ANTIHAIL ROCKET AND HAIL SUPPRESSION METHODOLOGY USED IN BULGARIA

1. Background

The hail suppression project in Bulgaria starts with protection of about 250 000 ha and since 1987 the protected area reaches 1 500 000 ha. In the beginning Russian rockets are used like “PGI”, “Oblako”, “Alazan” , which carry an active reagent based on lead iodide, and a Georgian methodology for hail clouds identification and their seeding. Since 1986 a Bulgarian methodology for identification and seeding of hail clouds is introduced, based on physics-statistic methods. Since 1994 the active reagent in the available “Alazan” rockets is replaced with silver iodide and the implementation of the first model for reagent diffusion in the atmosphere starts. Since 1999 the manufacture of a Bulgarian anti-hail rocket starts; the rocket carries the upgraded version of the active reagent, based on silver iodide. In 2000 the diffusion model is modernized taking into account the temperature conditions in which the active reagent generator works. The software, which is used translates the location of all objects to the radar coordinate system and selects the most suitable launching site for clod seeding according particular meteorological conditions in that day. Also the area of seeding and the method is made more precise. As a result of the activities:

- the consumption of rockets is reduced 5 times;
- the reagent used is environment friendly;
- the physical effect from the cloud seeding intervention is increased;
- reduction of risk when handling the rockets;
- reduction of rocket and launcher weight, which allows the establishment of mobile launching sites;
- reduction of the upper flight height and allowing additional space for civil aircraft traffic;
- introducing the reagent in the warmer parts of clouds, thus increase in the active track of a rocket.

2. Advantages of the Bulgarian rocket as a technical carrier of reagent into clouds, compared to similar items:

- **with respect of the active reagent :**

  It is tested

  in the Testing Laboratory of the National Institute of Meteorology and Hydrology at the Bulgarian Academy of Sciences

  in the P. DeMott laboratory at the Colorado State University

  in the Aerosol Research Laboratory at the Central Aerological Observatory (CAO), Moskow.

  It has a high number of ice-nucleus in 1 gr. of pyrotechnic compound. For a comparison: at -10^0 C the number of ice-nucleus is 1.5×10^{13} nucleus. Besides the pyrotechnic compound contains additives, which allow the reagent to be reactivated at negative temperatures even if at the moment (and level) of initial intervention the temperatures have been positive.
- **with respect to safety:**

  The rocket is in a hermetic container, which protects it from atmospheric influences and protects the personnel even in case of self-destruction of the rocket on the ground due to certain reasons.

In the self-destruction chain of the rocket there are not strong explosive substances like hexogen, TNT, elastit, etc.

According to the European Convention on Transportation of Dangerous Materials, the rocket is classified as class IIIB, the self-destruction system – as class IB. The whole rocket ADR classification is 1.4S.

- **with respect to the weight:**

  The weight of the rocket is 2.6 kg, and together with the container – 3.65 kg. The mass of the active pyrotechnic compound is 400 gr. The launcher weights about 70 kg. These parameters allow a complex to be built by 1 stationary and 3 – 4 mobile points. At the stationary launching site the rockets and the vehicles, which carry the launchers are kept, the mobile points are used only when shooting and are small concrete area with thunder-protection.

3. Technology for determining the hail-peril of the cloud:

The starting point is that **the cloud is a process, rather than an object**. The peril estimation starts with evaluation of atmosphere state, i.e. how much is it capable of supporting convective processes leading to hail formation. This estimation is based on synoptical and aerological analysis.

Presence of conditions for strong convection is necessary for radiolocation's observations. The isocontours height are determined having radiolocation's reflectivity of 15, 25, 35, 45, and 55 dBz, together with the temperature values at these heights. The time variation is monitored of the so-called Discriminative Function, which divides "hail" from "non hail" clouds.

How this discriminative function is determined?

Initially the database containing all observed clouds is divided in two - clouds that have led to hail fall and clouds that haven't. Using an "expert estimation", after that a moment is chosen from the cloud history when it was in its maximum development (for rain clouds) or in a " before-hail " state (i.e. the moment preceding the cloud development) for hail clouds. Thus two excerpts of radiolocation and temperature parameters are formed, corresponding to two cloud types. Linear discriminative analysis permits to generate a function of cloud parameters, which separates in the best way the two excerpts.

We consider that the best criterion for cloud transition into a " before-hail " state is the condition:

$$A = H_{45} - 0.1\ T_{H15} > 9.3,$$

where H_{45} is the height [km] of isocontour with reflectivity of 45 dBz and T_{H15} is temperature [^{o}C] at the top of the isocontour with reflectivity of 15 dBz.

When the value of A is around the critical 9.3, additional criteria are used to determine the cloud type, such as the type of the general convective scene in the region, isotermic heights, gradients and dynamics of isocontours, etc.

All this brings an answer to "WHEN to intervene?".

The observations are carried out using meteorological radiolocation station MRL-5 with 10 cm wavelength, analog system for multicontour signal display and digital system for real time display and recording of radiolocation data.

4. Technology of intervention :

The radiolocation observations use classification of uni- multi- and super-cell processes. The cell is defined as an isocontour of 45 dBz reflectivity. The process type is determined by the number of cell in one isocontour of 35 dBz and by the reached stage of development. Unicell process is trivial. It is more difficult to determine the transition moment between multicell and supercell processes. Supercell process requires that at the same moment cells in different development stage exist in an isocontour of 35 dBz (at stages of genesis, maximum development and raining) and that the generation is going continuously in time. In this case the atmosphere energy realisation becomes an uninterruptible process leading to greatest hail damages. In some multicell and all supercell cases radiolocation shape of the cloud has a peculiar "incline" or an asymmetrical structure.

WHERE to interfere, or the place of seeding agent introduction depends on the process type.

In all cases the agent is activated at height in the layer between -5°C and -10°C.

Symmetrical processes require seeding in the region with reflectivity of 35 dBz. For asymmetrical processes the seeding region lies below the "incline", excluding the isocontour with reflectivity 55 dBz, large horizontal gradients require that seeding includes the region up to the border of isocontour 15 dBz.

HOW much to seed?

Our method requires filling of the seeding region with about 10^4 - 10^5 particles per cubic meter.

Before 1992 the seeding agent used was lead iodide (PbJ). The seeding agent quantity required was determined by the volume of the seeding region in order to obtain a density of 10^5 particles per cubic meter.

Since 1994 a new seeding agent is used. The pyrotechnical compound contain 10% silver iodide (AgJ), issuing 5.10^{13} nuclei per gram. The seeding agent quantity is determined using a diffusion model. As a result the rockets quantity was reduced five times.

5. Comparison between rocket method and other hail suppression methods:

In the world there are 3 methods for cloud seeding with active reagent. When estimated each of them has their advantages and disadvantages in case of hail suppression activity.

A. Ground-based generators seeding

Advantages:

- low maintenance costs; does not require high qualification of the staff who can work on a partial-time basis; does not require air-traffic co-ordination.

Limitations:

- large and non-effective agent spending; seeding is not made in the right places and at the right time and the seeding agent is quite often deactivated (moistened) before reaching the required height.

B. Aircraft seeding

Advantages:

- does not require special restrict to air-traffic control; needs few staff; can seed in the correct region at the correct time, **unless heavy clouds**.

Limitations:

- the continuous seeding is impossible; heavy clouds limit the precision of seeding in space and time; needs high staff qualification.

C. Rocket seeding

Advantages:

- can seed with high space and time precision; continuous seeding is possible; low agent spending.

Limitations:

- requires restrict to air-traffic control; staff is required for rockets lines maintenance, although not highly qualified.