minutes later, another funnel started to extend from the cloud (Fig. 3). This one was transparent in the middle and it was possible to see swirling water on the sea surface. It appeared to the west of the first whirl (approximately 10 degrees to the left as viewed from the observation point). The sense of rotation of the second funnel was the same as for the first tornado. The diameter of the water swirl on the sea surface was probably 100–200 m and water drops seemed to be elevated to a height of several tenths of meters, probably even higher. Both funnels existed simultaneously for about one minute. Later, the first tornado decayed and the second tornado continued to exist for several minutes and propagated southwards. It vanished a few minutes before 1100 LST. Both whirls slanted prior to dissipation, which was very fast (in order of seconds). During the event, the wind did not substantially amplify at the observation point. Rotation of the base of the clouds was not observed“.

The weather and the appearance of the sky changed very rapidly during the next ten minutes after the tornadoes had disappeared; however, showers propagating over the sea were still present (documented by a photograph, not shown). Both tornadoes propagated during their whole life time over the sea. Material damage or injuries related to the tornado occurrence are not known to the authors.

3. SYNOPTIC SITUATION

On August 14, 0600 UTC, Croatia was situated in a bright area of low pressure with its major centre above Denmark and a secondary, shallower centre over northern Italy (Fig. 4). There was also a high pressure area of small extent over Albania and Macedonia. At the

Figure 3. Second tornado observed at Novigrad, approximately at 1052 LST. The direction of the view is similar as in figure 2, but more to the right (courtesy Kvetoslav Jansík).

Slika 3. Drugi tornado uočen kod Novigrada u 1052 po lokalnom vremenu. Slika prikazuje pogled približno u istom smjeru kao prethodna s malim otklonom u desno (autor slike Kvetoslav Jansík).

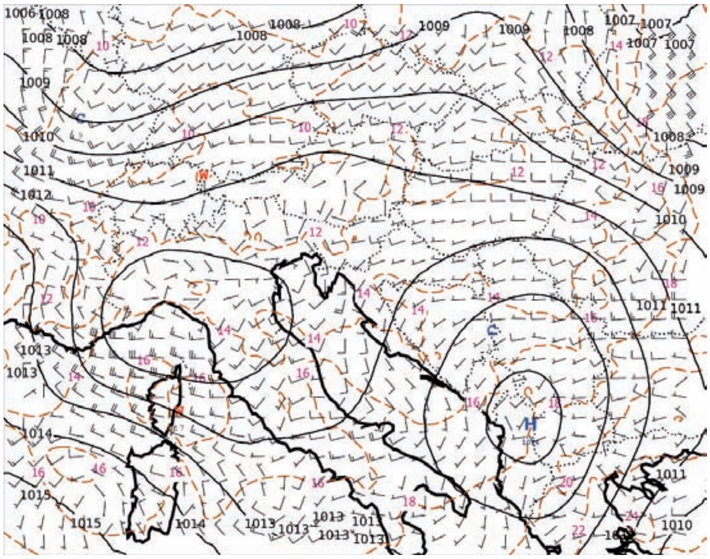

Figure 4. Mean sea level pressure (hPa) and 925 hPa level wind (wind barbs) on 14 August 2006, 0600 UTC. The wind field is based on ALADIN SHMÚ model analyses, the isobars are obtained from combination of SYNOP and ALADIN SHMÚ data.

Slika 4. Tlak na razini mora (hPa) i vjetar na 925 hPa 14.8.2006 u 6 sati po UTC-u.

925 hPa level, some relatively warmer air was advected over the Adriatic Sea towards the Istrian peninsula. At the 500 hPa level, at 0900 UTC, there were two centres of a driving cyclone as well – one over Denmark and northern Germany, the second over the border of Germany and France (Fig. 5). At the 300 hPa level, the direction of the flow was between southwesterly and westerly – the axis of the jet stream was crossing the central Adriatic Sea. The frontal zones were analyzed at 0000 UTC over central France and easterly from Croatia (a synoptic analysis of the UK MetOffice, not shown). Hence, the thunderstorms, which appeared over Istria in the morning hours, were not connected to the synoptic scale fronts.

Aerological observation from 0000 UTC was available from the Udine station (Fig. 6a) and it shows that the air mass over northern Italy was unstable, relatively moist, having a rather weak CAPE (437 Jkg^{-1}). The wind was veering with height from southeasterly to westerly, although the increase in wind speed with height was rather moderate (the wind speed was less than 20 ms^{-1} below the tropopause). At 1200 UTC (Fig. 6b), the air became drier and the wind shear increased significantly, although the instability was weaker (133 Jkg^{-1}). The wind speed was 15 ms^{-1} at 700 hPa and 25 ms^{-1} at 400 hPa. The maximum wind speed below the tropopause was 37 ms^{-1}. There was also a change in wind direction (veering) from southerly to westerly in the lower and middle troposphere.

4. MESOSYNOPTIC CONDITIONS

More information about the weather course over Istria on 14 August can be inferred from the MSG and NOAA satellite imagery. The first band of convective cloudiness appeared over the northern Adriatic already at 0500 UTC. However, this cloudiness passed north of Istria and propagated in the direction towards Slovenia. At 0700 UTC, a line of convective clouds started to form on its southwestern flank. This line was elongated in a southwest-northeast direction and was slowly propagating northeastwards, across the northern part of the Istrian peninsula. Besides this propagation, new clouds were developing at the tail of this line of clouds which had a wavy shape, as can be seen on the High Resolution Visible (HRV) channel of the MSG satellite at 0845 UTC (Fig. 7a). The cloud top temperature was higher than 230 K (according to NOAA imagery, not shown). On the other hand, the 6 channel composition of the MSG imagery (differences of channels: 6.2–7.3μ, 3.9–10.8μ and 1.6–0.6μ) after 0900 UTC shows the presence of small ice particles at the tops of the clouds, downstream of the tornado occurrence point (Fig. 7b). This might be evidence of intense convection (Kerkmann, 2005).

Data from the radar situated on Mount Medvednica near Zagreb show, between 0834 and 0946 UTC, a line of convective cells crossing the northwestern part of Istria in a southwest-northeast direction. The cells were charac-

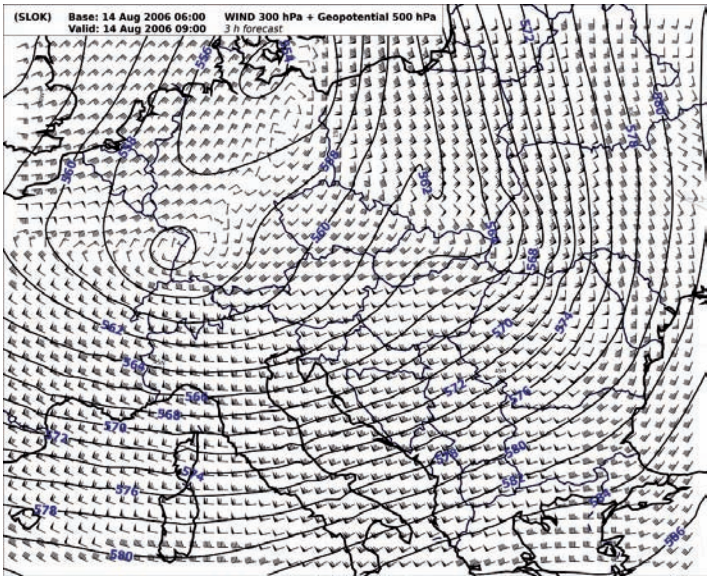

Figure 5. 3 hour forecast of geopotential field at 500 hPa level (gpdam) and 300 hPa wind (wind barbs) by ALADIN SHMÚ, based at 0600 UTC.

Slika 5. Trosatna prognoza geopotencijala (gpdam) i vjetra na izobarnim plohama tlaka 500 hPa i 300 hPa prema modelu ALADIN SHMÚ s početnim vremenom u 6 sati.

terized by moderate to high radar reflectivity (45–55 Dbz), which corresponds to surface observations (almost 27 mm of rain measured between 0800 UTC and 0900 UTC at Portorož, Slovenia). However, the convective cloudiness at Novigrad and to the west of Istria was very weakly detected. The thunderstorms occurred 200 km far from the radar observation point and only the tops of the clods at a height of 8–9 km were visible. The surface observations closest to Novigrad (at Umag and Pula) showed only weak wind (mostly below 5 ms^{-1}) with a possibility of anticyclonic wind shear relative to the direction of the thunderstorm line detected by satellite and radar (azimuth of 240 degrees).

Some of the mesoscale conditions of thunderstorm development can be inferred from the analysis and forecasts of the ALADIN hydrostatic limited area numerical model (Radnóti et al., 1995). Stability parameters were computed from the ALADIN SHMÚ version, using 9.0 km horizontal resolution and 37 vertical levels (Derková, 2005). The fields of Convective Available Potential Energy (CAPE), Storm to Relative Environmental Helicity (SREH), Bulk Richardson Number (BRN) and Energy Helicity Index (EHI) were examined. The CAPE index was integrated with the use of virtual temperature (Emanuel, 1994). SREH was computed in the layer of the lowest 3 km of the troposphere using the 0–6 km density averaged mean wind turned by 20 degrees to the right and decreased to 85% of the original wind speed as a guess for the storm motion vector (Davies-Jones et al., 1990).

The analysis of CAPE on August 14, 0600 UTC shows moderate values up to 1400 Jkg^{-1} on the northern Adriatic (Fig. 8). At the same time, an area of moderate SREH of 70–150 Jkg^{-1} was present over the Istrian peninsula (Fig. 9). The outputs of BRN (Droegemeier et al., 1993) and EHI (Rasmussen and Blanchard, 1998) show local maxima close to the area where the tornadic thunderstorms occurred (Figs. 10 and 11). However, the values of SREH and EHI are rather below the usual thresholds for supercell thunderstorm and tornado development.

Further, 0600 UTC model analyses indicate the presence of a mesoscale trough at 925 hPa and a moderate surface moisture convergence over the northern Adriatic (not shown). This eventually supported the rise of the first thunderstorm cells observed north of Istria. Nevertheless, convective instability (buoyancy) should be considered to be the main generator of the thunderstorms. Besides the CAPE analysis, its presence is confirmed also by outputs of other indices and parameters. These are, for example, KO index analyses (Kurz, 1995), which demonstrate a decrease of the equivalent potential temperature with height at low and mid-tropospheric levels.

a)

b)

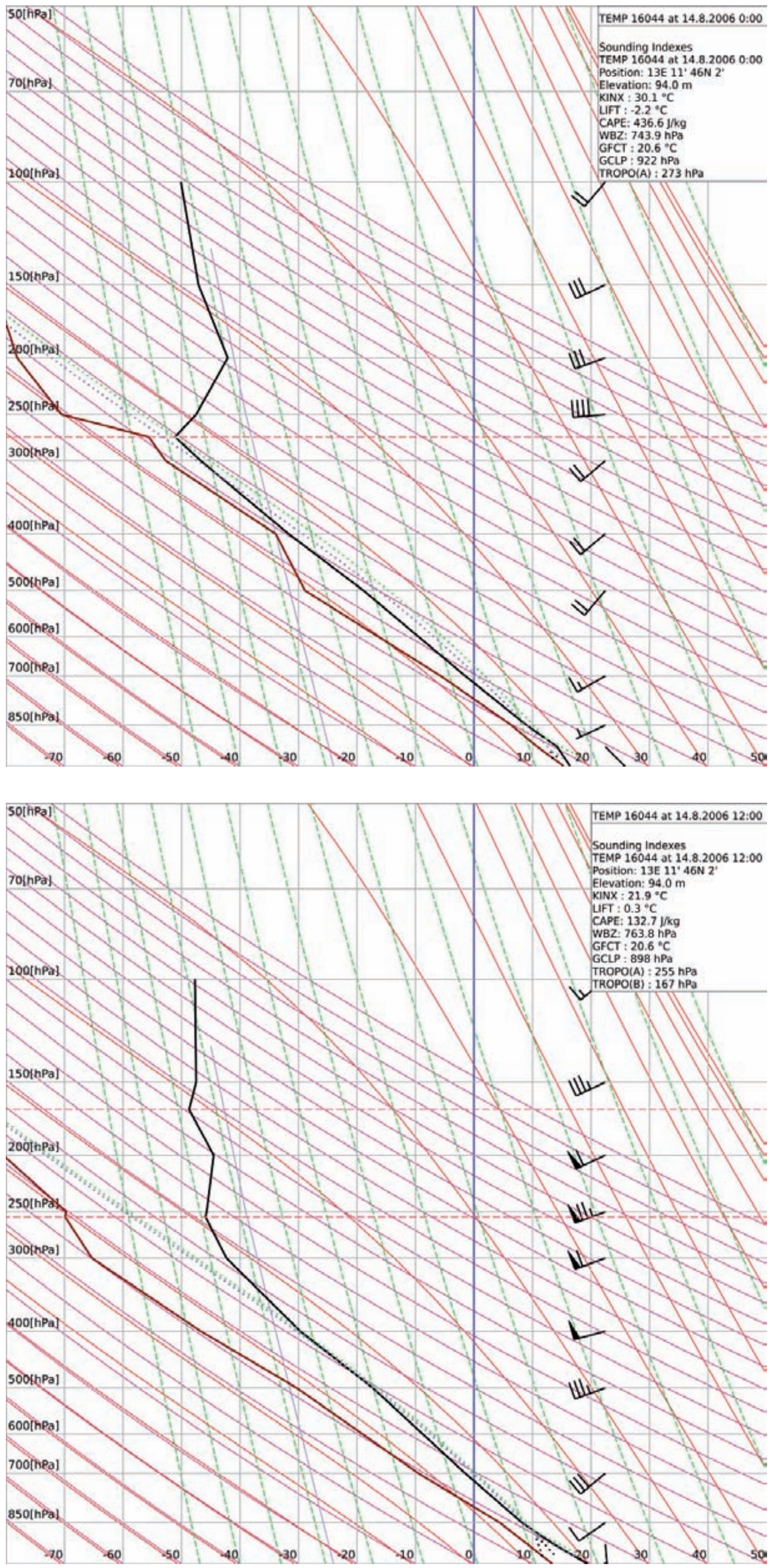

Figure 6. a) Soundings from UDINE aerological station on 14 August, 2006, 0000 UTC. b) the same, except for 1200 UTC.

Slika 6. a) Sondaža aerološke postaje Udine 14.8.2006. u 00 sati; b) Isto, za 12 sati.

a) b)

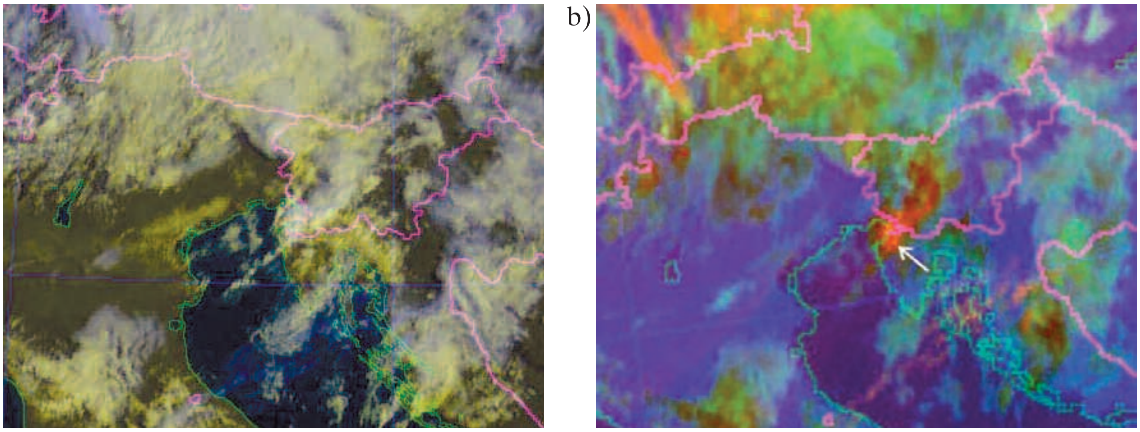

Figure 7. a) Image of the HRV channel of MSG satellite, valid for 0845 UTC; b) composite RGB image of MSG 6.2–7.3μ, 3.9–10.8μ and 1.6–0.6μ channels differences used for detection of convective storms. The arrow points to the locality of new convective storm formation with strong updraft (appearing as small yellow spot in the colour composite image). Another place with severe convection can be found upstream (southwestwards) to the highlighted point. The image is valid for 0900 UTC.

Slika 7. a) Slika HRV-kanala MSG-ova satelita za 0845 UTC; b) RGB-kompozitna MGS satelitska slika sastavljena prema razlikama radijacije između kanala 6.2–7.3μ, 3.9–10.8μ i 1.6–0.6μ koja sa koristi za otkrivanje konvektivnih nestabilnosti. Strelica pokazuje mjesto novog razvoja konvektivne nestabilnosti s jakom uzlaznom strujom (žuta točka na slici). Drugo područje s konvektivnim nevremenom nalazi se u smjeru uz vjetar od prvog (jugozapadno) od oznake na slici. Slika prikazuje situaciju u 9 sati po UTC-u.

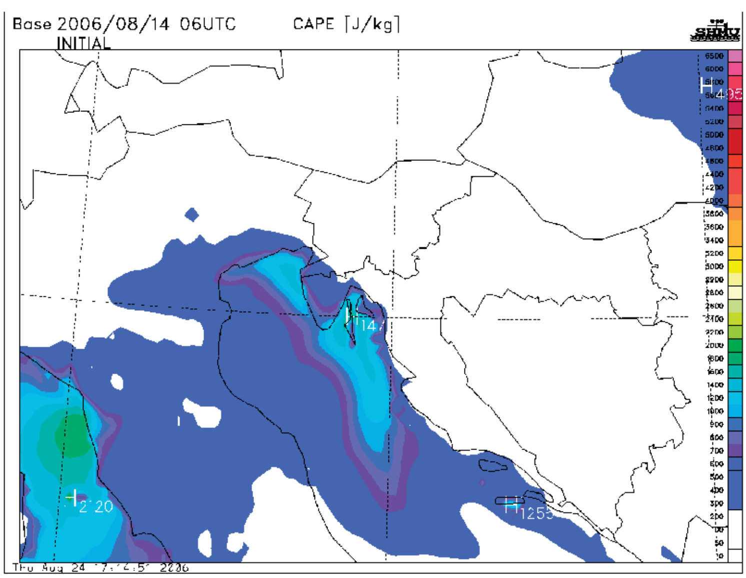

Figure 8. Analysis of CAPE (isolines plotted every 200 Jkg^{-1}) from ALADIN SHMÚ, valid for August 14, 2006, 0600 UTC.

Slika 8. CAPE (izolinije crtane svakih 200 Jkg^{-1}) prema prognozi ALADIN-a SHMU za 14.8.2006. u 6 sati.

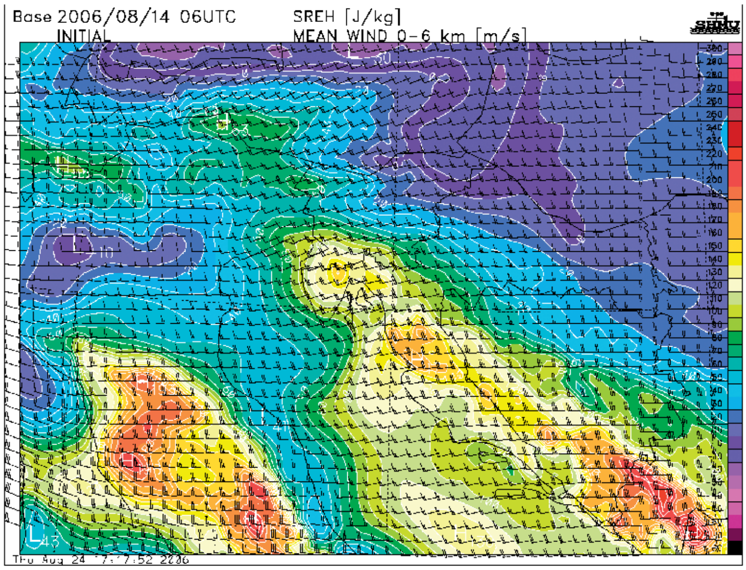

Figure 9. Analysis of SREH (isolines plotted every 10 Jkg^{-1}) and of storm motion vector (wind barbs) from ALADIN SHMÚ, valid for August 14, 2006, 0600 UTC.

Slika 9. SREH (izolinije crtane svakih 10 Jkg^{-1}) i vektor gibanja nevremena prema prognozi ALADIN-a SHMU za 14.8.2006. u 6 sati.

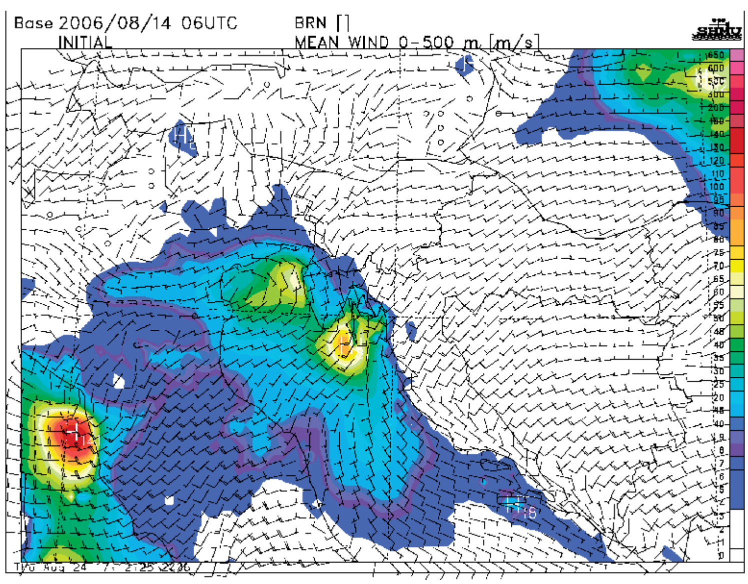

Figure 10. Analysis of BRN (dimensionless, isolines plotted by every 5 units) and of density averaged low level wind computed for the lowest 500 meter layer (wind barbs) from ALADIN SHMÚ, valid for August 14, 2006, 0600 UTC.

Slika 10. BRN (bez dimenzije, izolinije crtane svakih 5 jedinica) i srednja vrijednost količine gibanja u donjih 500 m atmosfere prema prognozi ALADIN-a SHMU za 14.8.2006. u 6 sati.

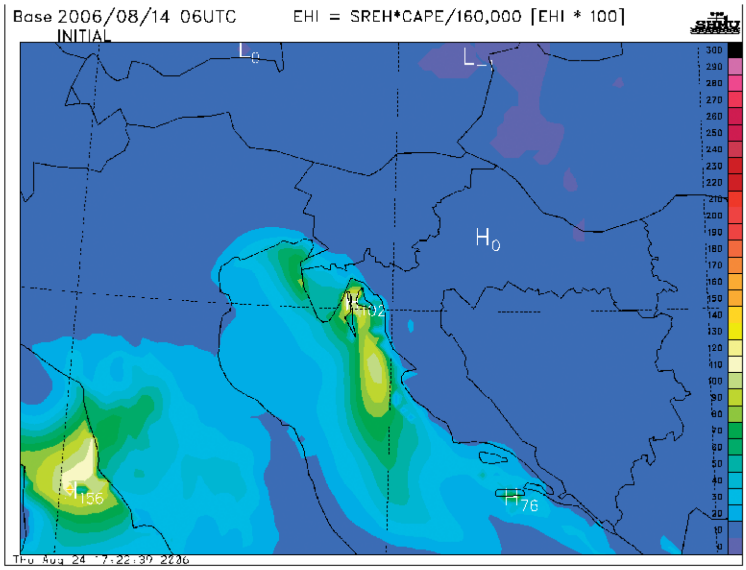

Figure 11. Analysis of EHI (dimensionless values, plotted by every 0.1 unit and multiplied by 100) from ALADIN SHMÚ, valid for August 14, 2006, 0600 UTC.

Slika 11. EHI (bez dimenzije, izolinije crtane svakih 0.1 jedinica pomnoženo sa 100) prema prognozi ALADIN-a SHMU za 14.8.2006. u 6 sati.

5. DISCUSSION

The observation report and the photographs are the only (but very clear) evidence of the occurrence of two tornadoes in the vicinity of Novigrad, on August 14, 2006. Tornadoes moving over water are sometimes called or classified as "waterspouts". However, there is no objective reason for different definitions of tornadoes over water and tornadoes over land, because there is no important difference in their structure and kinematics (Glossary of Meteorology, 2000, see also the essay of Doswell, 2001). The speed of wind in tornadoes over water usually cannot be estimated after the Fujita or TORRO scales, which are based on damage survey (Fujita, 1981). Nevertheless, several cases of "waterspouts" entering land surface show that the severity potential of tornadoes appearing over water cannot be underestimated.

Visual observation of the weather at the observation point matches very well with the information from satellite imagery. The series of thunderstorms propagating in a southwest-northeast direction can be identified by a narrow, wavy line of convective clouds shown by HRV MSG outputs. Convection was probably induced (supported) at the outflow boundary of the right-rear flank of an older system of thunderstorms. An increase in horizontal wind shear could be the reason for the creation of wavy structures at the leading edge of the outflow, thus supporting convergence and the production of vertical vorticity. Such conditions can be favourable for the development of non-supercellular tornadoes, as proved by numerical simulations (Lee and Wilhelmson, 1997a, Lee and Wilhelmson, 1997b). Lee and Wilhelmson showed that the stretching term in the vorticity equation was the primary factor of vorticity intensification in their experiment. Their simulation showed also the possibility of more coexistent misocyclones developing along the outflow boundary.

The tilting of the streamwise horizontal vorticity is another possible mechanism explaining the creation of rotating storms and the tornadogenesis (see, for example, the textbook by Bluestein, 1993). Although veering of the wind with height and positive SREH, diagnosed from aerological observations and model forecasts, rather favours the development of cyclonic vortices (Davies-Jones, 1984), it does not entirely exclude the formation of anticyclonic rotation or anticyclonic tornadoes. The process of a pure crosswise vorticity tilting implies cell splitting and the generation of a pair of cyclonic-anticyclonic vortices. The latter mechanism is not supported by any kind of observation or diagnostics mentioned in this study.

Although SREH or EHI indices are widely used to detect and forecast conditions of supercellular events, the concept of streamwise vorticity has in fact a much wider sense. Streamwise vorticity is generally important for the maintenance of organised convection. Thus, it supports the evolution of intense and persistent updrafts – which is necessary for both supercellular and non-supercellular tornadogenesis.

It can be hypothesized that the presence of streamwise vorticity diagnosed by the SREH and EHI parameters rather contributed to the mesoscale development of the whole thunderstorm line, while the generation of the tornadoes was probably induced by a different mechanism, as by the tilting of horizontal vorticity towards the thunderstorm updraft. The combination of horizontal shearing instability at the lower tropospheric boundary and the stretching of the air column by rapidly developing convection, proposed by Lee and Wilhelmson, seems to be a more plausible hypothesis for the 14 August tornadogenesis.

Evidence of intense convection appearing at the time of the tornado observation is confirmed also by MSG composite pictures. The 14 August case shows that tornadoes must not be necessarily related to large thunderstorm systems with cold cloud tops, which are easy to recognize on standard visible or infrared satellite imagery. This underlines the importance of using more sophisticated satellite outputs that give signals of processes related to changes in the microphysical structure of convective clouds.

Unfortunately, high resolution radar measurements of the evaluated thunderstorm cloudiness (which was probably situated also within the range of the Italian radar at Fossalon) were not available to the authors. Nevertheless, the results obtained by the evaluation of both radar and satellite data suggest that the recognition of small-scale severe convection, similar to the case of the 14 August tornadic thunderstorms requires data of a resolution well below 1 km. Operational forecasting of non-supercell tornadoes based on present accessible satellite, radar or NWP tools is not very likely. Besides high-resolution data and a more sophisticated technology, the forecasters need to be well informed about the typical weather conditions in which the tornadoes form. This should be a good motivation for collecting and producing more case studies of tornadoes along the Adriatic Coast.

Acknowledgement: *The authors thank Mr. Kvetoslav Jansík for his detailed description of the tornadoes observed at Novigrad and for the generously offered photo-documentation. The presented case study would not have come to existence without his help and information.*

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