Trends in the development of technical means on weather modification of clouds and supercooled fog

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Abstract: The modern state and prospects of further development of technical means on weather modification for anti-hail works, works on regulation of atmospheric precipitation and for dissipation of supercooled fog are considered. The characteristics of anti-hail systems, ground-based aerosol generators and their control systems, aircraft means for firing pyrotechnic cartridges and controlling the operation of generators, as well as means for dispersing supercooled fog included in the «List of technical means on weather modification (WM) used by specialized organizations of WM on meteorological and other geophysical processes» are analyzed. Recommendations are given for further improvement and implementation of developed technical means in the practice of works on WM activity.

1. Introduction
Currently, a number of technical means of delivering and dispersing the reagent into the supercooled cloud, such as aircraft pyrotechnic cartridges and stationary silver iodide generators, ground-based aerosol generators and anti-hail rockets, have been developed to implement existing WM methods.

The characteristics of existing technical means of WM of clouds, the results of works on creation of new and modernization of existing technical means, carried out in ANO «Agency ATTECH», as well as proposals for further development of existing technical means of artificial regulation of atmospheric precipitation (RAP), dissipation of supercooled fog, frost control, as well as in conducting anti-hail operations are presented below.

2. Aircraft pyrotechnic aerosol generators
As it is known, in works on RAP in the world, aviation technology of WM of clouds is mainly used. In this case the most effective means of influencing on powerful clouds are silver iodide pyrotechnic aerosol generators (pyrotechnic cartridges) launched (fired off) from special devices. In USSR the development of silver iodide pyrotechnic cartridges for cloud seeding PV-26 and PV-50 type (SAG-PM and SAG-26 generators) was based on serially produced anti-aircraft defensive systems such as ASO-2I, KDS-155, UV-26, which were mounted on all types of aircraft of that time (An-12, Il-18, An-26, An-30). Since in modern conditions works on RAP became episodic and maintenance of special aircraft for these works became economically unprofitable, there was a need to create special quick-removable mobile aviation means for WM activity. In addition, a fundamentally new (cheaper and simpler to produce) design of squibs and generators was required.

In this regard, and taking into account the wider use of light aircraft such as An-2, TVS-2MS, MV-500, Yak-18T in works on RAP, the Agency has developed a new generation of aircraft aerosol complexes such as SAG-26V and SAG-26 KS [1].
The SAG-26V firing system is an upgraded version of the ASO-2I firing system and allows to carry out attacks from the aircraft with the help of standard squibs of PV-26-01 type and SAG-26 generators (figure 1a).

The SAG-26 KC firing system (figure 1b) is a principally new firing device with multiple-use barrels designed for use of the no-gun pyrotechnic active elements «Dojd-C» and «Dojd-K» (figure 2), with «Dojd-C» elements designed for horizontal cloud seeding along the aircraft flight path, and «Dojd-K» elements perform vertical cloud seeding similar to the aircraft type PV-26-01 squibs.

![Figure 1. Aircraft aerosol complexes SAG-26KS (a) and SAG-26V (b).](image)

![Figure 2. Active elements «Dojd-K» (a) and «Dojd–C» (b).](image)

The developed SAG-26V and SAG-26KS aircraft means in combination with the guideless pyrotechnic active elements «Dojd-S» and «Dojd-K» will allow to simplify the procedure of storage, transportation and operation of WM means, to use in operative works on light-motor planes that will promote expansion of works for needs of agriculture at the expense of use of ground aerodromes and decrease in their cost.

SAG-26V and SAG-26KS complexes and «Dojd-S» and «Dojd-K» active elements were developed at the expense of the Agency, passed ground and flight tests on M-500 MVEN aircraft. However, the Agency's attempt to organize MVK in 2018 to accept these technical means and add them to the Roshydromet list of WM means was rejected by the former leadership of the Federal Service for Hydrometeorology and Environmental Monitoring under the far-fetched pretext of the need to certify these means. It is known that none of the WM means included in the aforementioned List has a certificate.

3. Ground aerosol generators
Interest in these technical means of WM in Russia arose in the 2000s years, when due to insufficient funding of anti-hail services, began to consider alternative methods of WM on clouds in order to protect crops from hail storms and artificial precipitation enhancement. As a result of the work performed at the Agency, the ground aerosol generators NAG-07M and NAG-07A were created.
NAG-07M generators use pyrotechnic active elements with AgI as a reagent and have a modern and reliable control system. The control system allows to control the generators by wire, radio and GSM channels.

Ground aerosol liquid generator NAG-07A uses silver iodide solution in acetone as a reagent [2]. Important advantages of the developed generator are the possibility of long continuous operation, a fairly simple technology of preparation of acetone AgI solutions, which allows to easily change its concentration, and as a consequence, lower costs of the work.

In order to enhance the efficiency of the use of NAG-07A, its modernization was carried out in the Agency in 2021 (figure 3).

![Figure 3. Modified NAG-07A (a) and the generator control unit (b).](image)

Within the framework of the modernization the following activities were performed: 1) the NAG-07A design was equipped with a telescopic mast, allowing to disperse the reagent at height of 4-5 m from the ground; 2) the NAG-07A control system was developed, allowing automatic ignition of the working substance when starting the generator, to control the presence of flame during the operation of the generator, to give warning signals when the burner flame goes out, automatically stop the generator when an abnormal situation occurs.

According to specialists of the Agency, the use of ground-based generators in addition to aircraft and missile means of influence will increase the efficiency of works on RAP and hail protection. However, even in this case with the inclusion of these means of WM in the «List of means of WM used by specialized organizations on WM of meteorological and other geophysical processes» a strange story happened. Land generators are included in this list only as a means to increase precipitation, but not as a means to combat hail, although these generators are widely used abroad precisely to hail protection and have been field-tested in the North Caucasus AF, receiving a positive conclusion. In our opinion, this is due to the reduction in the institute of qualified specialists in the field of WM.

4. Means of dispersing supercooled fog

At present, when carrying out works on artificial fog dispersion, stationary and mobile ground generators GMCHL-40H are used, which carry out dispersion of liquid nitrogen in the surface layer of the atmosphere. Application of such nitrogen generators was confirmed by successful works on dispersion of supercooled fog at airports and highways in the USSR, Italy and Kazakhstan.

The available experience in artificial fog dispersal has revealed some significant disadvantages of using ground-based nitrogen generators. Thus, for works on large areas (in particular at airports) it is required to create a dense network of points of influence, and when dispersing fog on roads, a great influence on their effectiveness has a change in wind speed and direction, which is almost impossible to take into account when using mobile generators.

However, due to scientific and technological advances in recent years, unmanned aerial vehicles (UAVs) have been increasingly used in various fields of human activity. To draw attention to the use...
of UAVs as an alternative to the use of ground-based aerosol generators is also possible due to the fact that in recent decades the variety of unmanned systems has increased significantly. In addition to unmanned systems of miniature class, unmanned systems of medium (tactical) class began to appear, allowing the lifting of payloads with a total weight of 1 to 30 kg, and provide a flight time of 2 to 4 hours.

One of the main advantages of using UAVs in works on artificial fog dispersion, in comparison with the technology of using NAG, is the possibility of conducting the impact taking into account the wind speed and direction in the surface layer of the atmosphere.

In this regard, the use of different types of UAVs equipped with generators of fine ice particles (GMCHL) to disperse fog over certain sections of roads, at airports, in quarries and other inaccessible areas seems to be a promising direction for further development of technical means of WM to disperse supercooled fog.

According to the Agency specialists, as well as based on the results of numerical modeling of the processes of artificial dispersion of supercooled fog [3], both existing UAVs and developing UAVs, which meet the following requirements, can be involved in the work:

- flight altitude: up to 200 m;
- horizontal speed: from 40 to 350 km/h;
- payload: up to 50 kg;
- flight duration: at least 3 hours.

The aircraft-type unmanned systems already available in the Russian Federation and having the required characteristics, as shown in figure 4.

![Figure 4](image)

**Figure 4.** Orion UAV developed by «Kronshtadt» (a), Tipchak «Vega Concern's» (b), S-70 «Hunter» «Sukhoi Design Bureau's» (c), Irkut-200 «Irkut» (d).

Partially or fully advanced unmanned helicopter and multicopter systems have the required characteristics, figure 5.

![Figure 5](image)

**Figure 5.** «Kamov» K-137 (a), Aerones drone (b), «Horizon» G-Air S-100 (c).

The Agency is currently conducting experiments to test supercooled fog dispersion modes using the liquid nitrogen dispersion system installed on the DJI-s900 (figure 6).
5. Frost control means

In spite of the works carried out in the USSR to study the problem of frost control and creation of appropriate technical means, the problem of frost control is still urgent. It is known that at present the main method of frost control is creation of smoke screens. To create smoke screens, both pyrotechnic means and warm fog generators can be used [4]. Pyrotechnical smoke means have a number of significant drawbacks, among which the main ones are fire hazard, short duration of their combustion and high cost, which makes the use of smoke generators preferable.

According to specialists of the Agency, the modern technology of frost control involves the creation of a kind of semi-automated complex, which includes the following elements: 1 - operational information - measuring system; 2 - network of aerosol generators (smoke, warm fog); 3 - control unit.

This complex will allow, based on the monitoring of meteorological parameters in the protected area (temperature, humidity, wind speed and direction) to control and monitor the operation of generators.

At present, the Agency is testing the technology of frost control with the developed information-measuring system and pulsating aerosol generators (figure 7), as well as selecting and researching environmentally friendly and effective reagents for them.

6. Missile systems

For more than 70 years the USSR and now Russia have been developing anti-hail missile systems. During this time, a lot of experience has been accumulated in creating anti-hail missiles such as «PGl», «Oblako», «Alazan», «Nebo», «Alan», «As» (and their modifications) and their launchers [5]. A lot of experience in creating and operating anti-hail systems has been accumulated abroad: in China, Bulgaria, Georgia, Serbia, Macedonia, Romania. Some of the modern foreign systems are shown in figure 8.
Figure 8. Modern anti-hail systems: (a) Chinese-made for launching WR-98 and WR-1D missiles; (b) Bulgarian-made for launching Loza 6 missiles (Sky Clear 6); (c) Georgian-made NTC «Delta».

The analysis of this extensive material makes it possible to determine the directions of rocket means development and formulate the requirements to them. On the basis of this analysis, the Agency made an attempt to elaborate an advanced anti-hail system, which should meet the following technical requirements:

- to have sealed transportation and launch containers for missiles with a high degree of protection;
- to have an effective range of at least 12 km;
- to have a low dispersion (more than 1/40);
- to have a no-failure probability of operation of not less than 0.999;
- to have automated mobile launchers;
- to have the number of ice-forming nuclei generated by the product not less than 10^{16};
- to have the lowest weight and size characteristics without prejudice to other technical requirements.

Figure 9 shows two rocket configuration options. The first option is a jet missile (a), the second option is an active-jet missile (b).

Figure 9. Layout of the anti-hail missile version 1 (a) and 2 (b).

The main technical characteristics of both missile variants are presented in table 1 [2].
### Table 1. The main technical characteristics

| General characteristics                        | Values   | Layout option v.1 | Layout option v.2 |
|-----------------------------------------------|----------|-------------------|-------------------|
| Mass of missile, kg                           |          | 3.7               | 2.5               |
| Missile caliber without container, mm         |          | 60                | 60                |
| Length, mm                                    |          | 1000              | 750               |
| Effective range, km                           |          | 10                | 10                |
| Number of ice particles generated by the unit, not less |          | $10^{16}$         | $10^{16}$         |

The proposed variants of rockets will reduce the cost of products due to the use of ice-forming solid propellants in the design and the pulsed mode of operation of the cruise engines. The use of folding stabilizers will make it easier to transport the missiles and keep them on the launcher, which will reduce the cost of the launchers.

### 7. Conclusion

All of the above confirms the need for continuous improvement and renewal of the technical means of the technical facilities in use and the absence at present a clear technical policy in Roshydromet in this area. In spite of the extensive list of the technical means of the WM used by the specialized organizations of Roshydromet in operational-production works at present, most of them are obsolete, both morally and physically. Many of these technical means were created by the USSR State Committee on Hydrometeorology by defense enterprises on the basis of military equipment samples or simply adapted for use in WM operations. Since most of these means are manufactured at enterprises which are monopolists, the cost keeps growing. All this, as well as the digital and technological progress in the world in recent decades, has clearly revealed the problem of Roshydromet's technical policy in the field of creation of WM means.

In our opinion, it is necessary to create under Roshydromet a technical commission consisting of representatives of the central office, institutes and specialized organizations to develop a modern concept of creation and implementation of technical means of WM. Without solving this problem, further progress in this area is impossible.

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