THE CONNECTION BETWEEN SOLAR WIND CHARGED PARTICLES AND TORNADOES – CASE ANALYSIS

by

Milan M. RADOVANOVIĆ [1], ***Boško M. MILOVANOVIĆ*** [1], ***Mila A. PAVLOVIĆ*** [2], ***Aleksandar R. RADIVOJEVIĆ*** [3], ***and Milan T. STEVANČEVIĆ*** [4]

[1]Geographical Institute "Jovan Cvijić", Serbian Academy of Sciences and Arts, Belgrade, Serbia
[2]Faculty of Geography, University of Belgrade, Belgrade, Serbia
[3]Department of Geography, Faculty of Natural Sciences and Mathematics, University of Niš, Niš, Serbia
[4]Ex Federal Ministry of Telecommunications of Yugoslavia

Scientific paper
DOI: 10.2298/NTRP1301052R

The temperature of charged particles coming from the Sun ranges from several hundred thousands to several millions °C, in extreme cases. Theoretical possibilities of the hydrodynamic air mass seizing by charged particles, *i. e.* solar wind, are discussed in this paper. On one hand, they are characterized by extremely high temperatures, on the other, by the compression of cold air at an approximate altitude of 90 km towards the top of the cloud of the cyclone, they influence the phenomenon of extremely low temperatures. By using the Mann-Whitney U test we have tried to determine the potential link between certain indicators of solar activity and resulting disturbances in the atmosphere. Analysed data refer to global daily values for the 2004-2010 period. Our results confirm the possibility of coupling between the charged particles and the vortex air mass movements, based on which a more detailed study of the appearance of a tornado near Sombor on May 12th, 2010, was carried out. It has also been proven that there are grounds for a causality between the sudden arrival of the solar wind charged particles, *i. e.* protons, and the appearance of a tornado. Based on the presented approach, elements for an entirely novel prediction model are given.

Key words: Sun, charged particles, tornado, Sombor

INTRODUCTION

Sombor is located in the northwestern part of Serbia, near the border with Hungary and Croatia. According to available data, amateur footage shot on May 12th, 2010, is actually the only video footage of a tornado ever recorded in these regions. At the time, the media reported that in a minute and a half, a tornado or "twister" formed near the Gradina farm, carried away a trailer with hives, a caravan, pulled out several concrete poles, tore trees and caused damage in adjacent fields under sugar beet and wheat (fig. 1).

Only photographs of the tornado that occurred on June 6th, 2008, in the vicinity of Indjija (Serbia) exist, while there is no evidence of any other previous event of the kind, apart from eyewitness testimonies [2]. Bearing in mind that this is an extremely rare occurrence in Serbia, the hypothesis linking the processes on the Sun, *i. e.* its charged particles, with the whirling motions of air masses on Earth, has enticed a lot of attention, including the assumption that tornadoes might be a result of this presumed Sun-Earth relation.

Figure 1. Amateur image of a tornado near Sombor on May 12th, 2010 [1]

The idea of a dominant influence of the processes on the Sun (including cosmic rays) on the climate and meteorological processes in Earth's atmosphere is not new [3-8]. Figure 2 shows a strong relationship between the magnetic indicia based on modules of geomagnetic fields, refering to the interdependance of solar radiation and global mean temperature. Therefore, many authors have pointed out the necessity of improving methods for the investigation of Sun-Earth dependancies, not just when it comes to forecasting models related to air temperature.

* Corresponding author; e-mail: m.radovanovic@gi.sanu.ac.rs

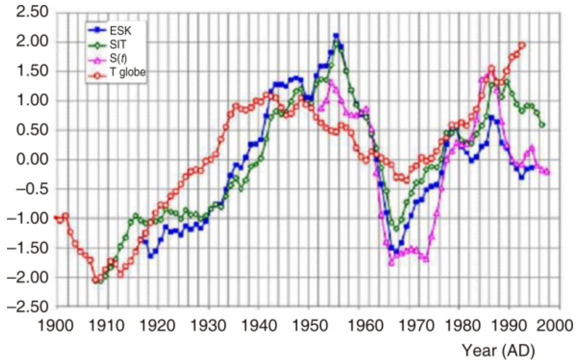

Figure 2. 20th century time evolution over eleven-year running averages of magnetic indices based on moduli of the geomagnetic field at the Eskdalemuir and Sitka observatories (ESK and SIT), compared to the solar irradiance, *S*(*t*), and global mean temperature, *T* globe [9]

Based on available data and applying the complex linear regression for the period 1891-2004, the authors [10] have tested the connection between solar activity and atmospheric circulation. The values for the adjusted R^2 were calculated from 0.572-0.825. In the case of the atmospheric disturbances in the lower troposphere above Torino (Italy), arguments have also been given for establishing a connection between solar wind (SW) protons and cyclonic air mass movements [11]. In contrast, opinions that the genesis of tornadoes is yet to be adequately explained, remain [12, 13]. The marginally significant tendency towards cyclonic types being more frequent under moderate solar activity cannot be explained in terms of changes in the modes of atmospheric circulation variability, the reason behind this remaining unclear [14].

MATERIALS AND METHODS

Daily data on solar activity pertaining to the 2004-2010 period were used in this paper [15], as well as data on geomagnetic activity presented in the *aa* index [16] and daily data on hurricanes around the globe for the investigated period [17]. By daily graphic checks of the distribution of variables by which solar activity is represented, we have found that there is no normal distribution at any of them. Therefore, the Mann-Whitney U test [18] was used to test the significance of the differences in the values of variables in days when there were no atmospheric disturbances (such as hurricanes, tropical cyclones, tropical storms), as well as those days when there were no signs of such disturbances. Access to the data analysis is the same as in the previous research [2], with a difference that, this time, a somewhat longer period is analysed, along with the changes in the geomagnetic activity, as presented in the *aa* index. It also has to be noted that, as for the 2004-2007 period, there is a statistically significant difference between the solar activity represented by variables of 1 MeV protons, 0.6 MeV electrons and 2 MeV electrons in days when there is a disturbance of the atmosphere and those in which such disturbances have not been registered.

Results obtained for the 2004-2010 period differ. It turned out that at variables of 1 MeV protons, 100 MeV protons and the *aa* index, a statistically significant difference at $p = 0.05$ and 0.6 MeV electrons at $p = 0.1$ exists between the days with a specific disorder of the atmosphere and those in which these disorders were not noted (tabs. 1-3).

Table 1. Mann-Whitney U test score[1]

	Rank sum 1	Rank sum 2	*U*	*Z*	*p*-level	*Z*	*p*-level	Valid *N*	Valid *N*
1 MeV proton	**2309572**	**806684.0**	**575144.0**	**2.638568**	**0.008326**	**2.638827**	**0.008320**	**1816**	**680**
10 MeV proton	2242668	873588.5	592831.5	–1.53516	0.124745	–1.54504	0.122336	1816	680
100 MeV proton	**2222163**	**894093.5**	**572326.5**	**–2.81433**	**0.004888**	**–2.81786**	**0.004835**	**1816**	**680**
0.6 MeV electron	**2295086**	**821170.5**	**589630.5**	**1.734851**	**0.082768**	**1.734937**	**0.082753**	**1816**	**680**
2 MeV electron	2271202	845054.0	613514.0	0.244917	0.806521	0.244923	0.806516	1816	680
aa index	**2303557**	**810203.0**	**578663.0**	**2.398971**	**0.016442**	**2.399030**	**0.016439**	**1815**	**680**

[1]Statistically significant results at $p = 0.05$, that is, $p = 0.1$ are bolded

Table 2. Median, minimum, and maximum values, variances, and standard deviations of the indices of solar and geomagnetic activities in days without atmospheric disturbances

	Median	Minimum	Maximum	Variance	Standard deviation
1 MeV proton	9.000000E+05	55000	1.100000E+09	2.117541E+15	4.601674E+07
10 MeV proton	1.700000E+04	11000	1.100000E+08	2.385777E+13	4.884441E+06
100 MeV proton	3.800000E+03	2000	6.100000E+06	2.340604E+10	1.529903E+05
0.6 MeV electron	1.000000E+10	10000000	1.800000E+11	4.889271E+20	2.211170E+10
2 MeV electron	2.100000E+07	32000	9.300000E+09	1.770131E+17	4.207293E+08
aa index	1.190000E+01	2	1.826000E+02	2.427256E+0.2	1.557965E+01

Table 3. Median, minimum, and maximum values, variances, and standard deviations of the indices of solar and geomagnetic activities in days when there are no disturbances of the atmosphere

	Median	Minimum	Maximum	Variance	Standard deviation
1 MeV proton	7.700000E+05	110000	6.700000E+08	7.426713E+14	2.725200E+07
10 Mev proton	1.700000E+04	10000	2.200000E+07	8.165046E+11	9.036064E+05
100 MeV proton	3.900000E+03	1800	5.800000E+04	8.052540E+06	2.837700E+03
0.6 MeV electron	9.550000E+09	19000000	1.400000E+11	4.514014E+20	2.124621E+10
2 MeV electron	1.900000E+07	33000	5.400000E+09	1.841019E+17	4.290710E+08
aa index	1.035000E+01	2	1.183000E+02	1.755708E+02	1.325031E+01

Meteorological and astrophysical analysis of atmospheric disturbances in Europe and the Balkans for the investigated period

According to the heliocentric hypothesis on the influence of SW on the hydrodynamic seizing of air masses, before sudden disturbances occur in the atmosphere, a coronary hole and/or energy region [19-21] must position itself at geoeffective position on the Sun.

Based on fig. 3, it can be seen that on the day when the tornado occurred near Sombor, coronary hole CH403 existed on the Sun and that the irradiation of its charged particles was directed towards the Earth. According to the results of the previous research [23, 24], the seizing of air masses by SW occurs in two basic ways. The first pertains to the re-connection, *i. e.* penetration of the charged particles above the polar areas. The process takes place under the condition that the resultant SW interplanetary magnetic field vector and the geomagnetic field merge. In the second scenario, the SW penetrates into the lower parts of the troposphere over the areas of the geomagnetic anomaly, that is, above the area where the force of the geomagnetic field is the weakest [25]. Regardless of the kind of penetration, satellites will register a sudden rise of SW velocity and, hence, the sudden influx of kinetic energy.

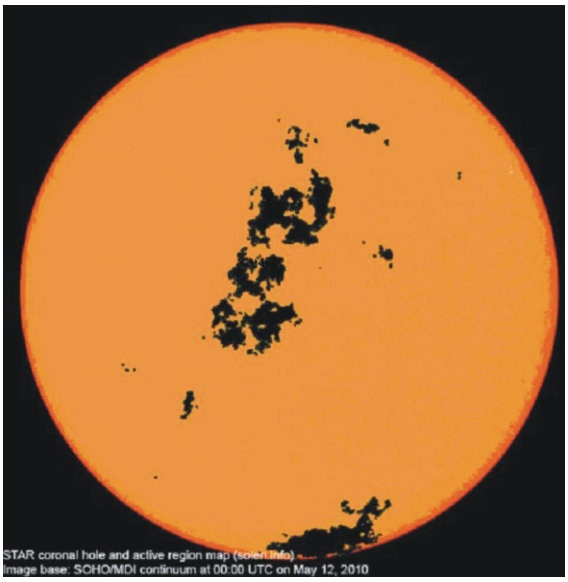

Figure 3. Position of coronary holes on the Sun on May 12th, 2010 [22]

As can be seen from fig. 4, in the early morning hours of the 12th of May, there was a sudden increase in SW speed, reaching at certain moments over 500 km/s. The values of the flow of protons and electrons before the tornado are given in tab. 4.

Apart from the values for protons, the values for electrons are also given in the previous table. Bearing in mind the assumption made in previous papers [28, 29] that protons are closely related to low, and electrons to high air pressure, tab. 4 also shows how the values for electrons, in both energy ranges, decreased up to the day when the tornado occurred in Serbia. In contrast, the flow of protons in the range >1 MeV increased continually from the 8th-11th May when the highest average daily value was recorded. At other indices for protons,

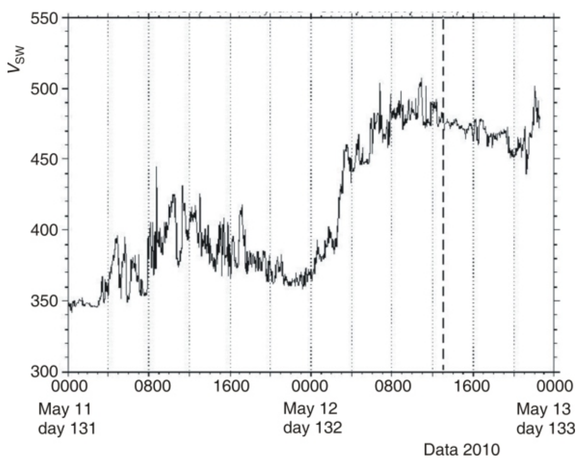

Figure 4. Speed of the SW a day before the tornado and on the day when the tornado struck the vicinity of Sombor [26]; the broken vertical line shows the approximate moment of the occurrence of the tornado

Table 4. The number of protons and electrons of certain energy ranges several days before and after the appearance of the tornado near Sombor [27]

Date	Protons $[cm^{-2}d^{-1}sr^{-1}]$			Electrons $[cm^{-2}d^{-1}sr^{-1}]$	
	>1 MeV	>10 MeV	>100 MeV	>0.6 MeV	>2 MeV
2010.05.08	1.7E+05	1.8E+04	7.5E+03	4.1E+09	4.1E+08
2010.05.09	2.2E+05	1.9E+04	8.0E+03	5.3E+09	5.6E+08
2010.05.10	5.6E+05	2.0E+04	8.3E+03	4.5E+09	5.4E+08
2010.05.11	5.9E+05	2.0E+04	8.2E+03	2.5E+09	2.1E+08
2010.05.12	3.9E+05	2.0E+04	8.0E+03	1.6E+09	1.0E+08
2010.08.13	5.3E+05	2.0E+04	8.6E+03	1.9E+09	1.6E+08

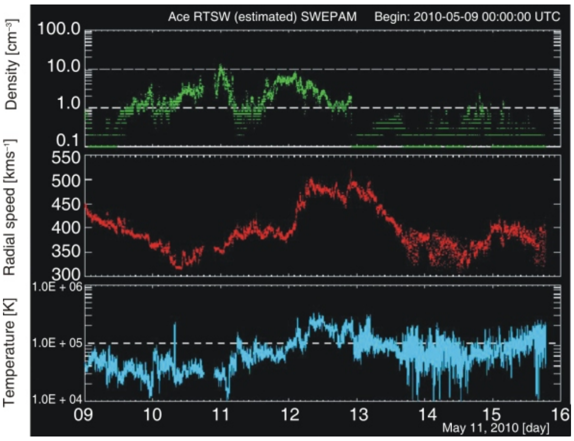

Figure 5. SW parameters characterised by a sudden rise in particle density, radial velocity and temperature, a day before the occurrence of the tornado in the vicinity of Sombor [30]

the sudden rises were not recorded in the investigated period.

As shown in fig. 5, a sudden increase in the density, velocity, and temperature of particles on May 11th, 2010, is evident. SW particles are moving through the atmosphere in the form of jet streams. After the opening of jet streams, the particles of corpuscular radiation penetrate the free atmosphere with a certain quantity of moving. Proton particles seize the cold air masses at higher altitudes and direct them towards the ground by the force of their dynamic pressure. It can, hence, be concluded that if the particles of corpuscular radiation have a small mass (electrons), the quantity of moving is, likewise, small. Generally, it has to be noted that the opening of jet streams in the upper layers of the atmosphere, outside the equatorial belt, occurs at air temperatures of approximately –40 °C to –65 °C [31].

Extremely low temperatures were recorded during hurricane Wilma (October 19th, 2005) over a surface of 700 mb in the zone of the clouds. GOES-12 10.7 μm IR images revealed cloud top brightness temperatures as cold as –87 ºC [33]. In the case of the tropical storm 07W Molava (305 nautical miles north-northeast of Manila, Philippines) that occurred on July 16th 2009, the temperature at the top of the cloud was –92.4 ºC [34]. Considering that such low

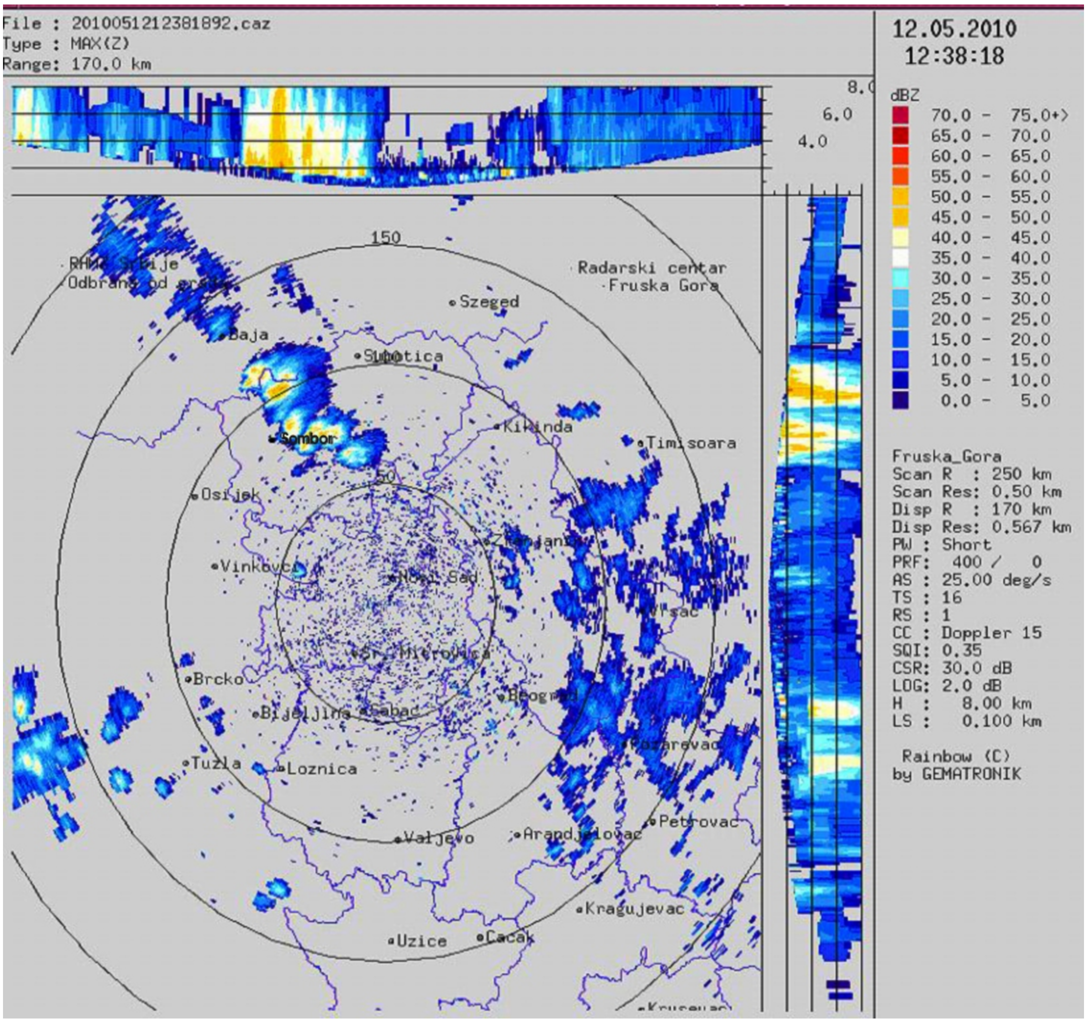

Figure 6. Radar image of cloudiness during the occurrence of the tornado near Sombor [32]

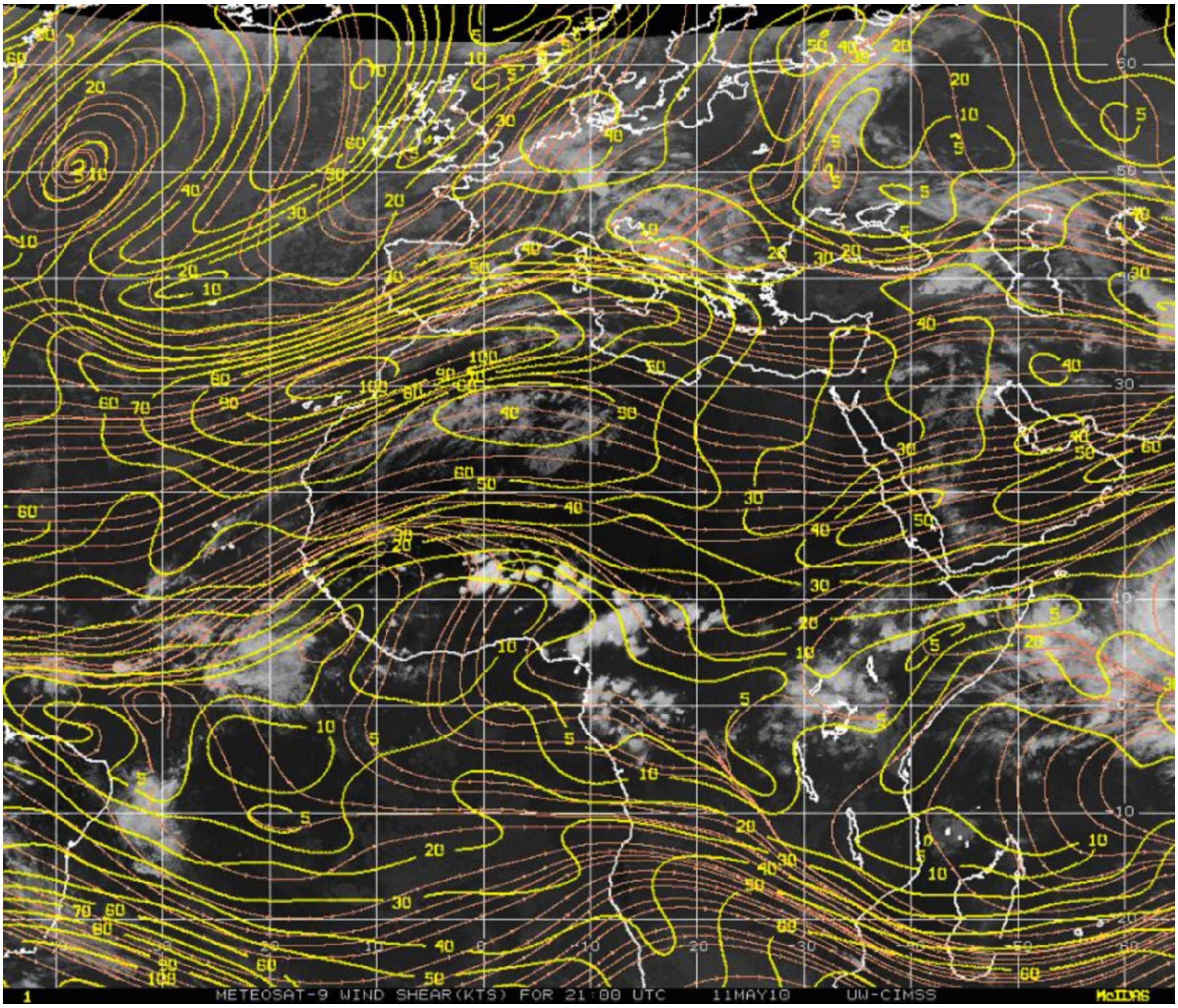

Figure 7. Mean tropospheric wind speed (knt) shows a strong top-to-down movement of air masses coming from the direction of northwest Africa towards the southern Mediterranean, a day before the appearance of the tornado in the vicinity of Sombor [35]. The white line shows the axis of the movement of air masses of highest velocities

values can only be found at the upper border of the mesosphere in the environment of the Earth, the explanation for the possible seizing of air masses by the SW up to the cloud of the cyclone poses a pressing question.

It may, thus, be concluded that the fall in temperature in regions of low atmospheric pressure is a consequence of the descending advection of cold air masses under the impact of the dynamic pressure of proton particles of the corpuscular radiation of the Sun, that is, the front wave of the particles.

Having examined the position of the isolines from the previous figure depicting the movement of high winds, (up to 100 knt), from the southwest to the northeast, one can predict that there is a strong possibility that, the next day, a disruption of air masses over the Balkan Peninsula is to be expected as well. According to tab. 4, maximum flow rates of protons >1 MeV were recorded on the same day the recording was made, that is, one day before the appearance of the Sombor tornado. As for the flow of protons >100 MeV, maximum values were measured two days before the studied case. The report by [36] shows that stratospheric mean-flow variations induce circulations that penetrate into the lower troposphere. To investigate these results in more detail, [37] we have used GPH data on 16 pressure levels covering both hemispheres, so as to establish if the proposed correlation exists in both the terrestrial stratosphere and its troposphere. Results have shown a statistical E-GPH connection extending from the lower stratosphere all the way down to the surface.

In a moderate latitude, SW always penetrates the Earth's atmosphere at an angle θ_{SW}, which is the angle that the speed (v) forms with the vector of magnetic induction B. We can separate the speed into two components: the first, $v\cos\theta_{SW}$, pertaining to the direction of the magnetic field, and the second one, $v\sin\theta_{SW}$, being perpendicular to the direction of the magnetic field. Then, the result will be that the trajectory of the SW (which is the trajectory of SW particles) is in the form of a spiral (helix), where the momentary diameter of the cylinder around which the SW is spiraling equals

$$r \quad \frac{mv\sin\theta_{\mathrm{SW}}}{qB} \tag{1}$$

while the step of the SW trajectory is

$$d \quad \frac{2\pi r}{v\sin\theta_{\mathrm{SW}} \quad v\cos\theta_{\mathrm{SW}}} \quad \frac{2\pi mv\cos\theta_{\mathrm{SW}}}{qB} \tag{2}$$

However, when a cloud of SW particles moves through the atmosphere, speed *v* is gradually reduced (meaning: its particles undergo a slowdown) and, consequently, the radius, *r*, becomes smaller. This could be the explanation for the fact that the trajectory of the SW, its speed growing ever lower, does not take the shape of a cylinder, but rather of a funnel, with the SW winding itself around this funnel, with its wider turned towards the Sun.

The speed of the spinning motion of air masses is calculated from the relation that describes the time needed for a particle to make a full circle

$$t \quad \frac{2\pi r}{v} \quad \frac{2\pi m}{qB} \tag{3}$$

CONCLUDING REMARKS

According to current literature, it can be concluded that the achievements in the field of prognostic simulations are, after all, limited. In results previously mentioned [13], conclusions are made on the impossibility of determining the date when and where tornadoes are going to occur, not only smaller in size, as is the case with the tornado near Sombor. This view is outlined in relation to medium and long-term predictions. Also, clear assertions are presented concerning the impossibility of perceiving, *i. e.* understanding tornado occurrences in terms of decades-long periods. In this regard, there are claims that the occurrence of tornadoes in the studied twenty-year time series cannot be attributed to the anthropogenic influence on climate changes [38]. Some scientists are of the opinion that the physical mechanism of the solar activity effect on weather events on Earth remains unclear [39]. It is assumed that a significant part in the transfer of solar variability to the lower part of the atmosphere can be performed by charged particles of solar and galactic origin, mainly protons, with energies from ~100 MeV to several GeV. There are indications that an interactive link occurs if there is an adequately focused guidance of jets of energy towards the ground [40]. Namely, the possibility that the vortex motion in the lower layers of the troposphere will depend on the manner of dissipation of energy through the magnetosphere and atmosphere, taking into account the angle of incidence of the basic SW jet.

The results of our study indicate possible directions of future research, with the expectation that this will provide a novel basis for understanding the genesis of tornadoes. In favor of this hypothesis are the data obtained by the Mann-Whitney U test for the 2004-2007 period, as well as those pertaining to 2004-2010. The differences observed indicate the necessity of distinguishing the activity of the Sun at the end of one cycle and the beginning of a new one. Such studies could most likely yield a better understanding not only of cyclogenesis, but a classification of atmospheric circulation, as well [41].

The influence of the high temperature of charged particles, not only on atmospheric processes, represents a particular challenge for different aspects of the geographical environment [42]. In that sense, special models, requiring interdisciplinary projects, are needed.

ACKNOWLEDGEMENT

This study is supported by the Ministry of Education, Science and Technologycal Development of the Republic of Serbia – grant III47007 and 176008

AUTHOR CONTRIBUTIONS

Theoretical analysis was carried out by M. M. Radovanović and M. T. Stevančević. Statistical analysis was carried ou by B. M. Milovanović. The manuscript was written by M. M. Radovanović, B. M. Milovanović, M. A. Pavlović, A. R. Radojević, and M. T. Stevančević and the figures were prepared by M. M. Radovanović and M. T. Stevančević.

REFERENCES

[1] ***, Blic online, www.blic.rs/Vesti/Drustvo/189386/Tornado-moze-da-se-pojavi-bilo-kad-i-bilo-gde (in Serbian)

[2] Radovanović, M., Waterspout near Indjija – the Analysis of the Case from 6th June 2008, *Glasnik SGD, 81* (2009), 4, pp. 295-305

[3] Landscheidt, T., New Little Ice Age Instead of Global Warming, *Energy and Environment, 14* (2003), 2-3, pp. 327-350

[4] Radovanović, M., Stevančević, M., Štrbac, D., A Contribution to the Study of the Influence of the Energy of Solar Wind upon the Atmospheric Processes, *Journal of the Geographical Institute "Jovan Cvijić" SASA, 52* (2003), 1, pp. 1-18

[5] Palamara, R. D., Bryant, A. E., Geomagnetic Activity Forcing of the Northern Annular Mode via the Stratosphere, *Annales Geophysicae, 22* (2004), 3, pp. 725-731

[6] Shaviv, J. N., On Climate Response to Changes in the Cosmic Ray Flux and Radiative Budget, *Journal of geophysical research, 110* (2005), A08105

[7] Lilensten, J., Bornarel, J., Space Weather, Environment and Societies, Springer Ltd., Berlin, Heidelberg, 2006

[8] Mukherjee, S., Cosmic Influence on the Sun-Earth Environment, *Sensors, 8* (2008), 12, pp. 7736-7752

[9] LeMouël, J.-L., *et al*., Evidence for Solar Forcing in Variability of Temperatures and Pressures in Europe,

Journal of Atmospheric and Solar-Terrestrial Physics 71 (2009), 12, pp. 1309–1321
[10] Milovanović, B., Radovanović, M., The Connections between Solar Activity and the Circulation of Atmosphere in the 1891-2004 Period (in Serbian), *Journal of the Geographical Institute "Jovan Cvijic" SASA, 59* (2009), 1, pp. 35-48
[11] Nikolić, J., Radovanović, M., Milijašević, D., An Astrophysical Analysis of Weather Based on the Solar Wind Parameters, *Nucl Technol Radiat, 25* (2010), 3, pp. 171-178
[12] Markowski, M. P., Richardson, P. Y., Tornadogenesis: Our Current Understanding, Forecasting Considerations, and Questions to Guide Future Research, *Atmospheric Research, 93* (2009), pp. 3-10
[13] Love, G. B., Statement on Tropical Cyclones and Climate Change, Prepared by the WMO/CAS Tropical Meteorology Research Program, Steering Committee for Project TC-2: Scientific Assessment of Climate Change Effects on Tropical Cyclones. Submitted to CAS-XIV under Agenda Item 7.3, 2006
[14] Huth, R., *et al*., Solar Activity Affects the Occurrence of Synoptic Types over Europe, *Annales Geophysicae, 26* (2008), 7, pp. 1999-2004
[15] ***, Historical SWP Products from 1996, www.swpc.noaa.gov/ftpmenu/warehouse.html
[16] ***, NOAA Solar Data, ftp.ngdc.noaa.gov/STP/SOLAR_DATA/RELATED_INDICES/AA_INDEX/aaindex
[17] ***, JAXA/EORC Tropical Cyclone Database, sharaku.eorc.jaxa.jp/TYP_DB/index_e.shtml
[18] von Storch, H., Zwiers, F. W., Statistical Analysis in Climate Research, Cambridge University Press, Cambridge, UK, 1999
[19] Radovanović, M., Lukić, V., Todorović, N., Heliocentric Electromagnetic Long-Term Weather Forecast and its Applicable Significance, *Journal of the Geographical Institute "Jovan Cvijić" SASA, 54* (2005), 1, pp. 5-18
[20] Stevančević, M., Radovanović, M., Todorović, N., Analysis of Characteristic Mistakes in the Heliocentric Electromagnetic Long-Term Forecast (in Serbian), in the Collection "Touristic Valorization of Mountain Tara", The Geographical Institute "Jovan Cvijic", SASA, Sporting-Tourist Centre, Bajina Bašta, Serbia, 2006, pp. 101-110
[21] Gomes, J. F. P., Radovanović, M., Solar Activity as a Possible Cause of Large Forest Fires – A Case Study: Analysis of the Portuguese Forest Fires, *Science of the Total Environment, 394* (2008), 1, pp. 197-205
[22] ***, Solar Terrestrial Activity Report url: www.solen.info/solar/old_reports/2010/may/20100512.html
[23] Ducić, V., Milenković, M., Radovanović, M., Contemporary Climate Variability and Forest Fires in Deliblatska Pescara, *Journal of the Geographical Institute "Jovan Cvijić" SASA, 58* (2008), pp. 59-73
[24] Radovanović, M., Gomes, J. F. P., Solar Activity and Forest Fires, Nova Science Publishers, New York, USA, 2009
[25] Gomes, J. F. P., *et al*., Wildfire in Deliblatska Pescara (Serbia) – Case Analysis on July 24th 2007, in: Forest Fires: Detection, Suppression and Prevention, Nova Science Publishers, New York, USA, 2009, pp. 89-140
[26] ***, MTOF/PM Data by Carrington Rotation, umtof.umd.edu/pm/crn/CRN_2096.GIF
[27] ***, NOAA, Space Weather Prediction Center, www.swpc.noaa.gov/ftpdir/latest/DPD.txt
[28] Radovanović, M., Milovanović, B., Gomes, J. F. P., Endargement of Undeveloped Areas of Serbia by Forest Fires, *Journal of the Geographical Institute "Jovan Cvijić" SASA, 59* (2009), 2, pp. 17-35
[29] Radovanović, M., Forest Fires in Europe from July 22-25, 2009, *Archives of Biological Sciences, 62* (2010), 2, pp. 419-424
[30] ***, NOAA, Space Weather Prediction Center, www.swpc.noaa.gov/ace/SWEPAM_7d.html
[31] Milenković, M., Radovanović, M., Ducić, V., The Impact of Solar Activity on the Greatest Forest Fires of Deliblatska Pešcara (in Serbian), *Forum Geographic, 10* (2011), 1, pp. 107-116
[32] ***, RHSS, Republic Hydrometeorological Service of Serbia, www.hidmet.gov.rs/ciril/osmotreni/radarska4. php?id=5668
[33] ***, University of Wisconsin-Madison Space Science and Engineering Center, CIMSS Satellite Blog, cimss.ssec.wisc.edu/goes/blog/archives/data/2005/10
[34] ***, University of Wisconsin-Madison Space Science and Engineering Center, CIMSS Satellite Blog, cimss.ssec.wisc.edu/goes/blog/archives/2993
[35] ***, CIMSS TC Webpage Product Archive, cimss.ssec.wisc.edu/tropic/real-time/europe/winds/wm7shr.html
[36] Boberg, F., Solar Wind Electric Field Modulation of the NAO: A Correlation Analysis in the Lower Atmosphere, *Geophysical Research Letters, 30* (2003), 15, p.1825
[37] Mukherjee, S., Radovanović, M., Influence of the Sun in the Genesis of Tornadoes, *The IUP Journal of Earth Sciences, 5* (2011), 1, pp. 7-21
[38] Klotzbach, J. P., Trends in Global Tropical Cyclone Activity over the Past Twenty Years, *Geophysical Research Letters, 33* (2006), L10805
[39] Veretenenko, S., Thejll, P., Effects of Energetic Solar Proton Events on the Cyclone Development in the North Atlantic, *Journal of Atmospheric and Solar-Terrestrial Physics, 66* (2004), 5, pp. 393-405
[40] Baldwin, M. P., Dunkerton, T. J., Stratospheric Harbingers of Anomalous Weather Regimes, *Science, 294* (2001), pp. 581-584
[41] Stanojević, G., The Classifications of Atmospheric Circulation, *Journal of the Geographical Institute "Jovan Cvijić" SASA, 60* (2010), 2, pp. 27-37
[42] Radovanović., M., *et al*., Astrophysical Analysis of Earthquake near Kraljevo (in Serbian) on November 3, 2010, *Journal of the Geographical Institute "Jovan Cvijić" SASA, 61* (2011), 3, pp. 1-15

Received on July 9, 2012
Accepted on October 23, 2012

**Милан М. РАДОВАНОВИЋ, Бошко М. МИЛОВАНОВИЋ,
Мила А. ПАВЛОВИЋ, Александар Р. РАДИВОЈЕВИЋ, Милан Т. СТЕВАНЧЕВИЋ**

ПОВЕЗАНОСТ ИЗМЕЂУ ВИСОКОЕНЕРГЕТСКИХ ЧЕСТИЦА СУНЧЕВОГ ВЕТРА И ТОРНАДА – АНАЛИЗА СЛУЧАЈА

Температуре високоенергетских честица које доспевају са Сунца крећу се у опсегу од неколико стотина до неколико милиона степени целзијуса. У овом раду разматрана је теоријска могућност хидродинамичког захватања ваздушних маса сунчевим ветром (СВ), односно високоенергетским честицама СВ. На једној страни, ове честице карактеришу екстремно високе температуре, а на другој, оне изазивају компресију веома хладног ваздуха са висине од око 90 km ка врху циклона. Употребом Ман-Витнијевог У теста, покушали смо да детектујемо повезаност између одређених показатеља сунчеве активности и поремећаја у атмосфери (коришћени дневни подаци на глобалном нивоу за период 2004-2010). Добијени резултати потврђују могућност везе између високоенергетских честица СВ и вртложног кретања ваздушних маса, због чега је урађена детаљнија анализа случаја појаве торнада (тромбе) код Сомбора 12. марта 2010. године. Овом анализом показано је да постоји основаност уверења да изненадни прилив високоенергетских честица (протона) сунчевог ветра може изазвати појаву торнада. На основу приказаног, дати су и елементи за израду прогностичког модела.

Кључне речи: Сунце, високоенергетске честице, торнадо, Сомбор