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GEOGRAPHICAL-HISTORICAL ANALYSIS OF THE IMPACT OF THE 1883 ERUPTION OF KRAKATAU VOLCANO ON WEATHER IN SERBIA*

Abstract: The eruption of Krakatau volcano in 1883 is one of the most powerful eruptions in the past nearly 150 years. Based on the average air temperatures in Belgrade from 1881 to 1886 and average maximum and minimum air temperatures in Šabac from 1883 to 1885, we have tried to analyze whether the mentioned eruption had an impact on weather and climate conditions in Serbia. Bearing in mind that the mentioned measurements were not standardized, we have also tried by analysis of the former official state media to determine whether there are potential signs of possible connection. It turned out that neither measured data nor news reports indicate unusual weather conditions. In other words, there is no evidence that would indicate that an extremely powerful eruption of Krakatau in 1883 caused any weather disturbances over Serbia.

Key words: volcanic eruption, weather, Krakatau, Serbia

Introduction

The eruption of Krakatau volcano (Java Island 6° 06' 10 "S 105 ° 25' 23" E) in August 1883 is one of the most powerful volcanic eruptions in the last nearly 150 years. According to the table provided by Robock and Mao, the only volcanic eruption that had a DV index (Dust Veil Index) 1000 as Krakatau was the Pinatubo eruption (Mt. Pinatubo) in June 1991, and the VE index (Volcanic Explosivity Index) of 6 was the same in both cases.[1] Askja volcano which started working in March 1875 also had a DV index of 1000, but VE index was 5. DV index could be translated as an index of turbidity of the Earth's atmosphere by volcanic dust. Lamb created it in 1970 in an attempt to quantify and numerically express the impact of volcanic dust and aerosols, which are released during the eruptions, on the Earth's radiation balance. VE index is used as a measure of explosiveness, which was developed by Newhall and Self in

* This study was supported by the Serbian Ministry of Education and Science (Projects no. III47001 and 177031).

1 A. Robock, J. Mao, "The volcanic signal in surface temperature observations", *Journal of Climate*, 8 (1995), pp. 1086–1103.

1982.[2] The index is a combination of qualitative and quantitative parameters on the basis of which explosive eruptions can be approximately determined in the closer and distant history for which there are no sufficiently detailed reports.[3]

Under powerful, explosive eruptions, volcanoes eject into the atmosphere huge amounts of volcanic material (gas, ash and dust). The ejected material can affect the climate at different spatial and temporal scales. Bearing in mind that at that time a systematic observation of meteorological elements was not established in Serbia, we tried to perceive the potential link between these eruptions and weather conditions on the basis of available archives. Also, we tried through the observations of contemporary research to point to the potential link that occurred between the eruption of Krakatau volcano and meteorological phenomena and processes in Serbia during the 1883 late summer and autumn.

Theoretical Background

Globally, strong volcanic eruptions can be detected on the basis of the amount of volcanic aerosols in the atmosphere.[4] Volcanic ash and dust remain in the atmosphere for several weeks, and then fall to the ground. Smaller quantities of materials, which have no significant influence on the climate, can survive in the atmosphere for several months. When it comes to the protruding gases, according to Textor et al. the most common are water vapour (H_2O), carbon dioxide (CO_2), sulphur dioxide (SO_2) and to a lesser extent, carbon monoxide (CO), hydrogen (H_2), hydrogen sulphide (H_2S), hydrogen fluoride (HF), hydrogen chloride (H_2Cl) and helium (He).[5] Robock and Mao (1995) note that the climate impact is directly related to the amount of sulphur dioxide protruding into the atmosphere, where there is a reaction of this gas with water vapour and the creation of sulphate aerosol which, surviving in the atmosphere for several years, affects the increased diffusion and the solar radiation rejection. By reducing the direct and total amount of radiation that reaches the Earth's surface, troposphere comes to cooling, but at the same time, keeping the Earth's long-wave irradiation, an increase in stratospheric temperature occurs. Graf et al. note that the heating of the stratosphere during strong volcanic eruptions is higher in low than in high latitudes, which leads to intensification of zonal circulation of the atmosphere during winter in temperate and sub-polar latitudes and advection of warm maritime air over the continents of northern hemisphere, i.e.

2 C. G. Newhall, S. Self, "The volcanic explosivity index (VEI): An estimate of explosive magnitude for historical volcanism", *Journal of Geophysical Research*, 87 (1982), pp. 1231–1238.

3 http://www.volcano.si.edu/world/eruptioncriteria.cfm #VEI

4 http://data.giss.nasa.gov/modelforce/strataer/

5 C. Textor, H. F. Graf, M. Herzog, J. M. Oberhuber, W. I. Rose, G. G. J Ernst, "Volcanic particle aggregation in explosive eruption columns. Part I: Parameterization of the microphysics of hydrometeors and ash", *Journal of Volcanology and Geothermal Research*, Vol. 150, Issue 4 (2006), pp. 359–377.

increase in winter air temperature.[6] Contrary to these results, Robock (2000), analyzing the global air temperatures after strong volcanic eruptions in the 19th and the 20th century, observed lower winter temperatures in the tropical and mostly in subtropical latitudes of the northern hemisphere, as well as lower summer temperatures in the period up to two years after major eruptions. The author explains it by the reduction of solar radiation reaching the surface of our planet.[7]

Fisher et al. studied the impact of 15 large volcanic eruptions of the tropical latitudes on the climate of Europe in the last 500 years. It has been found that in the year of eruption and the first year after, it came to lower summer temperatures, especially in northern and north-eastern Europe. The lowering of summer temperatures in central Europe and parts of the Mediterranean is not as pronounced as in the abovementioned areas. Increasing winter temperatures are present in the year of eruption and the first year after it, especially in the area of Scandinavia and the Baltic. In contrast, in southern Europe a slight chill is present.[8]

Milovanović in his doctoral dissertation, among other things, studied the influence of powerful volcanic eruptions on climate changes in Serbia from 1902 to 1991. The period of study is limited by the beginning of instrumental measurements in Serbia (August 1887) and the last very strong eruption that took place in 1991 – a total of 11 cases. In order to remove the effect of urban heat island from the time series, in the first step the values are set without trend. To detect the possible impact of volcanic eruptions on air temperature in Belgrade, a design of superposed epochs was used. Using analysis of variance and post-hoc LSD (Least Significant Difference) test in data designed in such a way, the differences between the variations of air temperature on the annual and seasonal level were examined, during the two years prior to eruption (codes -2 and -1), in the year of eruption (code 0) and during the two years following the eruption (codes 1 and 2). Based on the results it is concluded that the annual maximum negative deviation of temperature is in zero year (the year in which eruption occurred). The first and second years after the eruption are slightly colder than the two that preceded it. The most pronounced decrease in temperature in the year of the eruption is at spring air temperatures. It is interesting to note that of the eleven cases analyzed, seven were eruptions that occurred in the period March–May.[9] In contrast to the results that Fisher et al. (2007) got, the variations of winter air temperature in the first year after the eruption are strongly negative, while the second winter after the eruption is much warmer.

6 H. F. Graf, Q. Li, M. A. Giorgetta, *Volcanic effects on climate: revisiting the mechanisms. Atmospheric Chemistry and Physics Discussions*, vol. 7, no. 2, pp. 3941–3962.

7 A. Robock, "Volcanic Eruptions and Climate", *Reviews of Geophysics*, 38 (2) (2000), pp. 191–219.

8 E. M. Fisher, J. Luterbacher, E. Zorita, S. F. B. Tett, C. Casty, H. Wanner, "European climate response to tropical volcanic eruptions over the last half millennium", *Geophysical Research Letters*, vol. 34 (2007), pp. 1–6.

9 Б. Миловановић, *Утицај спољашњих климатских фактора на колебање климата у Србији,* докторска дисертација, Географски факултет, Универзитет у Београду (2012), стр. 1–148.

Summer and autumn temperatures are in the year of the eruption higher than in the years that precedes it, but summers in the first and second year after the eruption are a little colder.

Available Documentation on the Weather Conditions Immediately Before and After the Eruption of Krakatau

Before analyzing the existing historical record of weather conditions in Serbia before and after the eruption of Krakatau volcano, it would be necessary to envisage how one of the largest eruptions in the last 150 years actually manifested.

Krakatau Island was created by volcanic activity, but the volcano was inactive until the eruption of 1680. In the 19th century, the stronger eruption than one from 1883 was observed only when the volcano Tambora exploded on the Indonesian island of Sumbava. The 1815 eruption poured five times as much volcanic material. A German warship passing by reported on 20th August a seven-mile high cloud of ash and dust over Krakatau. For the next two months, similar explosions would be witnessed by commercial liners and natives on nearby Java and Sumatra. With little to no idea of the impending catastrophe, the local inhabitants greeted the volcanic activity with festive excitement. An enormous blast on the afternoon of August 26 destroyed the northern two-thirds of the island, as it plunged into the Sunda Strait, between the Java Sea and Indian Ocean, the gushing mountain generated a series of pyroclastic flows (fast-moving fluid bodies of molten gas, ash and rock) and monstrous tsunamis that swept over nearby coastlines. Four more eruptions beginning at 5:30 a.m. the following day proved cataclysmic. Shortly after 10:00 a.m. of the 27th of August 1883 Krakatau was blown by one of the biggest explosions ever recorded. The sound of explosion could be heard in Australia, at a distance of 3 500 km. The island itself collapsed and turned to dust. About 19 cubic kilometres of volcanic material flew out in the air. The dust cloud rose up to 80 kilometres high, and then circulated for years around the Earth, causing climate changes and spectacular sunsets around the world. A thick cloud of smoke spread across the sky and darkened the whole area a few days. The ships were swamped, and the sailors had to shovel hot mud and ash in the dark, breathing stale sulphur air. The sea was rising in waves of unusual forms, and as it arrived to the shores of Java and Sumatra, it wiped out whole settlements. There were more than 36 000 people killed. The eruption itself was not as deadly, but the giant tsunami waves that were higher than 40 meters when the volcano collapsed, destroyed 163 villages along the coasts of Java and Sumatra. Several months later, the roar became even louder. Ships passing there reported on the explosions that were so loud that perforated the sailors' eardrums. Sunda Passage, a busy marine route between the islands of Java and Sumatra, became full of the floating volcanic rocks. Nothing left of the island, and today on that place there has been

Rakatu Island. The eruption occurred at the time of occurrence of mass communication, and news of it spread around the world via telegraphs for a few hours. Scientists carefully collected information about the explosion that became the major impetus for the study of the causes and behaviour of volcanoes.[10]

In the historiography periodicals in Serbia there are two papers that have been written lately on the impact of volcanic eruptions on weather in the Balkans. Jelena Mrgić analyzed data on weather changes caused by the eruption of Vesuvius in 1631, while Dejan Jakšić presented the impact of eruption of Icelandic Laki volcano in 1783 on the climate changes in Vojvodina.[11] Therefore, these are primarily the powerful volcanic eruptions, which, moreover, occurred in Europe, but contemporaries due to scarcity of general knowledge and poor communication failed to connect extreme and unusual natural phenomena with the mentioned natural phenomena.

Since the eruption of Krakatau volcano was the first natural disaster in the world which, owing to established intercontinental telegraph network, was commented with great interest in the international press, it also had the echo in the Kingdom of Serbia. In the *Serbian newspaper*, the official state newspaper, under Smesice, signed by the initials of Z-a, titled *Earthquake on the island of Java*, 11/23 September 1883, according to letters published in the American and European newspapers, the disaster caused by the volcano Krakatau was described in details. "[...] At the same time the lava ravaged the interior of the island, and with the rest of the burning mass covered Tetarang town with 1 800 residents. On the 15th of the last month, so many horrors were joined by an earthquake that lasted several hours; through the rain of rocks and lava, mighty thunderbolts flashed. …As the cloud was larger, the more terribly the ground shook. The streets were crowded with people, mashed corpses littered around, dying moans did not provoke any sorry; all expected the end of the world [...]"[12]

In order to determine whether there was any impact of the Krakatau eruption on weather in Serbia and, if any, in what proportions, one should visualize the state of the sources from which conclusions can be drawn. Namely, at the start of the ninth decade of the 19th century in the Kingdom of Serbia there had not yet been established a network of meteorological stations (started working in 1887), although Vladimir Jakšić, professor of the Lycée and head of the statistical department of the Ministry of Finance, recognizing the importance of meteorology, every day from 1848 to his death 1899 measured air temperature in Belgrade. Jakšić's data on daily extreme temperatures and mean air temperature, cloudiness and rainfall and the number of precipitation days from 1851 to 1856 were printed in Statisque de Serbie in 1857. In addition, in 1856 Jakšić organized the work of twenty meteorological stations, and data from a number

10 http://www.history.com/this-day-in-history/krakatau-explodes

11 Ј. Мргић, „,Паде прах са небеса на земљу' – ерупција Везува 1631. и балканске земље", *Balcanica*, 35 (2004), стр. 223–238; Дејан Јакшић, „Одјек ерупције исландског вулкана Лаки у нашим крајевима", *Истраживања*, 20 (2009), стр. 105–115.

12 *Serbian newspaper*, no. 197, 11th September 1883.

of those stations were published for the period 1856–1862. Significant data on the weather in Serbia in the ninth decade of the 19th century can be found in the reports of county and district chiefs who sent them ten-day and monthly to the Ministry of Internal Affairs and the Ministry of National Economy. Namely, the local authority was informing the central administration, among other things, on the natural disasters, state of agricultural species, extraordinary phenomena in nature, and the like. It should be said that these reports, regardless of the authenticity and the temporal and spatial proximity with which they were written, were not completely reliable, because they were often written with a bureaucratic routine and expressed subjective feeling of air temperature. For example, in one county, district chiefs sent contradictory assessments of weather conditions. Besides Jakšić's data on air temperature in Belgrade, measurements were performed in Šabac (1883–1885), Kruševac (1885–1887) and Aleksandrovac (1887). The data were published in *Težak*, the Journal of Serbian Agricultural Society.

The weather in Serbia until August 1883, when the Krakatau volcano eruption occurred, was changing and spring was common. After a cold winter, warm and rainy intervals were changing throughout spring. Exceptions are the snowfall in most parts of Serbia from 8/20 May to 10/22 May, and a hail in the Timok County, Zaječar, Ćuprija and Belgrade.[13] Unstable weather continued in June, with frequent storms and periods of warm weather.[14] From late July to early September 1883, the weather in most parts of Serbia was favourable. Warm days and little rainfall characterized much of August.

However, since 8th September 1883, ten days after the eruption of Krakatau, the weather suddenly worsened throughout Serbia. That day in Podrinje and Valjevo districts "was so much rain that the Drina and Kolubara and other rivers flooded, and made a lot of damage around their beds." In Šabac that day was the lowest temperature for the month of August, actually 8th September according to new calendar, of 10.6 Reaumur (13.2 degrees Celsius).[15] The heavy rain and cold spell that prevailed since 8th September 1883 were reported from Jagodina, where the Belica flooded and caused damage to crops of 19,000 dinars. Cold nights in the period from 13th to 23rd September 1883 were mentioned in the reports of the chiefs of Zaglava County in the east of Serbia and Rudnik County. Generally, in most official reports in mid-September 1883 it was stated that the weather was variable, except for the districts in the north of the Kingdom of Serbia, Belgrade, Šabac and Smederevo, where good weather still prevailed.

However, September and beginning of October of 1883 were marked by hail in Čačak, Kruševac, Podrinje, Niš and Požarevac districts. On that phenomenon a contributor to the *Težak* wrote: "It is quite surprising that it hails in

13 *Težak, official of the Serbian Agricultural Society*, XIV (1883), p. 323.

14 *Težak,* XIV (1883), p. 481; The Archives of Serbia, Belgrade (AS), The Ministry of National Economy, department of agriculture 1883 (MNP), non-filed material, without a number.

15 *Težak,* XV (1884), p. 232.

September, but this year it hailed in several places: on 11/23 September in the counties of Posavotamnava and Pocerina, Šabac District and the counties of Kragujevac and Lepenica, Kragujevac District; on 12/24 September afternoon it hailed in the county town of Jasenica of Smederevo District with a strong storm that uncovered the houses in the small town Palanka; on 20 September/2 October strong hailstones fell in the size of turkey eggs in some villages of the County of Radjevina, Podrinje District; that same day it hailed in some villages of the counties of Resava and Paraćin in Ćuprija District. Wherever this month the hailstones fell, they were very large, and much damage was done to vegetables, plums, and especially vineyards" (underlined by M. R.; R. J. P.)[16] It hailed in some places in early October, for example in Ćuprija District.[17]

Judging by the reports of local authorities, in Serbia by the end of 1883 there were no other extraordinary meteorological phenomena, i.e. the weather was usual for this time of year. One of characteristic reports of the period is the report of the chief of District Kruševac for October 1883: "The weather was changeable. There were no storms".[18]

The eruption of Krakatau volcano caused the unusual optical phenomena, such as colourful sunsets, which are caused by aerosols in the stratosphere. The sources do not record such occurrences in Serbia[19] Possible indirect impact of the Krakatau eruption on weather in Serbia, however, can be traced by comparing the air temperatures in the years after the eruption, which are globally lower than 0.1 to 0.2 °C.[20]

But first, let us see the average air temperatures in Serbia in the second half of the 19th century. Before the continuous meteorological measurements that began in 1887, in the period from 1856 to 1862, under the leadership of Vladimir Jaksic, 20 meteorological stations worked in the Principality of Serbia, owing to which the table that follows was created (Državopis, 2). There are similar data, with minimal variations, for the period 1856–1872, but we opted for an earlier period, due to the reliability of data.[21]

Table 1 – *Average air temperatures in Serbia in the period 1856–1862*

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
C	0.2	2.3	6.0	12.9	16.5	20.8	21.9	21.9	17.8	13.8	5.8	0.6

16 *Težak*, XIV (1883), pp. 761–762.

17 *Serbian newspaper*, no. 228, 20th October 1883.

18 AS, MNP-3 1883, non-filed, no. 1201–3317.

19 О. Љерка, *Девет храстова, записи о историји српске метеорологије*, Београд, 1998.

20 A. Robock, J. Mao, "The Volcanic Signal in Surface Temperature Observation", *Journal of Climate*, 8 (1995), pp. 1086–1103.

21 В. Јакшић, „Погодопис Београда 1881–1889", Архивска грађа Републичког хидрометеоролошког завода у Београду, (Description of weather in Belgrade); *Државопис Србије I*, Београд, 1863; В. Карић, *Србија, опис земље, народа и државе*, Београд, 1887, стр. 49.

There was a cessation of organized meteorological measurements, and only in the ninth decade of the 19th century the results of individual measurements for individual towns were published. The average air temperatures in Šabac for the period 1883–1884 and partly 1885 with the record of the average, highest and lowest temperatures for each month, based on measurements carried out by high school teacher Mihailo Ruvidić, are important for our subject, because, to some extent, they confirm the above mentioned theory of Fisher et al. on a slight lowering of the summer and slight increase in winter temperatures in the first year after the eruption. From a number of archive documents, we learn that the summer of 1884 in Serbia was marked by heavy rains and frequent hail storms. Chief of Vranje District, M. Stojićević, talking about the weather in June in 1884 wrote in the report: "The first twenty days were rainy and with very variable temperatures, so that strong hoar frost and snow could be seen on peaks".[22] After a relatively stable weather conditions in July, the August of 1884 was cold and rainy.

Table 2 – *Average, highest and lowest air temperatures in Šabac in the period 1883–1885*[23]

	Mean monthly temperature			Highest daily temperature			Lowest daily temperature		
	1883	1884	1885	1883	1884	1885	1883	1884	1885
I	1.7	3.8	0.91	8.2	6.6	7.0	-6.4	-2.5	-6.0
II	2.6	3.1	6.0	7.9	9.1	16.6	-4.1	- 2.9	0
III	8.6	8.2	-	16.2	13.2	-	-2.0	4.5	-
IV	15.9	15.2	11.3	23.7	20	20.7	8.2	10	10
V	20.6	17.7	17.7	27	21.6	25.3	8.7	12.5	9.1
VI	23.7	18.2	22.3	30.3	24.5	28.7	17.8	13.5	12.5
VII	23.6	21.6	-	30.6	28.7	-	20.7	13.7	-
VIII	20.9	17.6	-	26.2	24.1	-	13.2	14.1	-
IX	14.9	16.1	-	18.2	15.3	-	7.25	4.5	-
X	9.5	12.1	-	14.5	12.5	-	0.75	4.1	-
XI	2.75	0.4	-	7.2	4.5	-	-4.1	-8.25	-
XII	-0.2	2.7	-	5.4	6.6	-	-5.7	-2.7	-
Ann	12	12		30.6	28.7	-	6.4	-8.2	-

However, the example of the average air temperatures in Belgrade in the period 1881–1886 and the table drawn on the basis of meteorological measurements of Vladimir Jakšić, which included two years before and three years after the eruption of Krakatau, more clearly than in the previous table, there is no significant temperature variations in Serbia in that period.

22 AS, MNP-3, non-filed 1883, 1300–2209.

23 *Težak*, 1884 (XV), p. 232; *Težak*, 1885 (XVI), pp. 127, 193, 277, 347, 516, 571.

Table 3 – *Average air temperatures in Belgrade in the period 1881–1886 (Jakšić, 1881–1889)*

	1881	1882	1883	1884	1885	1886
I	-1.71	0.5	-0.8	0.8	-0.8	2.8
II	0.5	4.9	1.8	4.0	4.0	0.5
III	7.5	11.5	2.2	7.6	9.2	3.1
IV	10.9	12.7	10.0	12.1	14.4	13.0
V	15.6	16.3	16.6	17.5	21.0	16.6
VI	19.5	18.8	20.1	18.0	20.9	19.7
VII	22.6	22.4	22.3	21.8	22.2	22.2
VIII	23.9	18.9	21.1	20.0	21.2	21.9
IX	17.9	18.9	18.0	17.4	18.7	19.3
X	10.5	13.2	13.4	11.3	14.5	14.3
XI	4.9	8.4	6.8	2.4	7.9	8.5
XII	-2.9	4.9	0.9	2.6	-1.9	6.4
Ann.	10.8	12.6	11.0	11.3	12.6	12.9

Based on the available sources, we have seen that in the field of meteorological events in late summer and in the second half of 1883 nothing unusual was occurring. Actually, it has appeared that the eruption of Krakatau volcano, with all the material that was ejected into the atmosphere, did not significantly affect the weather conditions in Serbia. However, the indirect influence is evident in the slight changes.

In recent years, it seems that the research process is intensified between Sun – Earth. There are numerous results which indicate that the eruption of charged particles toward the planet has a profound effect on the environment and atmospheric processes, both regionally and globally.[24]

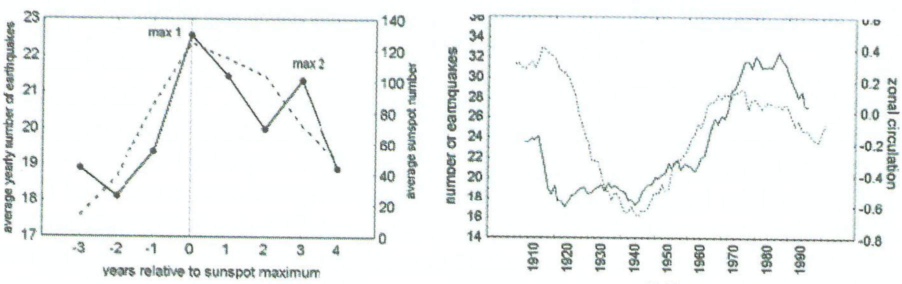

Figure 1. *Average number of earthquakes (solid line) and solar activity (dotted line) in the elevenyear solar cycle for the period 1900–1999 – left chart and annual number of earthquakes M ≥ 7 in the period 1900–1997 (solid line) and intensity of zonal circulation (dotted line) in the same period – right chart (Odintsov et al., 2006)*

24 J. F. P. Gomes, M. Radovanovic, V. Ducic, M. Milenkovic, M. Stevancevic, „Wildfire in Deliblatska Pescara (Serbia) – Case Analysis on July 24th 2007", *Handbook on Solar Wind: Effects, Dynamics and Interaction*, (2009), Nova Science Publishers, New York, pp. 89–140; J. F. P. Gomes, M. Radovanović, "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), pp. 197–205; J. Nikolić, M. Radovanović, D. Milijašević, "An astrophysical analysis of weather based on solar wind parameters", *Nuclear Technology & Radiation Protection*, Vol. 25, No. 3 (2010), pp. 171–178; M. Radovanović, "Forest fires in Europe from July 22–25, 2009", *Arch. Biol. Sci.*, Belgrade, 62-2 (2010), pp. 419–424.

However, papers that point out the connection between processes on the Sun and geotectonic events have become very intriguing.[25]

According to the heliocentric hypothesis, which is observed in the mentioned references, there are two basic ways of penetration of charged particles to the ground. The first relates to reconnection, i.e. connection of the opposite vectors of the interplanetary magnetic field and geomagnetic field.[26] In such conditions, one of the relatively frequent resultant trajectories of air masses, which are affected by hydrodynamic pressure, is moving from the north-west Atlantic to the south-east. The extent to which such penetrations will reflect in the weather of any part of Europe depends primarily on the electro-magnetic and physical-chemical characteristics of the interplanetary magnetic front. Understanding these processes is difficult because the quantitative parameters of the solar wind, registered by satellites, are never the same. This refers primarily to the wide ranges of speed, density and temperature of charged particles, as well as their very diverse chemical composition. Pulsation energy which carries the mentioned particles further complicates the creation of models that could simulate the above hypothesis.

Another way of the charged particles penetrating to the ground takes place in the equatorial regions, that is, in those parts of Earth where the geomagnetic field strength is the weakest. As the possibility that such processes take place, as far as we know, the first time in science was stated by Gomes, Radovanović.[27] According to these results, the kinetic energy of the solar wind (represented by speed, which can reach in extreme situations over 1000 km/s) in the equatorial regions causes the seizing of air masses dictating their further movement (figure 2).

"Solar flares are known to contain as much as 10^29 joules of energy and can accelerate electrons and protons to energies of many MeV and even hundreds of MeV at times. (...) These coronal mass ejection ...events, as they propagate away from the sun, are also capable of accelerating interplanetary particles to higher energies – perhaps many tens of MeV. The relationship of these CME events to solar phenomena such as sunspots and flares is not yet well understood. However, CMEs are now known to be important sources of disturbances of the interplanetary medium and of the space environment of Earth, even during years of low sunspot conditions. (...) Space weather influence on the Earth's weather and climate is still a developing topic".[28] The extent to which mentioned events are associated with the operation of the volcano itself remains

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25 S. Odintsov, K. Boyarchuk, K. Georgieva, B. Kirov, D. Atanasov, "Long-period trends in global seismic and geomagnetic activity and their relation to solar activity", *Physics and Chemistry of the Earth*, 31 (2006), pp. 88–93; M. Radovanović, M. Stevančević, D. Milijašević, S. Mukherjee, Ž. Bjeljac, "Astrophysical Analysis of Earthquake near Kraljevo (Serbia) on 03 November 2010", *Journal of the Geographical institute Jovan Cvijic SASA*, No. 63 (3) (2011), pp. 1–14, figure 1.

26 M. Radovanović, M. Stevančević, D. Štrbac, "A contribution to the study of the influence of the energy of solar wind upon the atmospheric processes", *Journal of the Geographical institute Jovan Cvijic SASA*, No. 52 (2003), pp. 1–18.

27 Gomes, Radovanović, *op. cit.*, (2008).

28 P. K. Marhavilas, E. T. Sarris and G. C. Anagnostopoulos, (2004), *Elaboration and analysis of Ulysses' observations, in the vicinity of a magnetohydrodynamic shock. The-eggs_org _* NewsLetter & Information Service of the E_G_U.htm, Issue #08 30 June 2004.

an open question. Other scientists have also noticed there are unclear details on the mechanism of the SW penetration as well as the parameterization of losses in speed, temperature and chemical structure of the particles. "The associated changes in the Brewer–Dobson circulation have a non-local effect on the thermal structure in the lower tropical stratosphere leading to significant solar signals in e.g. temperature, cloud cover, precipitation in the tropical troposphere.

Figure 2. *Schematic survey of the way of SW penetration towards topographic surface (Gomes et al, 2009)*[29]

(...) It must however be noted that many questions concerning the impact of solar variability on the atmosphere are still open. E.g. the observed solar signal in stratospheric ozone can so far not be reproduced by models. The contribution of energetic particles to the solar signal is not yet well understood".[30]

29 J. F. P. Gomes, M. Radovanović, "On the Relationship between Solar Activity and Forest Fires", *Handbook on Solar Wind*, Chapter 1, Nova Science Publishers, New York, 2009, pp. 1–79.

30 U. Langematz, K. Matthes, L. J. Grenfell, "Solar impact on climate: modeling the coupling between the middle and the lower atmosphere", *Memorie della Società Astronomica Italiana*, Vol. 76 (2005),

However, the problem here considered is directed to the possibility for subordination of meteorological processes and phenomena in Serbia by penetration of air masses raised by the merger of the interplanetary and geomagnetic fields in the polar regions. "Relying on observations collected by NASA's Polar spacecraft and Japan's Geotail spacecraft, scientists associated with the International Solar-Terrestrial Physics (ISTP) program have gathered the first direct evidence that a process known as magnetic reconnection occurs naturally in the Sun-Earth system. Until now, reconnection had only been observed under contrived conditions in a few physics laboratories. During reconnection, magnetic fields that are heading in opposite directions – having opposite north or south polarities – break and connect to each other. (...) Reconnection is the fundamental process for transferring and exchanging energy in the Sun-Earth system" (www.nassa.gov 2003). Therefore, not only the described process is contested, but it gains more on its importance. "Magnetic reconnection – a phenomenon by which magnetic fields lines get interconnected and reconfigure themselves – is a universal process in space that plays a key role in various astrophysical phenomena such as star formation, solar explosions or the entry of solar material within the Earth's environment".[31]

The recent researches show that in case when **Bz** component of interplanetary magnetic field has direction opposite to the geomagnetic field, namely, when it has got a negative sign, the magnetosphere opens (magnetic reconnection). Then the solar wind particles enter the Earth's atmosphere (magnetospheric door) in the form of a jet stream and advance along geomagnetic lines to the magnetosphere equator. Therefore, the process is occurring in the area where Earth's magnetic field is the strongest. Otherwise, the solar wind does not penetrate through Earth's magnetosphere but passes, i.e. it rejects from it. "We found that the events occurring during closed geomagnetic conditions do not show common peaks at all the high latitude stations and tend to be coherent only among Antarctic stations, while there is a lack of coherence between high latitude opposite hemispheres. Conversely, during open geomagnetic conditions the pulsation events are characterized by discrete frequencies, the same at all stations, and are generally highly coherent between high and low latitudes and between opposite hemispheres".[32] According Tinsley, Yu "there is no decisive result at present to determine how much of the observed decadal variations are due to particle flux inputs as compared to total or spectral irradiance changes. However, there is no such ambiguity concerning the correlations of atmospheric dynamics with particle fluxes on the day-to-day timescale."[33] Disre-

MontePorzio Catone, June 27 – July 1, pp. 868–875.

31 http://www.esa.int/esaCP/SEMDI3T4LZE_index_0.html

32 S. Lepidi, L. Santarelli, L. Cafarella, P. Palangio, "The Earth's passage of coronal mass ejecta on october 29–31, 2003: ULF geomagnetic field fluctuations at very high latitude", *Memorie della Società Astronomica Italiana*, Vol. 76 (2005), MontePorzio Catone, June 27 – July 1, 2005, pp. 998–1001.

33 A. B. Tinsley, F. Yu, „Atmospheric Ionization and Clouds as Links between Solar Activity and Climate", in press in forthcoming AGU monograph: *Solar Variability and Its Effects on the Earth's Atmospheric and Climate System,* AGU press, Washington, DC (2004), p. 321–340, (http://www.utdallas.

garding lack of detailed knowledge of the mechanism of interactive connection Ponyavin et al emphasize that with usage of certain techniques, connections may be confirmed.“[34] Historical sunspot and climate records were analyzed by means of nonlinear tools to study long-term trends and relationships with the solar activity variations. Cross Wavelet technique and Recurrence Plot analysis were applied to the data (for annual averages of air-surface temperature in Central England, Stockholm and St.Petersburg) to find their similarities and phase coherence at different time and time-scale. (...) The second half of 20th century demonstrates unusual response of climatic system to the solar signal.”

Conclusions

Bearing in mind that in 1883 there were no satellite measurements, we can only assume that in the middle of August of 1883 a simultaneous penetration of the solar wind particles occurred. That is, based on previous research it seems more likely that there was penetration both in the polar and equatorial regions. Therefore, the development of weather conditions in Serbia was then largely dictated by the movements of air masses from the northwest eventually southwest than by the explosion of the volcano Krakatau. In addition, based on available documentation, we can see that even during the autumn and winter of 1883 nothing radical in Serbia in the field of meteorology was occurring.

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Резиме

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ГЕОГРАФСКО-ИСТОРИЈСКА АНАЛИЗА УТИЦАЈА ЕРУПЦИЈЕ ВУЛКАНА КРАКАТАУ 1883. НА ВРЕМЕ У СРБИЈИ

Кључне речи: вулканска ерупција, време, Кракатау, Србија

Аутори су интердисциплинарним приступом разматрали да ли је и колико ерупција вулкана Кракатау 1883. године имала утицаја на временске прилике у Србији. Теоријску основу рада чине новији резултати истраживања о утицају сунчевих високоенергетских честица према нашој планети, те веза између процеса на Сунцу и геотектонских поремећаја. Према хелиоцентричној хипотези која се опсервира у наведеним референцама,

постоје два основна начина продирања високоенергетских честица ка тлу. Први се односи на риконекцију, тј. спајање супротних вектора интерпланетарног магнетног поља и геомагнетног поља. При таквим условима, једна од релативно честих резултантних трајекторија ваздушних маса, које су захваћене хидродинамичким притиском, креће се од северозапада Атлантика ка југоистоку. У којој мери ће се такви продори одразити на временске прилике било ког дела Европе зависи у првом реду од електромагнетних и физичко-хемијских карактеристика интерпланетарног магнетног фронта. Међутим, разумевање наведених процеса је отежано због тога што квантитавни параметри Сунчевог ветра, који се данас региструју сателитима, никада нису исти. Мисли се пре свега на широке опсеге брзине, густине и температуре високоенергетских честица, као и на њихов разнолик хемијски састав. Пулсирање енергије (маховитост) која носи поменуте честице, додатно отежава креирање модела који би могли симулирати наведену хипотезу. Други начин продирања високоенергетских честица ка тлу одиграва се у екваторијалним областима, где је снага Земљиног геомагнетног поља најслабија. Према овим резултатима, кинетичка енергија Сунчевог ветра (представљена брзином, која може достизати у екстремним ситуацијама и преко 1.000 km/s) у екваторијалним областима условљава захватање ваздушних маса диктирајући њихово даље кретање.

У раду је разматрана усмереност метеоролошких процеса и појава у Србији продорима ваздушних маса насталим услед спајања интерпланетарног и геомагнетног поља у поларним областима. Имајући у виду да 1883. није било ни помена о сателитским снимцима, можемо само претпоставити да се крајем августа 1883. десио истовремени продор честица Сунчевог ветра у поларним и у екваторијалним областима. Дакле, развој временских прилика у Србији био је тада у већој мери диктиран кретањима ваздушних маса са северозапада него експлозијом вулкана Кракатау. Поред тога, на основу расположиве документације, можемо видети да се ни током јесени, као ни зиме, у Србији ништа радикално на пољу метеорологије није дешавало. Односно, ерупција вулкана Кракатау, са свим материјалом који је избачен у атмосферу, није битније утицала на временске прилике у Србији.