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Cold season tornadoes in Bulgaria – brief analysis

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Abstract: From the beginning of 21st century 58 confirmed cases of tornadoes and waterspouts were registered in Bulgaria. In the list of documented tornadoes there are 5 "winter" cases which occurred within the cold half of year: 4 of which in southern Bulgaria and 1 - in northeastern Bulgaria. According to synoptic analysis they were associated with strong thunderstorms which developed along cold fronts introducing cold and moist air masses in Bulgaria after a period of unseasonably warm and dry weather. Some thermodynamic parameters and four instability indices have been calculated. All received values are close to those favorable for development in our country of summer type convective storms.

Keywords: tornado; winter convection; instability indices

1. INTRODUCTION

Tornado is one of the most extreme weather phenomena. Although it is defined as a small-scale convective induced whirl with a width of several tens of meters up to a maximum of 2 km and a lifetime from several minutes to several hours, this type of vortex can cause significant material damages and even loss of life. According to accepted definitions for tornado (Glickman, 2000; Rauhala et al., 2012) "*A tornado is a vortex between a cloud and the land or water surface, in which the connection between the cloud and surface is visible, or the vortex is strong enough to cause at least F0 damage*". This allows all waterspouts to be included in the definition of a tornado.

In the northern hemisphere, tornadoes occur more often in the spring and much less in the winter, but it is possible to observe them at any time of the year, if the weather conditions are favorable. In Europe (excluding United Kingdom) tornadoes

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occur mainly in summer (46.9%) and autumn (24.4%). The lowest number of cases was recorded in winter (12.7%) and spring (16.0%). For continental Europe as a whole, the most tornadoes are recorded between May and September and the smallest activity takes place in December, March and April. The monthly distribution of tornadoes reflects the seasonal maximum of thunderstorm frequency over Europe. (Graf, 2008; Antonescu et al., 2016)

Tornadoes occur relatively rarely in Bulgaria compared to other parts of the world. They may often remain unreported when occur in remote and weakly populated mountainous regions of the country or if they leave no significant damage behind. The number of reports of tornado events in Bulgarian from the beginning of 21-century however has significantly increased thanks mainly to the revolutionary development of the information technology. For example, 58 tornadoes and waterspouts have been recorded in Bulgaria since 2001, against only 20 cases for the period 1956-2000 (Simeonov et al., 2013; Bocheva&Simeonov, 2016). The summarized information shows that the maximum frequency of tornadoes in Bulgaria is in warm half of the year between May and August with maximum in June. However, in the list of documented tornadoes there are 5 "winter" cases, all after 2003 year, which occurred within the cold half of year: 4 of them in southern Bulgaria and one - in northeastern Bulgaria. They present a great interest especially taking into account that severe thunderstorms in Bulgaria are not typical phenomena for winter. But recent investigations show that after 1991 frequency of thunderstorms days increased more rapidly during the cold months almost in all regions in the country (Bocheva&Marinova, 2016).

Two of such "winter" tornado cases were analyzed in previous works as a comparison for different types of severe convection and connected with them extreme events such as strong winds, heavy precipitations and hail (Bocheva et al., 2009; Bocheva et al., 2015). The aim of present paper is to summarize and compare all known cases of unusual cold season tornado events in Bulgaria. A serious challenge in this study was a real lack of radar information, because during the cold season the only radar data came from the airports radars, which cover only the short range nearby the main airports in Bulgaria in Sofia and Varna.

2. DATA AND METHOD OF INVESTIGATION

This study identifies the main characteristics of cold season tornadoes in Bulgaria. Data originated from eyewitness reports, site investigations, media news, and reports of the local administration. Press and TV are often the richest source of images of the tornadoes themselves or the damage they have caused. Data from the meteorological data base of National Institute of Meteorology and Hydrology (NIMH) are also included. The analysis of the vertical structure of the atmosphere at the location and the time of occurrence are based on the sounding data from the archives of NIMH. Two of the cases were also verified by using radar images and data: for one of them from the automated radar system of NIMH (X and S-band AMS-MRL5) based in Gelemenovo and for second – C-band Doppler radar of Bulgarian Air Traffic Services Authority (BULATSA) on Sofia airport. The tornado cases have also been classified by strength according the Fujita scale (Fujita, 1985). The cases have been verified also by means of analysis of the weather patterns based on the NCEP/NCAR Reanalysis (Kalnay et al., 1996), images from GFS (www.wetter3.de) and from EUMETSAT, as well as products from NOAA/ESRL Physical Sciences Division, Boulder Colorado (http://www.esrl.noaa.gov/psd/). The sounding data from the national (Sofia) or the closest foreign aerological station (Bucharest) have been used to calculate some thermodynamic parameters and indices of instability at the vicinity of occurrence of the tornadoes. Surface data (pressure, temperature, humidity parameters, wind speed and direction) from the closest synoptic station have been fitted to the lower part of the vertical profile. All computations have been made by the upgraded in 2013 non-adiabatic empirical model developed by Dimiter Syrakov and Petio Simeonov (Simeonov& Syrakov, 1988).

3. RESULTS

3.1. Characteristics of "winter" tornado cases in Bulgaria

The collected database about tornadoes in Bulgaria for the period 2000-2017 has shown the registration of 5 such cases during the cold half of the year after 2003. Cold season tornadoes in Bulgaria presented 12% of all events. For comparison in United Kingdom about 35% occurred in the end of the autumn or winter-time (Holden&Wright, 2004) and in France about 20% of all (Graf, 2008).

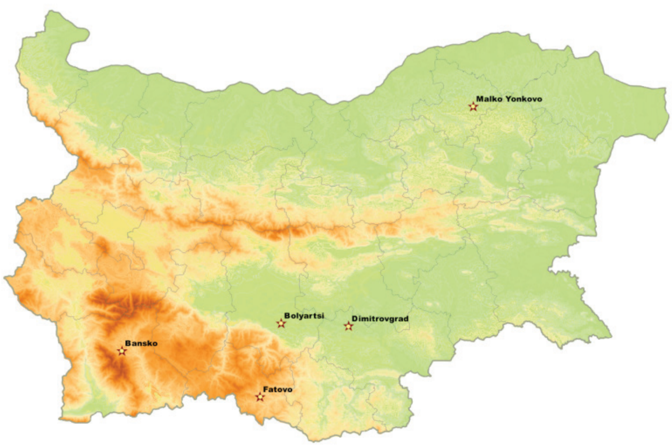


Fig. 1. Distribution of cold season tornadoes in Bulgaria.

Table 1. Main tornadic characteristics for all cold-season tornado cases

Location	Date	Start time UTC	Duration, min	Path length, km	Path widht, m	Max wind, m/s	T max, ° C	F-scale
Bolyartsi	24.03. 2004	13:30	about 10	0.4	35-130	20	17.6	F1
Fatovo	15.02. 2005	14:35	>30	2÷3	500	30	11.5	F1
Malko Yonkovo	21.03. 2007	13:30-14:00	about 10	*	*	40	17.8	F1
Bansko	02.12. 2010	07:30	10÷20	0.5	20-30	>20	18.0	F0
Dimitrovgrad	08.03. 2016	16:05	15	1	50	>20	17.8	F1

a) Broken and fallen radial pines near Fatovo

b) After a severe storm in Malko Yonkovo

c) After a tornado in Bansko

d) After a tornado in Dimitrovgrad

Fig. 2. Damages after cold season tornado outbreaks

The space distribution of "winter" tornadoes in Bulgaria is presented on Fig.1. The main ground-based characteristics of severe events are presented in Table 1. They have been classified by strength according to the Fujita scale on the base of information from damages reports and surface wind speed data – see Table 1. All cases can be classified as weak (less than or equal to F1) in which group belong about 76% of all tornadoes registered in the country. The available photos of damages after tornadoes are presented on Fig.2. After the tornado has passed, in all cases broken electric poles and damages on roofs of buildings have been reported. The biggest damages are recorded at the tornado case in the East Rhodopes on 15 February 2005. At least one tornado-like whirl has been observed at the Madan-Rudozem road. Local authorities have reported about a hundred and fifty hectares of pine forest destroyed by wind gust of up to 30 m/s between Fatovo and Tarun (Fig. 2a). The biggest damages in urban environment are registered on 08 March 2016 in Dimitrovgrad where more than 30 roofs of the houses were demolished and many windows and electric poles were broken (Fig. 2d).

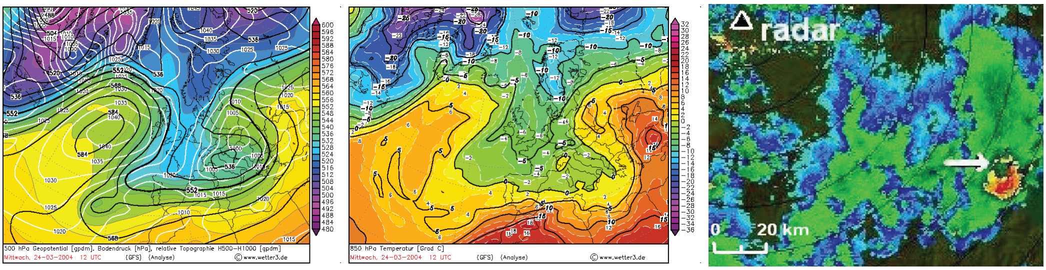
3.2. Synoptic and thermodynamic environment

The analyses of synoptic situation in Bulgaria show that the most tornadoes (90%) developed in the context of a cold front system with predominantly meridional extent from southwest to northeast which was associated with a strong air flow in the middle and upper troposphere. The cold-front system should have crossed the country. Such cold fronts are most often associated with a deep upper-level trough to the west of Bulgaria over the Central Mediterranean. When associated with tornadoes although, they appear to be rather stationary for a certain period of time or progress slowly through the country (Simeonov et al., 2013).

The same synoptic features are observed in all 5 cases of cold season tornadoes in Bulgaria. At 500 hPa charts the weather over the country is determined by a deep and slowly moving trough from the north with axes reaching Central Mediterranean (see Fig. 3-7 a). The strong jets from the south-southwest, typical for summer type convective processes, pass over the country. At the surface, Mediterranean cyclones are formed over northern part of the Adriatic Sea 48 hours before tornado and slowly moved eastward over the area. Bulgaria is situated in front of the low pressure area. The warm flows from south spread over the country. In all cases the measured surface air temperatures are with 10-15° C over the typical ones for the season at least 2-3 days before the tornado events. The maximum surface air temperature in tornado days is presented in Table 1. Cold atmospheric fronts connected with Mediterranean cyclones cross the country. After the cold front the temperature on 850 hPa decreased with 5-6 °C in all cases (Fig. 3-7 b).

There are many difficulties when attempting to study the thermodynamics at the vicinity of occurrence of tornadoes. We have only two radar images from quite different meteorological radars – for Bolyartsi from Sofia airport radar (Fig. 3c) and for Dimitrovgrad from NIMH radar (Fig. 7c). According to Fig. 3c the maximum reflectivity of convective clouds over Bolyartsi is about 45dBz (in red). The only available information from Fig.7c, which presents the software product from Gelemenovo radar, is the existence of the convective clouds with cloud top about 7 km. In addition to lack of radar information, there are only a few sounding profiles available in the region. The NIMH operates only one aerological sounding per day at 12:00 UTC in Sofia. This inhibits the attempts to see the instability factors prior to events occurring before noon for example as is the case in Bansko. For tornado which occurred in morning hours of

02 December 2010 the only available sounding data was from Sofia, because there is no information about Thessaloniki air sounding for this day. Regarding the Dimitrovgrad case, it is impossible to use Sofia sounding data, not because of the distance of 200 km between two towns, but mainly because of the jet from south to north which crossed the central parts of the country and created favorable conditions for severe storm development over Thracian lowland (see Table 2).

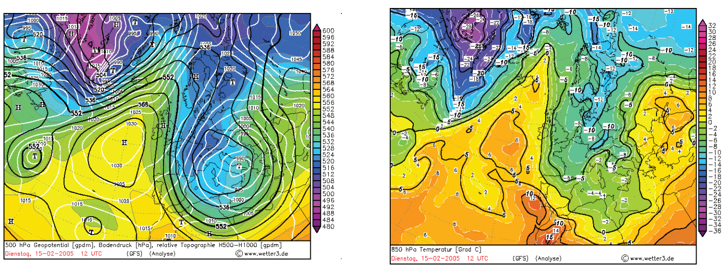


a) 500 hPa analyses from 1200 UTC 24.03.2004.

b) Temperature on 850 hPa from 1200 UTC 24.03.2004.

c) Sofia airport 13:30 UTC radar CAPPI image

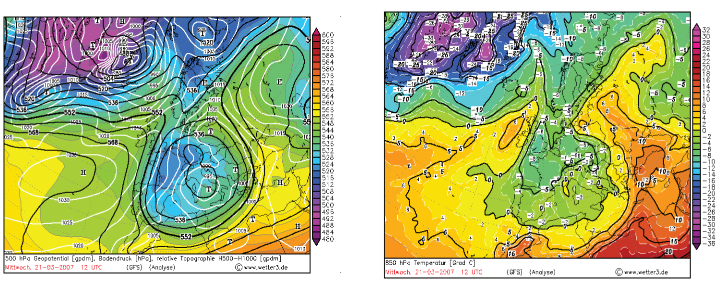
Fig. 3. 24 March 2004 – Bolyartsi tornado outbreak



a) 500 hPa analyses from 1200 UTC 15.02.2005.

b) Temperature on 850 hPa from 1200 UTC 15.02.2005.

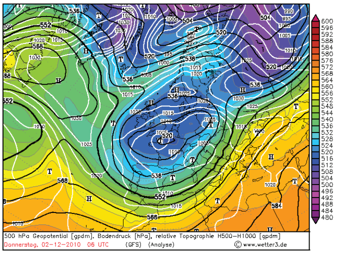
Fig. 4. 15 February 2005 – Fatovo tornado outbreak



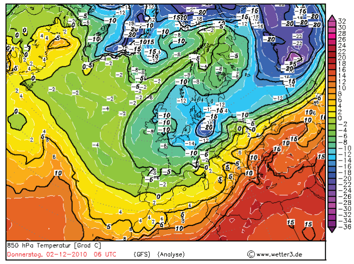
a) 500 hPa analyses from 1200 UTC 21.03.2007.

b) Temperature on 850 hPa 1200 UTC 21.03.2007.

Fig. 5. 21 March 2007 – Malko Yonkovo tornado outbreak

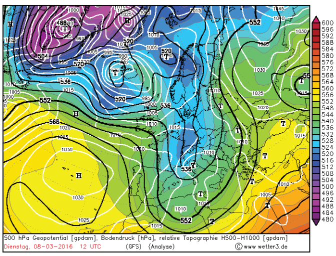


a) 500 hPa analyses from 0600 UTC 02.12.2010.

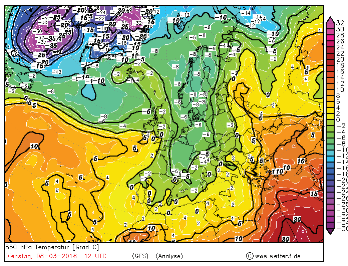


b) Temperature on 850 hPa 0600 UTC 02.12.2010.

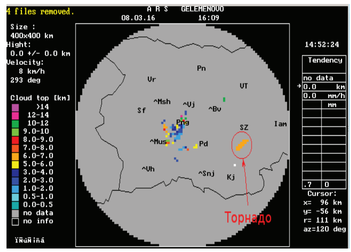
Fig. 6. 02 December 2010 – Bansko tornado outbreak



a) 500 hPa analyses from 1200 UTC 08.03.2016.



b) Temperature on 850 hPa 1200 UTC 08.03.2016.



c) Gelemenovo radar image 14:09 UTC

Fig. 7. 08 March 2016 – Dimitrovgrad tornado outbreak

In our case for description of thermodynamic conditions 4 instability indices and 4 parameters are chosen (Table 2). For their calculation the air sounding data from Sofia (for 3 cases in South Bulgaria) and Bucharest (for the case in North Bulgaria) are used as well as data from closest synoptic station in time interval near to tornado occurrence.

Table 2. Instability indices and thermodynamic parameters of the environment of Bulgarian cold-season tornadoes

Location	**KI,°C**	**TT,°C**	**LI,°C**	**SWEAT**	w_{max}, m/s	**Hwmax,** m	H_0, m	Z_{El}, m
Bolyartsi	31.4	61	– 6.6	187	15	5578	2128	8078
Fatovo	14.3	50.4	– 4.3	108	13	4392	2278	9142
Malko Yonkovo	30.8	54.8	– 7.5	385	15	5911	3059	10161
Bansko	33	54.4	– 5.66	385	13	5114	3524	10613
Dimitrovgrad	*	*	*	*	*	*	*	*

Parameters in Table 2:

Four specific indices of instability based on sounding profiles of temperature, humidity and wind in the lower and middle troposphere are:

- **K I**ndex (George, 1960)

$$KI = (T_{850} - T_{500}) + T_{d850} - (T_{700} - T_{d700}) \tag{1}$$

- **Total Totals Index** (Miller, 1972)

$$TTi = (T_{850} - T_{500}) + (T_{d850} - T_{d500}) \tag{2}$$

where T_{850}, T_{700}, and T_{500} denote temperature at levels 850, 700, and 500 hPa and T_{d850} and T_{d700} denote dew point at levels 850 and 700 hPa.

- **L**ifted **I**ndex (Galway, 1956)

$$LI = (T_L - T_{500}) \tag{3}$$

where T_L is the temperature of an adiabatically (dry or wet depending on the level of saturation) ascending air parcel from level 850 hPa to level 500 hPa; T_{500} is the air temperature at level 500 hPa.

- **S**evere **WEA**ther **T**hreat index (**SWEAT) -** Miller (1972)

$$SWEAT = 12T_{d850} + 20(TTi - 49) + 2V_{850} + V_{500} + 125(\sin(dd_{500} - dd_{850}) + 0.2) \tag{4}$$

where TTi is the Total Totals index, V_{850} and V_{500} denote the wind velocity at levels 850 hPa and 500 hPa respectively, and $dd_{500} - dd_{850}$ is the difference between the directions of wind in degrees at the two levels.

- W_{max} – the maximum value of updraft velocity - non-adiabatic empirical model (Simeonov& Syrakov, 1988)
- $H\ w_{max}$ – the level of maximum value of updraft velocity- non-adiabatic empirical model (Simeonov& Syrakov, 1988)
- H_0 – altitude of 0ºC isotherm
- Z_{El} – altitude of **E**quilibrium level (El)

The calculated high absolute values of indices, presented in Table 2, indicate increased instability. According to other studies (Siedlecki, 2009) values of KI >25, TT > 49 and LI < – 4 indicate conditions favorable for the development of strong thunderstorms with hail and/or tornadoes. The calculated indices for tornado events in Bolyartsi, Malko Yonkovo and Bansko completely satisfy these limits. In Fatovo case KI index is very low, but nevertheless the biggest damages are reported. The explanation of this is in the use of Sofia aerological sounding data for calculation of the index. In 12:00 UTC the cold front passed the Sofia region and the temperature decreased while in the region of Fatovo the situation was quite different.

The SWEAT is close to the one for Greece (Sioutas, 2011) but lower than 400 which was found to be a threshold value for summer tornado storms in the USA (David, 1976). However, the mean values of SWEAT indices obtained in the study are close with the ones estimated for winter months between November and March and close to those for month with the highest tornado frequency in the USA - May (SWEATmay = 253, in David, 1976). The other parameters are also near or above threshold values for strong thunderstorms in the warm half of the year in Bulgaria. The heights of the zero isotherm H0 (Table 2) are within the limits of typical values (Simeonov et al., 1990) for the development of severe hail thunderstorms during the end of the spring (in May). Regarding the altitude of the Equilibrium level, all calculated values fall within the ranges determined by Boev and Marinov (1984) for the development of convective clouds during the warm half of the year.

CONCLUSSION

The intensity analysis indicated that the cold season tornadoes in Bulgaria can be classified as F0–F1 of the Fujita scale which is equivalent to “weak” tornadoes. The analysis of the selected thermodynamic indices and wind parameters showed values comparable to those found in the literature as favorable for development of summer type severe convective storms.

The increased frequency of thunderstorms during the cold half of the year after 1991 (Bocheva&Marinova, 2016), as well as the accompanying severe convective events such as the winter tornadoes presented in this study, show the need for a detailed study of the causes of the occurrence and development of this type of phenomena, using more reliable information from meteorological Doppler radars, satellite data (or products) and other data for the vertical structure of the atmosphere.

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