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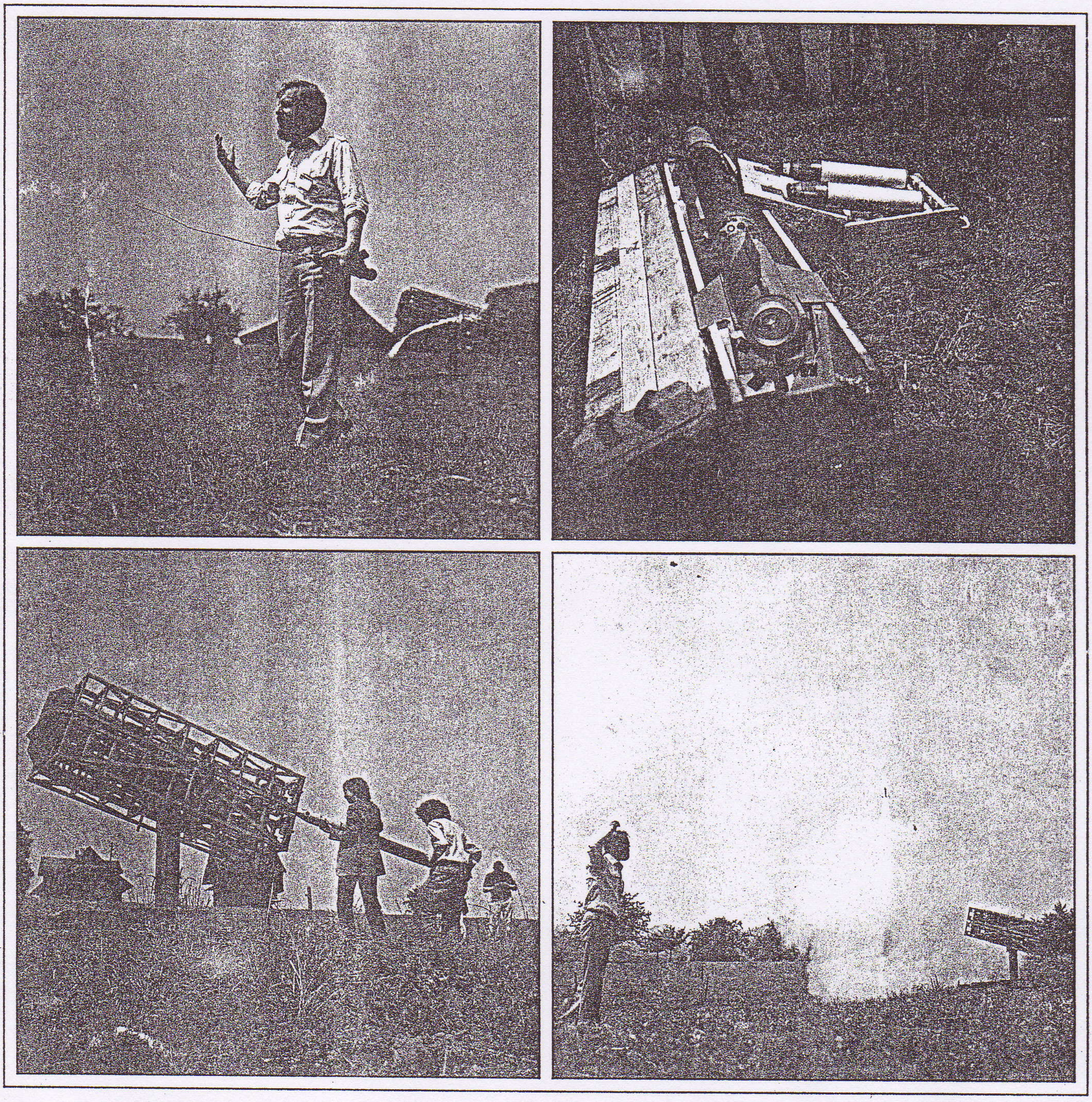

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CLOUD SEEDING WITH THE TG-10 ROCKETS

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Abstract. Efficiency of a hail suppression (HS) system is strongly affected by technical devices in use, and the way they are used. In case of antihail actions, it is necessary to inject the meteorological reagent into the proper seeding area, as soon as possible. A technical description for the rocket TG-10 is given, together with the methodology which is based upon investigations of rocket operating in beams 25^o wide, between -5^o to -10^{o}C isotherms on the front part of the Cb clouds.

1. INTRODUCTION

A rocket, designated the TG-10, has been used in the operational program of hail suppression in Yugoslavia, since 1980 (Lipovscak et al. 1980). Its development was based on many studies in the interdisciplinary fields of meteorology, ballistics and general rocket technology. Parallel with the operations methodology, evaluation of rocket performance has been accomplished.

Functional connection of the meteorology, TG-10 characteristics, and the nature of the seeding material resulted in the construction of the six-position launcher. This produces quasi-horizontal and slightly scattered cloud seeding trajectories. (Gelo et al. 1978, Horvat et al. 1980, Mozer et al. 1981).

Hail suppression in Yugoslavia during the past few years has been carried out with a better understanding of the meteorological processes as well as with the development of antihail seeding devices.

2. ANTIHAIL ROCKET TG-10

The TG-10 is a two stage rocket, made of fiber-glass plastics. The motor contains rocket propellant and a container is filled with a silver iodide based pyrotechnic mixture. Some characteristics are shown in Figure 1.

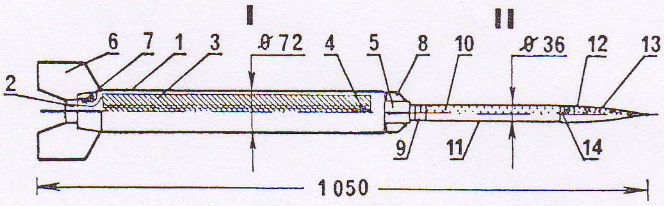


Fig. 1. Antihail Rocket TG-10

I Motor part (booster): 1. motor; 2. nozzle; 3. propellant; 4. igniter; 5. connector; 6. fins; 7. self-destruction system.

II Container: 8. nozzle with fins and connection part; 9. timing system; 10. pyrotechnic mixture with AgI; 11. fiber-glass plastic body; 12. plastic nose cone; 13. balast; 14. detonator.

2.1 Technical data:

total length	1050mm	mass	4.35kg
motor diameter	72mm	propellant mass	1.50kg
container diameter	36mm	pyr.mix.mass	0.40kg

timing of the start of seeding:
5s (± 0.5) to 25s (±2) max.
seeding time: 27s (±2).

2.2 Functions of the antihail rocket TG-10.

The timing system on the container must be set before launching. Electrical wiring is provided by simply inserting the rocket into the launcher. Current from the ignition box ignites the propellant and pyro-locker, freeing the container from the booster.

The booster motor burns about 1.2 s and accelerates the rocket to 700 m s^{-1} (± 50). When the propellant is exhausted, the container is separated due to the aerodynamical drag of the booster motor and then flies freely from the initial momentum. After 9 s. (±2) the booster motor section is disintegrated into harmless particles with a 24 g detonating fuse.

Speed-loss of the container is rather low due to its good aerodynamical properties and relatively large mass. In programmed time, the AgI pyro-mixture (reagent) is ignited and dispersed through the nozzle for 27 s (±2). In contact with the cold atmosphere an AgI aerosol is formed. When the pyro-mixture is completely dispensed, a detonator is activated which disintegrates the container in the form of harmless particles.

2.3 Balistic tables, isotherms and cloud-seeding.

Because of the high speed (700 m sec^{-1}) and good aerodynamical form, the container reaches an altitude of 8.3 km (±0.3) when launched at an elevation angle of 85^o. Ballistics curves are shown in Figure 2.

According to experience, best results are obtained with cloud-seeding between the -5^o and -15^o isotherms. (English et al 1982, Sedunov et al. 1979, Federer et al 1979) which are usually at the 3 - 6 km altitudes (Sedunov et al. 79).

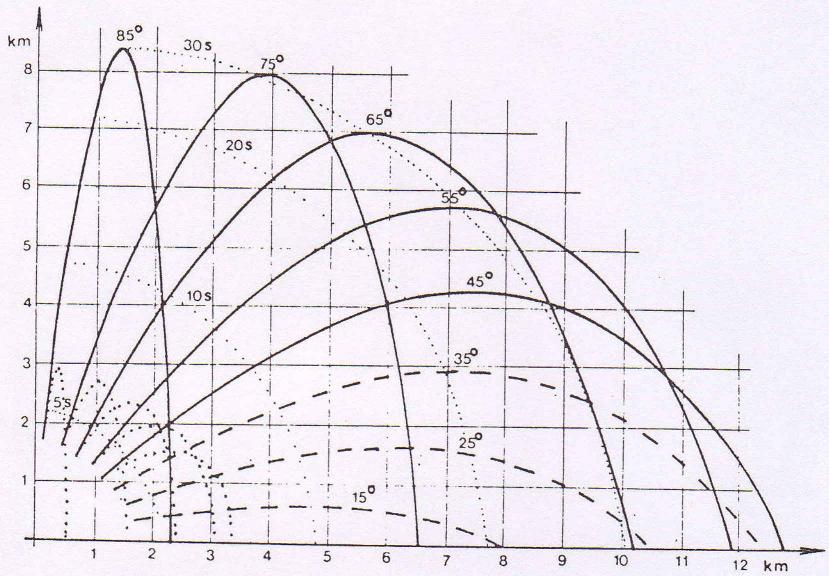


Fig. 2. Balistic trajectories of the TG-10 container.

In the Croatia program the destination of the cloud seeding material is the -10° isotherm, in the area of the first radar echo. With the quasi-horizontal trajectory, a long seeding path is produced within a narrow temperature range. The elevations used in Croatia are between 45° - 65° because of the rocket ballistic properties and as a result of isotherm studies on the days of anti-hail actions. Results of these isotherm studies are presented in Figure 3.

When firing rockets, attention is paid to the fact that the acceptable isotherms within the seeding area are at higher elevations compared with the surrounded atmosphere. (Krastanov et Stanchev, 73). Safety of air traffic is always considered when using smaller elevation angles.

In general, it should be noted that every rocket has wider optimal elevations with lesser max range at 85° elevation.

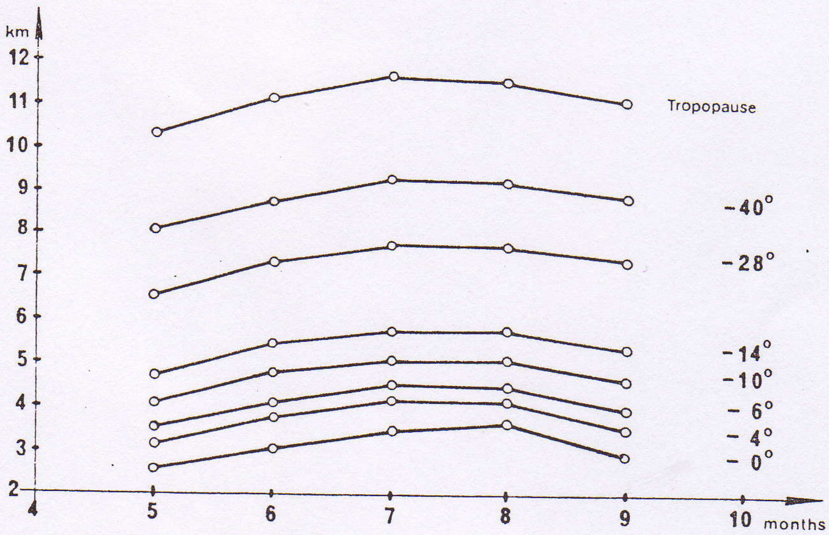
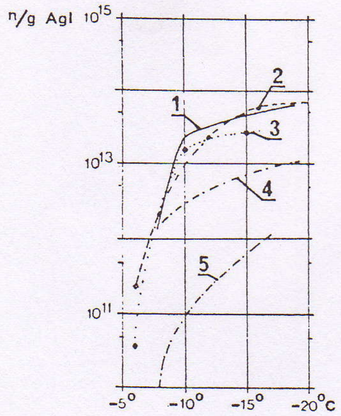


Fig. 3. Average altitudes of the isotherms on the days of anti-hail actions from surroundings taken at 1200 and 0000 during the 5-year period 1977-1981. (Peti et al. 1982).

3. PHYSICAL CONSIDERATIONS WITH AgI BASED REAGENTS

For the purpose of hail suppression a variety of reagents are used in different parts of the world. (Federer et al. 81, Fukuta 80, Bahlanov et al. 82). It seems that for relatively small rockets the best seeding material is a AgI based mixture. Activity of such a mixture is strongly affected by temperature. Dissipation of some types could cause deactivation of aerosol (Federe et al. 81) at temperatures from 0° to -5°C. However, dispersion at lower temperature, such as -15°C, shortens the time spent by the AgI aerosols in the ice crystal growth zone. Some activation curves are shown in Figure 4.



1. SILVERSPARE A-2 (2% AgI), ETH
2. HAILLES (28% AgI), CSU
3. RTG-10 (20% AgI), PMF Beograd
4. NEI TG-1, CSU
5. NEI TB-1, ETH

Fig. 4. Activity versus temperature diagram for several types of the AgI Based pyrotechnical mixture.

Since the temperature affects the rate of growth and shape of the ice crystals (Fukuta 80), it seems the best results could be obtained by seeding in the layer where temperatures are -5° to -10°.

3.1 Emission of the AgI from a TG-10 container

TG-10 container is filled with 400 g AgI based reagent with 20% AgI. According to measurements made at the University of Belgrade, AgI based mixture could release 4.1×10^{12} active nuclei per gram of mixture at -10°C, i.e. 1.6×10^{15} active nuclei per container.

Emission duration is 27 s (±2) at a 15 gr s^{-1} rate, i.e. 6×10^{13} active nuclei per second. At an average flight speed of 200 m s^{-1}, there are 3×10^{11} active nuclei per meter.

3.2 Spreading of the reagent

One of the mechanisms of spreading is turbulent diffusion. (Browning 77, Federer et al. 79). Turbulence in vertical streams of the Cb are important for reagent spreading. According to Browning (77), energy dissipation rate in the area of seeding could reach values between 500 and 1000 $cm^2 s^{-3}$.

Some measurements made in the SSSR with Po^{210}, P^{32} and D_2O aerosols show that the aerosol speed at the front zone (large drops) could reach 50 - 60 m s^{-1} and the speed of dispersal in the central zone could reach 6 - 60 m s^{-1} in different directions.

Further, it has been speculated that the spreading is probably affected by the electrical field inside and around Cb (Styra et al. 76). From the various studies and for purposes of operations, it is safe to assume that the spreading speed of the reagent in the area of seeding has a value of 10-20 m s^{-1} in all directions.

3.3 Seeding with a single TG-10 rocket

For the seeding of the hail-embryo growth zone, about 10^5 active nuclei are needed for 1 m^3. The seeding trail of the TG-10 container is about 5.4 km long (50° elevation). A simple calculation shows that a container at -10°C could seed about 16 km^3. As a result of the spreading, the concentration of reagent decreases. With the assumed spreading speed of 10 - 20 m s^{-1}, the full volume is seeded in 1 - 2 minutes. These concepts with the TG-10 are shown in Figure 5.

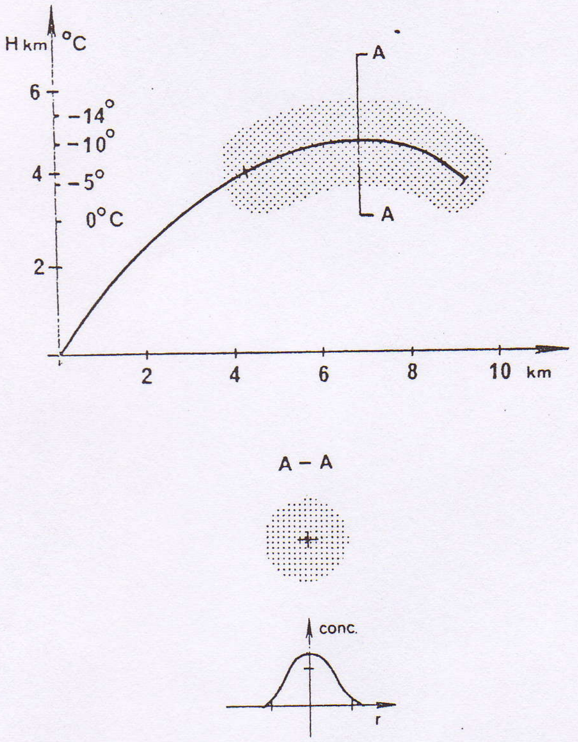


Fig. 5. Example of cloud seeding with single TG-10 rocket.

3.4 Multi-rocket cloud seeding

A hail suppression action is a race with time. For efficient seeding, TG-10 rockets are fired simultaneously from the launcher in beams. Guides in a launcher are inclined from the central line as follows: -8°, -4°, 0°, 0°, +4°, +8° (Gelo et al. 78).

At 50° elevation, a wider beam is used: -12.3°, -6.2°, 0°, 0°, +6.2°, +12.3° (Mozer et al. 81). Guides are numbered from 1 to 6 for various seeding possibilities (55° el.) are shown in Fig. 6.

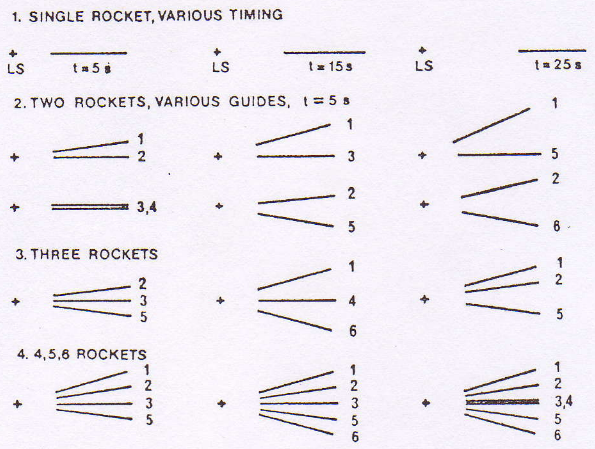


Fig. 6. Examples of seeding possibilities.

It is evident that a great volume can be seeded in a short time as shown in Figure 7.

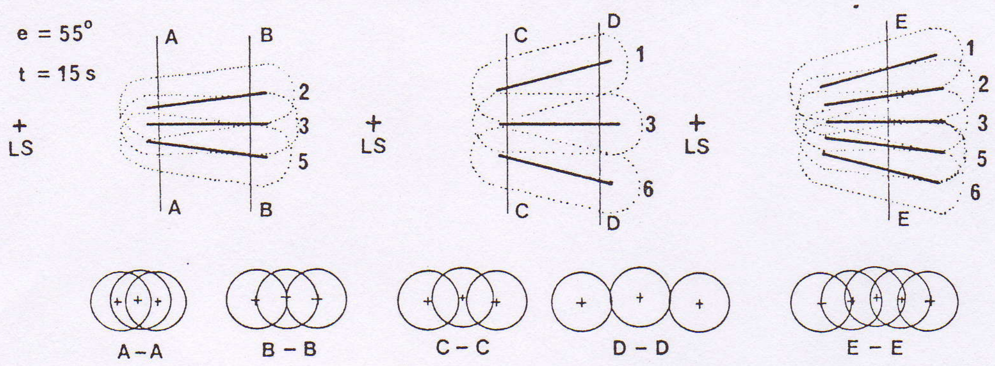


Fig. 7. Seeding area expected 1-2 minutes after firing.

3.5 Cloud possibilities of a single launching station (LS)

Using 45^{O} to 65^{O} elevations, every LS can seed a toroidal-shaped space with radius from 1.5 to 10 km and 1.5 to 6.5 km altitude, respectively (Gelo et al. 78, Horvat et al. 81). This is illustrated in Figure 8.

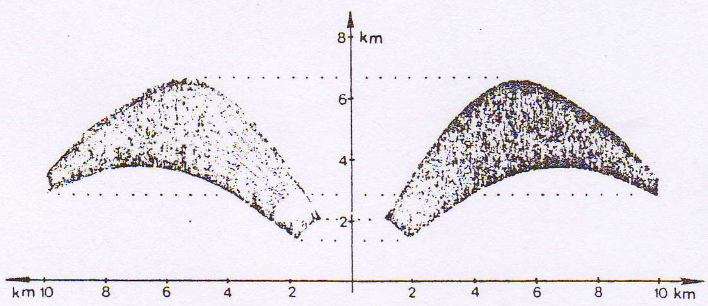
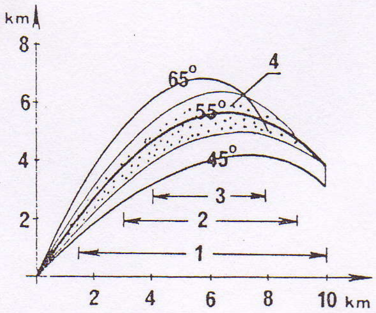


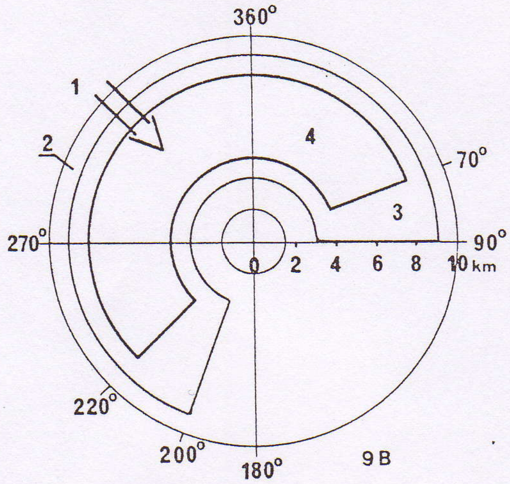
Fig. 8. Single LS seeding possibility.

After firing from an LS the distance between rockets increases with time. Due to wind influence, the deviation from the calculated trajectory is increased with the distance from launcher. The elevation influences the reagent activity. Therefore, good results are obtained at distances of 3-9 km, and the best are at 4-8 km. Firing rockets in precipitation areas should be avoided.

Targets should be front-right parts of the cloud from the launcher sites located along the possible cloud path. As a consequence several seeding areas exist (Fig. 9).



9 A



9 B

Fig. 9. Optimalization of the cloud seeding areas for single LS.

9. A 1. Possible seeding area; acceptable area; 3. optimal area; 4 optimal elevations.

9. B 1. Direction of the incoming thunderstorm (mostly NW);
2. possible seeding area; 3. acceptable area (in the case shown NW direction); 4. optimal area.

4. CONCLUSION

The investigations of ballistic properties show that optimal elevations for TG-10 launching rockets are from 50° to 55°. For introducing seeding materials in the temperature zone between -5° to -10°C, a six-guide launcher is set to 50° elevation with a beam width of 25° (from -12.3° to -12.3° of null direction at elevation 50°). Every launching station can seed a toroidal shape space 1.5 to 10 km in radius.

The best place to seed is in the front part of the arriving Cb cloud. The possible seeding area is optimized according to meteorological influences on the rocket as well as quality of the reagent.

The TG-10 rocket is an innovation among anti-hail devices. Low mass, ultimate precision and great range are prerequisites for easy handling and reliability in use. However, further development of methodology and technology of hail suppression requires a better understanding of atmospheric processes.

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