Acta geographica Slovenica, 53-1, 2013, 165–179

IS HAIL SUPPRESSION USEFUL IN SERBIA? – GENERAL REVIEW AND NEW RESULTS

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The radar center Bukulja in central Serbia was built for hail risk monitoring.

Is hail suppression useful in Serbia? – General review and new results

DOI: 103986/AGS53302
UDC: 551.578.7:551.509.6(497.11)
COBISS: 1.02

ABSTRACT: Anthropogenic influence on weather has been increasingly published and discussed in the last decades. Climate changes caused by inadvertent anthropogenic influence are well underway. Hail suppression, which has been proven to have no influence on weather, will be considered in the article. Even though hail suppression as scientifically ungrounded activity seemed to promise certain success several decades ago, it has spread over the whole territory of the Republic of Serbia after abundant experience, when many developed countries have given up on this activity. Reasons will be presented for the senselessness of hail suppression based on the latest research. By processing all hail data from the territory of Serbia in the period from 1967 to 2010, it was found out that the hail trend is rising which is in contrary to expectations and previous claims that hail suppression decreases hail frequency.

KEY WORDS: geography, hail suppression, seeding hypothesis, hail trend, hail cost, verification

The article was submitted for publication on July 18, 2012.

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Contents

1 Introduction

The atmosphere is one of the most complex natural physical systems. It is under the influence of almost all physical interactions, grouped as astronomical, geological and biological interactions, that have been active for approximately three billion years, as well as anthropogenic influences that have been active for approxiametly several hundred years.

Each group of influences creates in the atmosphere one or several atmospheric processes and/or circulations. These are relatively independent phenomena that interact, thus creating new circulations. Meteorological weather is the resulting interaction of all the circulations in the atmosphere up to several days and climate is the mean meteorological weather in periods longer than several days (Gavrilov 2008).

Anthropogenic influences on the atmosphere may be unintentional and intentional. Unintentional influences occur as unwanted by products of human activities. The most important one is the production of carbon dioxide and other greenhouse gases, deemed to cause of global warming. These factors belong to the so-called global climate influences. There are also local influences on climate such as changes in soil characteristics that cause the change in reflection of solar radiation, and heat production in cities. Both influences cause local temperature changes (e.g. Bornstein 1968; Andjelković 2005).

Intentional atmospheric influences are actions on atmospheric processes conducive to obtaining required effects. The term »weather modification« is used as a synonym for such influences. Successful weather modifications are modest, minor and non-spectacular; for example: fog dispersal, opening of »windows« in thin clouds, afforestation, irrigation, frost protection, and the stimulation of dew (World Meteorological Organization 2007). Hereinafter only hail suppression will be considered as the most widespread (un)successful weather modification. More information about other weather modifications may be found in Gburčik (2002).

2 Hail suppression

Hail suppression attempts to modify hail bearing clouds (*Cumulonimbus*) by seeding them with silver iodide or other agents. The main goal of hail suppression is to decrease the production of hail in order to decrease damage caused by it, primarily in agriculture (World Meteorological Organization 2007).

The following hypothesis has been made about the effects of silver iodide seeding: by seeding a hail bearing cloud with silver iodide crystallization nuclei, the number of potential deposition cores increases, since silver iodide also crystallizes in hexagonal grids like ice; thus, its small crystals will serve as additional deposition cores around which molecules of supercooled water vapor will be collected. It is expected that ice crystals grow on additional cores as on natural cores so that each hail grain will grow less and melt as

Figure 1: Before the development of modern techniques in hail suppression, people defended themselves using traditional approaches or applications. The figure shows the shooting towards storm clouds with bows and arrows which originated in ancient times. This approach was used in Scandinavia during the 16th century (Magnus 1976; Bergant 2011).

it falls and smaller sized hail and/or rain will fall instead of larger sized hail. (e.g., Sulakvelidze 1969). This hypothesis was first applied by rainmakers in the United States (USA). They attempted to stimulate common rain in dry areas of America. In the1950s, this hypothesis was also applied in Georgia (former Soviet Republic) for the purpose of defending vineyard plantations from hail. The Georgians even engaged the Red Army to launch rockets with silver iodide and similar reagents into the clouds (Gburčik 2002).

Thus, contemporary hail suppression was established based on (i) the hypothesis which was only expected to become a generally accepted scientific theory on the modification of hail bearing clouds and (ii) advanced technology, like rockets, radars, electronic communication, etc. That made everything very convincing and impressive!

3 Distribution of hail suppression

Many countries accepted hail suppression with due caution regarding its efficiency. In the mid-1970s and in the beginning of 1980s, two larger experiments were undertaken to evaluate in the effectiveness of cloud seeding with silver iodide; one in Western Europe (Switzerland, France and Germany) known as the »Great experiment« (*Grossversuch*) (Federer et al. 1986) and one in the USA known as the »National Hail Research Experiment« (Knight et al. 1979). The results showed that there were no statistically significant differences in the occurrence of hail between seeded and non-seeded hail bearing clouds.

Many European countries concluded then that cloud seeding cannot modify weather. Later no such comprehensive experiment was performed but individual countries implemented their own evaluations with similar results – for example in Slovenia (Rakovec et al. 1990; Roškar 2004; Bergant 2011) and in Serbia (Aleksic 1989). In Europe today, only in Serbia, Macedonia, Bosnia and Herzegovina and Croatia actively support weather defense against hail (Počakal and Štalec 2003), and in Croatia it is being abolished (Ministry of Science, Education and Sports of the Republic of Croatia and Meteorological Hydrological Service of Croatia, 2004). Elsewhere, hail suppression (especially by airplanes) is left to private initiative, enjoys limited government support, and is restricted to small areas (e.g. in Austria, Greece and Slovenia) (Slovenian Enviroment Agency, 2005; Bergant 2011; Rubin 2012).

The distribution of hail suppression in Europe in 2007 is shown in Table 1. In addition a serial number (SN) and the name of the country, the next two columns denote the presence of hail suppression (HP) with Yes and its absence with No, and financing (Fin.) from government budget with Yes, and from other sources with No.

Table 1: Distribution of hail suppression (HP) and mode of financing (Fin.) for 2007 (Internet 1).

SN	*State*	HP	Fin.	SN	*State*	HP	Fin.
1.	Austria	Yes	No	21.	Montenegro	No	–
2.	Bulgaria	Yes	Yes	22.	Croatia	Yes	Yes
3.	Lithuania	No	–	23.	Spain	No	–
4.	Israel	No	–	24.	Island	No	–
5.	Sweden	No	–	25.	Ireland	No	–
6.	Greece	Yes	No	26.	Albania	No	–
7.	Bosnia&Herzegovina*	No	–	27.	Romania	Yes	Yes
8.	Slovakia	No	–	28.	Finland	No	–
9.	Netherlands	No	–	29.	Portugal	No	–
10.	Hungary	Yes	Yes (40%)	30.	Azerbaijan	No	–
11.	Germany	No	–	31.	Latvia	No	–
12.	United Kingdom	No	–	32.	Russia	Yes	Yes
13.	Italy	No	–	33.	Turkey	No	–
14.	France	No	–	34.	Macedonia	Yes	Yes
15.	Poland	No	–	35.	Bohemia	No	–
16.	Switzerland	No	–	36.	Estonia	No	–
17.	Belarus	No	–	37.	Slovenia	Yes	Yes
18.	Armenia	No	–	38.	Norway	No	–
19.	Moldova	Yes	Yes	39.	Belgium	No	–
20.	Serbia	Yes	Yes	40.	Denmark	No	–

*Republic of Srpska carries out hail suppression on a minor part of its territory.

In the USA, financing of hail suppression was practically abolished by the beginning of the1990s. On the state level operational hail suppression is carried out only in Russia, and in some other states of the former USSR, as well as in most countries of the former Socialist Federal Republic of Yugoslavia-SFRY (Bosnia and Herzegovina (only in Republic of Srpska), Croatia, Macedonia, Serbia, Slovenia) and China (Wieringa and Holleman 2006). In some countries sporadic hail suppression is carried out on minor areas through private initiatives, local financing or within scientific projects, but without state involvement.

All this, as well as some other reasons, prompted the World Meteorological Organization (2007) not to recommend hail suppression; similarly Mason (1978), Rakovec and Waldvogel (1989), Jordanovski (2005), Gavrilov (2005; 2007; 2008), Roškar (2009) and Bergant (2011). From these it might be concluded that cloud seeding is an unsuccessful activity and that it is not possible to cause hail decrease and it may also cause damage (BBC NEWS, 2001). Thus, hail suppression belongs to unsuccessful weather modification.

4 Hail suppression in Serbia

4.1 Historical background and present condition

During the 1960s, hail suppression was taken from the USSR to the SFRY and remained operative until the present day. In Serbia, hail suppression by silver iodide seeding has been carried out according to the so-called Soviet method (Sulakvelidze 1967; Federer et al. *1*986; Mesinger and Mesinger 1992) since 1967 (Aleksić 1989, 271). The mentioned method was partly modified (Radinović 1970; 1972) for the purpose of hail suppression by silver iodide seeding in eastern areas of the SFRY (including Serbia). One of the latest papers with a description of hail suppression method by silver iodide seeding that is used in Serbia is found in the work by Vujović et al. (2007). Both methods, the original Soviet method and its modification that is applied in Serbia, are based on the previously mentioned seeding hypothesis.

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Figure 2: One type rocket-launching stations in use at the Radar centers in Serbia.

This hypothesis and the method based on it are applied in Serbia by the use of meteorological radars (article's cover picture) and a rocket-launching station (Figure 2). Radars serve for the identification of hail clouds and rockets for injection and seeding of silver iodide from the ground into the cloud. Present rockets reach heights of 6 to 8 km and each rocket bears 400 g of silver iodide (Vujović et al. 2007). Since 2003, hail suppression has been carried out from 13 radar centers using around 1650 rocket-launching stations which are evenly distributed over the territory of Serbia (Figure 3F). Each radar center is authorized for a certain number of rocket-launching stations and issues commands by radio communication on when, where and how may rockets should be used for firing into hail-bearing clouds. Hail suppression is operatively carried out six months a year, from April 15 to October 15, and has been operatively conducted by the Republic Hydrometeorological Service (RHMS) of Serbia (Internet 2). After 2010, all activities related to hail suppression came under the jurisdiction of the Ministry of the Interior of the Republic of Serbia, Sector for Emergency Management.

Since the introduction of hail suppression in 1967, the territory within which hail suppression measures have been carried out has changed significantly. Figure 3 shows six characteristic distribution phases of hail suppression on the territory of Serbia from 1967 to 2009 (Vujović et al. 2007; Gavrilov et al. 2010). At first, hail suppression was carried out only in a few municipalities (Figures 3A–3B). Hail suppression gradually expanded and coalesced so that by 1985 the area subject to hail suppression had expanded to encompass all of Serbia without the Vojvodina region but including Kosovo and Metohija (Figure 3D). From 2000 to 2003, hail suppression was carried out only on the territory of central Serbia (Figure 3E), and from 2003 to 2009, this area of spatially continuous coverage extended to include the Vojvodina region (Figure 3F).

Contrary to all other countries that abolished or decreased hail suppression, Serbia significantly expanded it and the region of Vojvodina has been covered by hail suppression since 2003. It has been stated that Serbian hail suppression is covers the whole territory of the Republic of Serbia without the region of Kosovo and Metohija (Figure 3F).

4.2 The costs

The purchase of 13,000 rockets was approved in the budget of the Republic of Serbia for 2008. It was also expected that the Ministry for Agriculture would provide additional funds for the purchase of an additional 6000–7000 rockets. The cost of one rocket is 270–300 Euros (Law on budget of the Republic of Serbia 2007). Similar data can be found for other years.

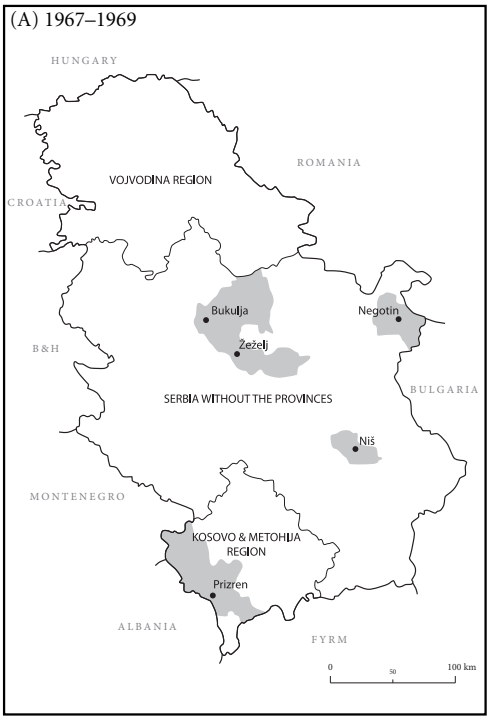
Hail suppression in Serbia consists of: about 250 full-time personnel, 3,500 part time personnel, 1,650 rocket stations, 13 radar centers, dozens of cars, around 12,000 rockets fired annually. It is estimated that the annual cost of hail suppression is around ten million Euros, financed by the budget of the Republic of Serbia.

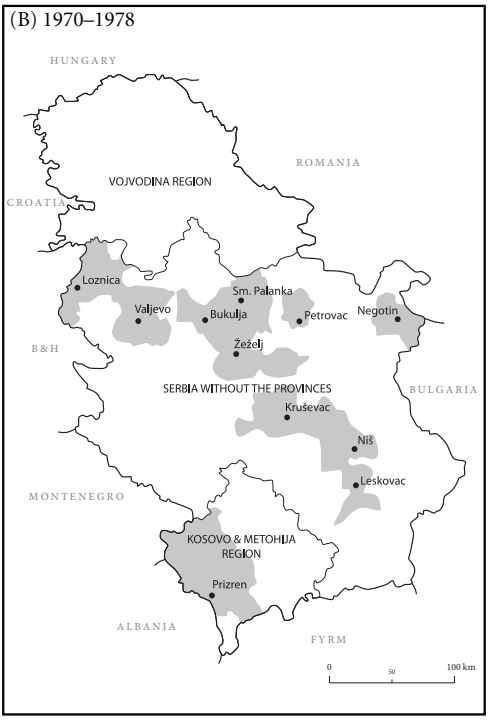
4.3 Legal foundation

Hail suppression is not clearly defined in the legislation. By 2008 the only place in the legislation that regulates the hail suppression activities were part of the Article 34 of the Law on Ministries of the Republic of Serbia (2008) that reads: »… *Republic Hydrometeorological Service of Serbia performs expert activities related to … defining hail risk degree and acting on hail bearing clouds* …«. From this it is difficult to figure out to what »activities« hail bearing clouds should be »exposed« to and why? After the transition of all the hail suppression activities to the Ministry of Interior of the Republic of Serbia, this activity is only regulated by the Article 8 of the Law on Emergencies of the Republic of Serbia (2009), in the »preventive measures of rescue and protection in extraordinary situations« paragraph.

4.4 Verification

In a document produced by the Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia (2006), the results are given of hail suppression verification carried out on four occasions. In the first case »*The efficiency of our hail suppression system is* [was] *verified to 63 to 73%*« (Radinović 1988; 1989).


(A) 1967–1969
HUNGARY
ROMANIA
VOJVODINA REGION
CROATIA
Bukulja
Negotin
Žeželj
B&H
SERBIA WITHOUT THE PROVINCES
BULGARIA
Niš
MONTENEGRO
KOSOVO & METOHIJA REGION
Prizren
ALBANIA
FYRM
0
50
100 km


(B) 1970–1978
HUNGARY
ROMANIA
VOJVODINA REGION
CROATIA
Loznica
Sm. Palanka
Valjevo
Bukulja
Petrovac
Negotin
B&H
Žeželj
SERBIA WITHOUT THE PROVINCES
BULGARIA
Kruševac
Niš
Leskovac
MONTENEGRO
KOSOVO & METOHIJA REGION
Prizren
ALBANIA
FYRM
0
50
100 km


(C) 1979–1984
HUNGARY
ROMANIA
VOJVODINA REGION
CROATIA
Loznica
Sm. Palanka
Valjevo
Bukulja
Petrovac
Negotin
B&H
Žeželj
Užice
SERBIA WITHOUT THE PROVINCES
BULGARIA
Kruševac
Niš
Leskovac
MONTENEGRO
Priština
KOSOVO & METOHIJA REGION
Prizren
ALBANIA
FYRM
0
50
100 km


(D) 1985–1999
HUNGARY
ROMANIA
VOJVODINA REGION
CROATIA
Loznica
Valjevo
Bukulja
Petrovac
Crni vrh
B&H
Bešnjaja
Užice
SERBIA WITHOUT THE PROVINCES
BULGARIA
Kruševac
Sjenica
Niš
Leskovac
MONTENEGRO
Priština
Klina
KOSOVO & METOHIJA REGION
ALBANIA
FYRM
0
50
100 km

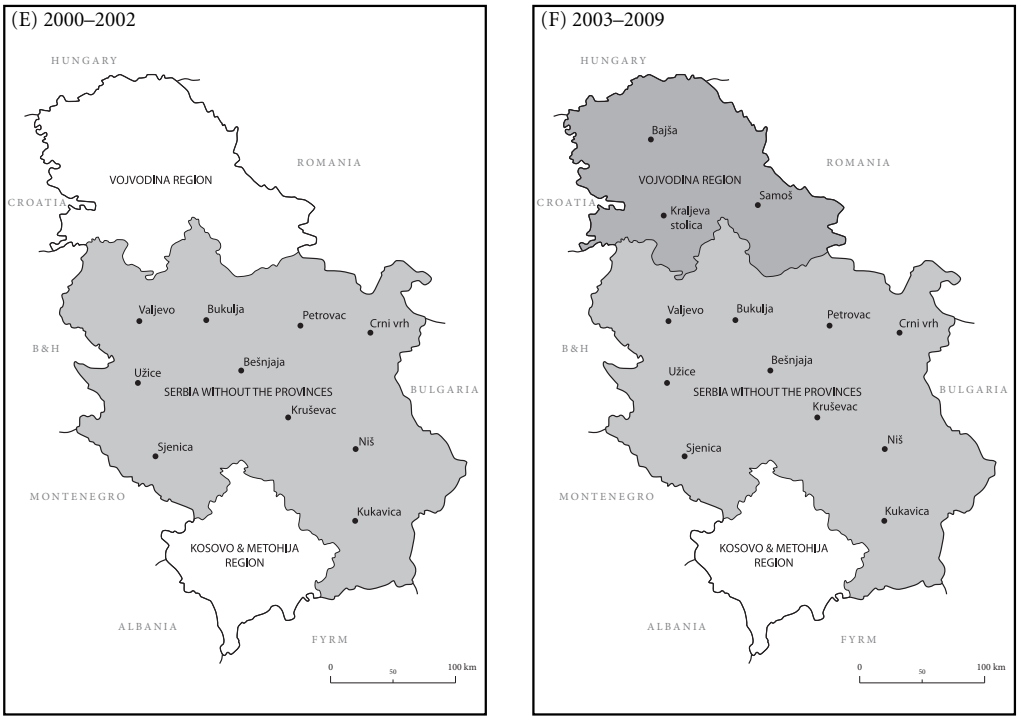


Figure 3: Maps of the Republic of Serbia showing (dark shading) the territories where hail suppression was carried out during the respective time period and locations of radar centers (adapted after Gavrilov et al. 2010). ◄ p. 172–173

The second case quotes: »*it seems that hail frequency decreases in the magnitude of 15 to 20%*« (Mesinger and Mesinger 1991; 1992). The third case quotes: »*The latest research showed that in Serbia in the period from 1971 to 2003, the hail suppression system retrieved 14 times more for every Dinar* [Serbian currency] *invested in it*« (Mitić 2006). The fourth case quotes: »*the benefit of hail suppression to Serbia is 48 million Euros*« (Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia 2006).

Existing verifications of hail suppression are not comparable. They are expressed with four different assessments: efficiency, hail frequency, economic benefit per invested Dinar and total economic benefit. But none of four verification procedures gives the answer to the question: Does hail suppression decrease the occurrence of hail in Serbia?

There are other attempts to assess the effectiveness of hail suppression as well as to reduce damage from hail (e.g. Simeonov 1992). Such an assessment makes sense if it prior estimate of decrease hail. Hail is quantity of which is assessed.

There are some reports about increases in rainfall in the areas where hail suppression was carried out (Krauss and Santos 2004). Such results can be very encouraging for weather modification in the future, but in numerous documents and papers regarding to hail suppression in Serbia, rainfall stimulation is not mentioned as an additional benefit.

5 Hail trends

All of the above, and especially the lack of correct verification of hail suppression, contributed to the research carried out at the beginning of 2010 on the influence of cloud seeding on hail trends in Serbia. The results are published in the papers Gavrilov et al. (2010; 2011), and only the most significant results will be presented here.

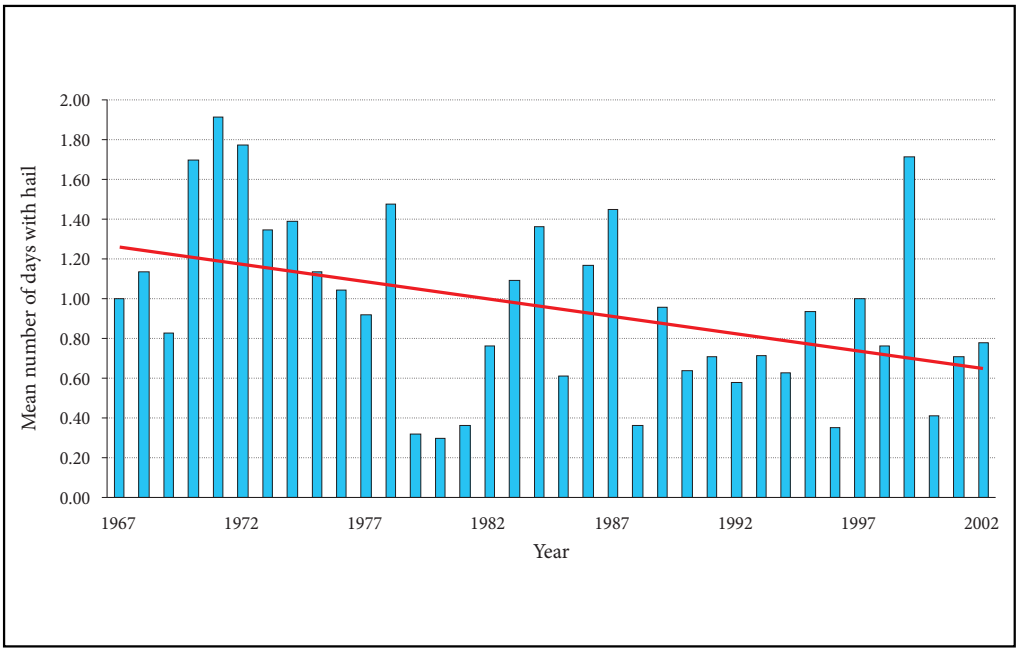


Figure 4: Mean number of days with hail per year and linear trend line (in red) from 1967 to 2002, when there was no hail suppression in Vojvodina (Gavrilov et al. 2010).

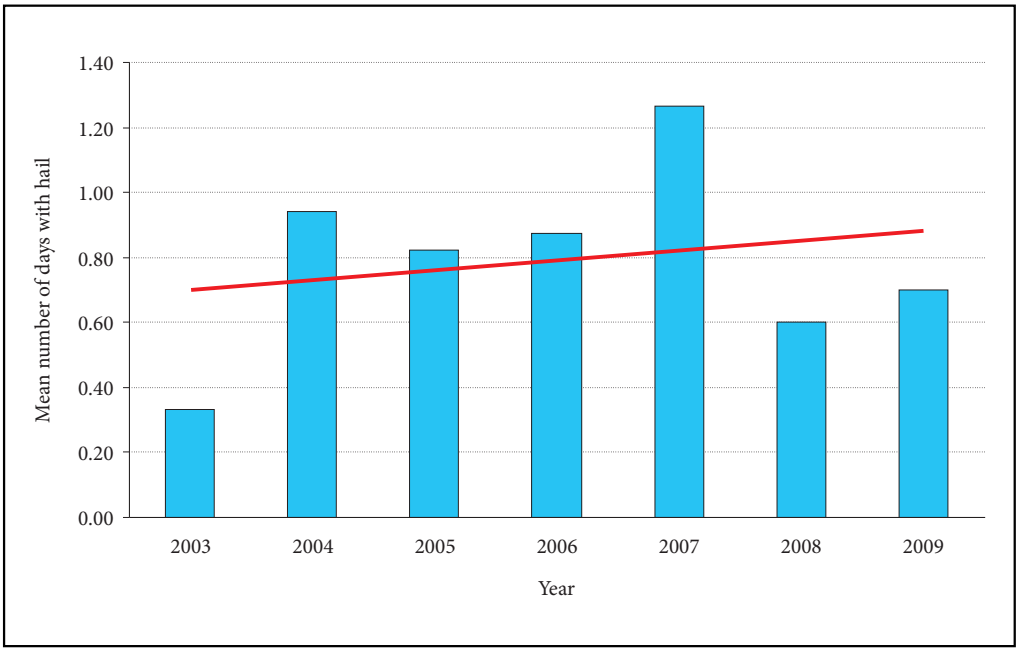


Figure 5: Mean number of days with hail per year and linear trend line (in red) from 2003 to 2009, when there was hail suppression on the whole territory of Vojvodina (Gavrilov et al. 2010).

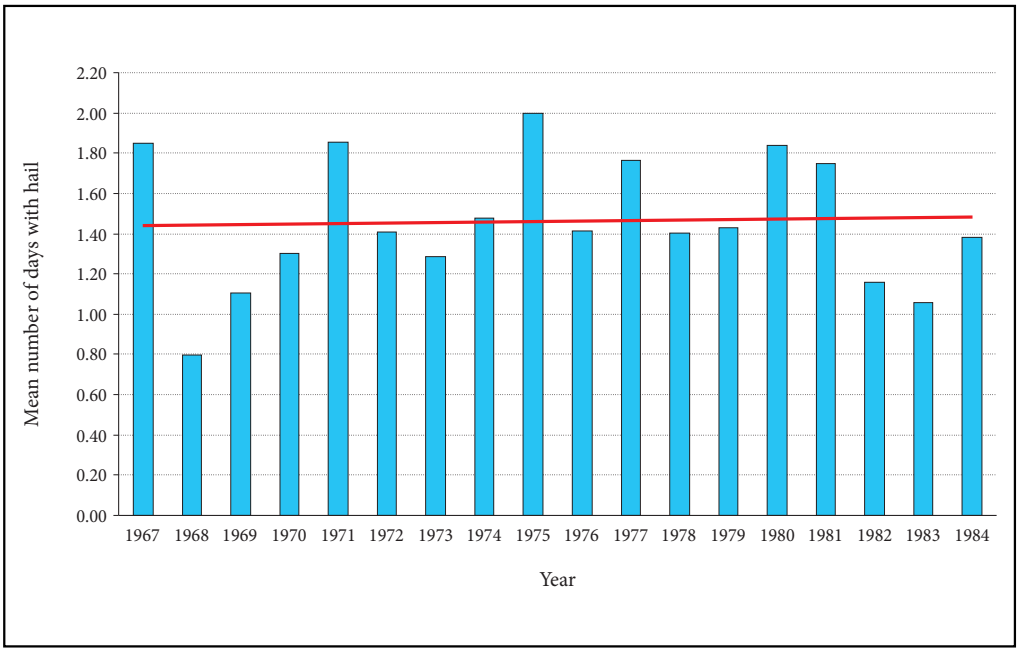


Figure 6: Mean number of days with hail per year and linear trend line (in red) from 1967 to 1984, when the territory with hail suppression in central Serbia expanded (Gavrilov et al. 2010).

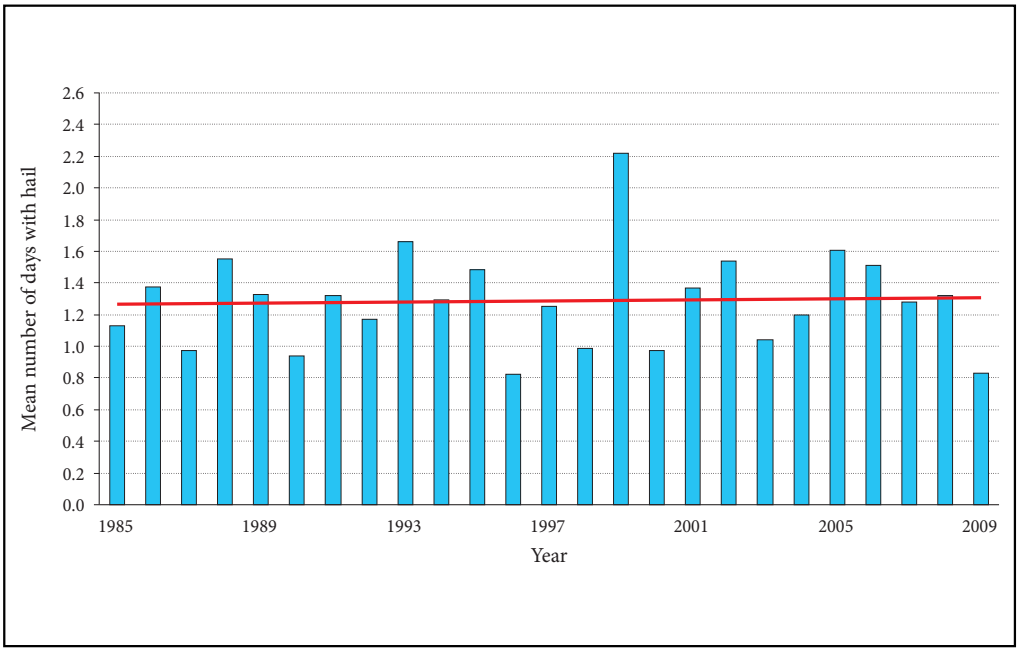


Figure 7: Mean number of days with hail per year and a linear trend line (in red) of hail from 1985 to 2009, when there was hail suppression on the whole territory of central Serbia (Gavrilov et al. 2010).

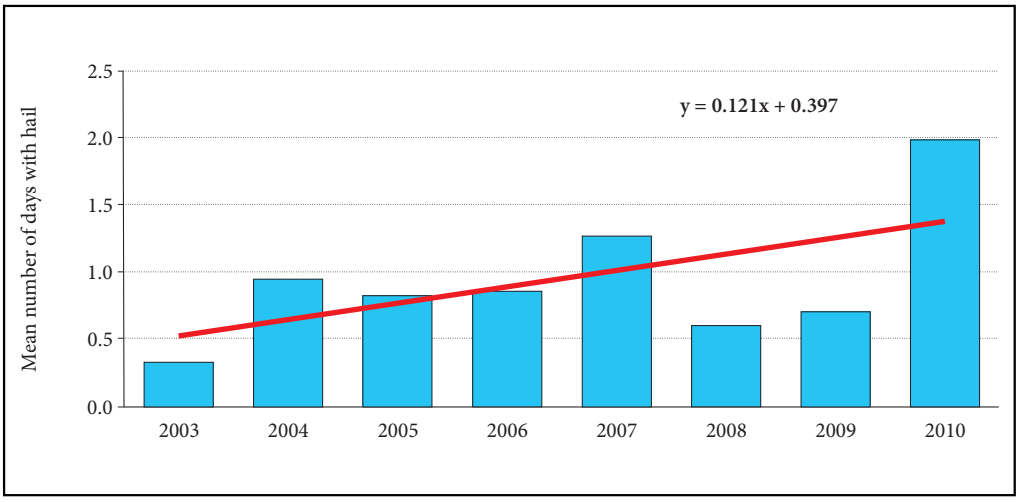


Figure 8: Mean number of days with hail per year and a linear trend line (in red) from 2003 to 2010, when there was hail suppression on the whole territory of Vojvodina (Gavrilov et al. 2011).

The goal of work Gavrilov et al. (2010) was to study whether hail suppression program in Serbia carried out from 1967 to 2009 had the expected statistical influence on hail trend, while all other influences were ignored. The hail trend was processed with a calculation of the linear hail trend equation. For the processing, all observed data were used on the number of days with hail on all synoptic and climatological stations for the period 1967–2009 Gavrilov et al. (2010). Data from the previous period could not be used since they had not been controlled, and there is no other hail data in Serbia. Since the aim of this research was to ascertain the influence of hail suppression on hail trends, data processing was adjusted to this criterion. With reference to that, hail trend was presented in Vojvodina and central Serbia in two cases and four periods.

In the first case, the hail trend was processed in Vojvodina for two periods. From 1967 to 2002 when there was no hail suppression, the trend equation (red line) indicates that hail trend was decreasing (Figure 4). In the period 2003–2009, when hail suppression was carried out on the whole territory, the trend equation indicates that the hail trend was increasing (Figure 5). It seems that in Vojvodina, hail suppression led to the stopping the decrease of the hail trend from the previous period.

In the second case, the hail trend was processed for central Serbia for two periods. The trend equations indicate that hail trends were increasing in both periods; 1967–1984, when hail suppression expanded (Figure 6), and 1985–2009, when hail suppression was carried out on the whole territory (Figure 7).

The previous two cases show that hail trend was increasing rather then decreasing it when there was hail suppression. The obtained results are not in accordance with the expectation that hail suppression decreases hail in Serbia.

Finally, the work of Gavrilov et al. (2011) considered only the case of Vojvodina from 2003 to 2010, when there was hail suppression. Figure 8 shows that the hail trend was increasing in that period.

6 Conclusion

Hail suppression is not a scientifically grounded activity. It is based only on the hypothesis on managing cloud processes. Wieringa and Holleman (2006) wrote that »*the question of whether hail suppression if feasible is emotionally loaded by the fact that damage to crops or cars can be so disastrous.*« According to Bergant (2011, 246): »*People want protection against hail, so they are sometimes willing to accept the ways of defense for which there is no clear evidence that they work. Local and state politicians want to help people, and are willing to support ways of defense for which there is no evidence that they work to gain their affection. Operators*

of hail suppression wish to obtain funding for their activities, and are willing to offer a means of defense for which there is no evidence that they work.« But in Serbia the hypothesis obtained the status of an absolutely confirmed and accepted scientific theory. On that hypothetic basis, for almost half a century hail suppression has been operative covering the whole territory of the Republic of Serbia except the region of Kosovo and Metohija.

There are a couple of reasons why is hail suppression is accepted in Serbia. One of the reasons is because of the credulity and misapprehension by the population and authorities. The authorities think that by spectacular actions of »shooting clouds« they protect the interests of the population. At the same time, because of primeval fears of catastrophes, the population accepts this as an earnest attempt at extending help. Besides the population and authorities, there are also meteorologists in favor of these actions. In time, they have grown so strong that they formed with other stakeholders powerful lobbies for the support of »shooting the clouds«. The lobby consists of rocket producers, budgetary controllers, operative workers, analysts, propagandists, scientists, etc.

Now, after 46 years of continuous operative experience with hail suppression, after firing a total of approximately 400,000 rockets (Vujović et al. 2007) and spraying approximately 160,000 kg of silver iodide, processing of all data on hail from 1967 to 2009/10 has shown that hail increases in Serbia (Gavrilov et al. 2010) and only Vojvodina (Gavrilov et al. 2011) which is contrary to the expectations of hail suppression.

Recently the National Assembly of the Republic of Serbia (2003), as well as the Government of the Republic of Serbia (2006) »timidly« announced a reconsideration of hail suppression. Hopefully the latest research (e.g. Gavrilov et al. 2010; 2011) and this study will help them in their decisions.

7 Acknowledgment

This research paper was financed by Project 176020 of the Serbian Ministry of Education and Science. The authors are grateful for the support of Mr. Miroljub Zarić and Mr. Ozren Jungic for the comments that improved the quality of the manuscript.

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