Study of Distribution Ice-Forming reagent in the Boundary layer of the atmosphere When Exposed by Ground Aerosol Generators NAG-07M

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Abstract. The paper describes the technical means, methods, and results of experimental studies of the spread of ice-forming agents in the boundary layer of the atmosphere under the action of ground-based aerosol generator NAG-07M. Comparison of the data on sampling by an AVA 3-240-01S probe mounted aboard Vilga-35A aircraft with aerosol propagation calculations using a 3-D SeedDisp model shows 1. The concentration of silver iodide measured in the atmosphere was above background one to a height of 1200 m at distances of 3 to 9 km from the place of the generator installation. 2. The developed SeedDisp numerical model in general qualitatively correctly describes the distribution of silver iodide aerosols in the boundary layer and the free atmosphere under the action of ground-based aerosol generator NAG-07M. Thus, the coefficient of correlation of the measured and calculated by model values of the silver iodide particles concentration in the sub-cloud layer exceeded the value of 0.7.

1. Introduction
Currently, in the world practice of active impacts (AB) on clouds in order to regulate precipitation and combat hail, ground-based aerosol generators are widely used. An analysis of the state of work in the field of AB on hydrometeorological processes from the ground indicates that using this method, work is carried out both on the artificial increase in precipitation and on combating hail, such as Brazil and France. The first arrangement of ice in quite a while stays one of the most moving cycles to comprehend and to evaluate in ice cloud development. At temperatures hotter than and supersaturations lower than required for homogeneous nucleation [1]. Vaporized perceptions are fundamental in the atmosphere and ecological investigations, for example, measuring Earth's vitality financial plan and describing surface air quality [2]. Temperature and rain intensity have been seriously changed over the last few decades because the climate change; it has been reported that the world faces a serious increase in atmosphere temperature [3-5], rain intensity [6, 7], and rain distribution [8-10]. Where it has been evidenced that some parts of the world became very dry with limited availability of freshwater, such as in Africa and some parts of Asia [11, 12], whereas other countries are facing flooding events, such as Europe and the USA [13-17]. These significant changes in the climate of our planet have resulted in an increase in water pollution and shortages of freshwater [18-20], where the concentrations of metals (like arsenic, chromium, iron, and lead) [21-23], organic matter [24], bacteria and viruses [25-27], nutrients (like nitrates and phosphates) [28, 29], coloring agents [20, 30], fluorides [31], Gesomin [32], turbidity-
causing pollutants [33, 34] and phenol [35] were dramatically increased in the watercourses. It must be indicated that climates change has been mainly caused by man activities, such as emitting gases and fine particles into the atmosphere of our planet [36-39], for example, the cement industries consumes huge amounts of the natural resources [40, 41], and at the same time produces harmful gases (like carbon dioxide) [42, 43], moreover the by-products of the demolition of the concrete structures spoil large areas (used as landfills) [44-46].

To decrease these negative impacts of climate change on our daily life and existence, expensive treatment technologies and effective monitoring technologies are needed, such as simple [47-50] and complex water treatments [51-53].

Onboard, polar-circling meteorological satellites measure the Earth's reflectance in six stations. Current sensors like the Moderate Resolution Spectroradiometer [54]. As of late, satellite distant detecting has progressed the perceptions of airborne properties on both nearby and worldwide scales. For example, historical sensors like the Advanced Very High-Resolution Radiometer. Being a surface explicit component, the likelihood of the event of ice-dynamic destinations was found to scale with the all-out accessible surface territory of the vaporizers [55]. The undoubted advantage of delivering an ice-forming aerosol to the cloud using ground-based generators is their simplicity and relative cheapness in comparison with aircraft and rocket-artillery aerosol delivery methods. The use of ground-based generators does not require the creation of a complex infrastructure in the protected area; generators can operate near aerodromes, state borders, and settlements. At the same time, it should be noted that the efficiency of ground-based generators directly depends on the orography of the area, on the wind field in the surface layer, and the upward flows.

2. Methods
In this regard, to assess the possibility of using ground-based generators in any region, to study the distribution of reagent particles and to select the operating modes of the generators, to study the features of the placement of ground-based generators taking into account the orography of the area, to select the flight paths of aircraft during cloud seeding, as well as exposure different weather conditions, a three-dimensional non-stationary numerical model “Seed Disp”. The created model allows calculating the transfer of reagents when exposed to clouds using ground and airplane aerosol generators using iodide silver, liquid nitrogen, and granular carbon dioxide as reagents. "Seed Disp" allows you to determine how the reagent is transported in the surface layer whether the reagent reaches the lower boundary of the cloud, and what is its concentration.

3. Results
The first results of comparing the results of numerical simulations with data obtained in experiments on exposure to clouds using ground-based generators NAG-07 and generators of aerosols of the firework type GLA-105 at the training ground of the North Caucasian Militarized Service in 2009 and 2010. showed that the created software is promising for use in planning and conducting active impacts on the clouds. To confirm the reliability of the calculation results using the Seed Disp three-dimensional non-stationary numerical model, as well as to verify the concentration of ice-forming aerosol in the atmospheric boundary layer when exposed to the ground-based aerosol generator NAG-07M developed at ANO ATTeX (Fig. 1), using As active elements, generators of ice-forming aerosol AG-1M, in May 2015, experiments were conducted at the test site “FNPC“ NII PH ”. The main technical characteristics of the NAG-07M:

- Operating time (one at a time, two active elements in sequence), h: up to 8
- Aerosol setting height above the ground, m: 3.5-5
- Number of active elements, pcs: up to 80
- Control system: optionally remote or control panel
The yield of ice-forming aerosol, 1/s (-6 °C): \(0.6 \times 10^{13}\)

![Image](image.png)

**Figure 1.** General view of the ground-based aerosol generator NAG-07M with installed active elements “AG-1M”.

To measure the content of silver iodide particles in the atmosphere, we used the ABA 3-240-01C instrument complete with replaceable filters (Fig. 2, b). The device was installed on a Wilga “Vilga35A” (Fig. 2, a), equipped with a dispatch system to control the flight path of the aircraft from the ground. A control center (PU) was deployed at the training ground, equipped with a dispatch system to control the flight path of the aircraft and communication with the pilot, and a laptop with SeedDisp program for numerically simulating the spread of ice-forming aerosol in the under-cloud layer in order to select vertical sections for sampling.

![Image](image2.png)

**Figure 2.** Wilga 35A plane with an air sampling device, B) ABA 3-240-01C.

According to ground-based meteorological observations and atmospheric radio sounding on the day of testing, the concentration fields of aerosol particles generated by the generators were calculated using the SeedDisp model. Based on the results of numerical simulation, vertical sections were selected for aerosol sampling and the coordinates of the beginning and end of airplane sampling routes were determined in vertical sections across the wind aerosol transfer (Fig. 3a). The start of the NAG-07M generator was carried out in accordance with the results of numerical simulation (the operating time of...
the NAG-07M generator was determined, the number of in pyroelectric and frequency of start). Podom
aircraft in the air produced by a command from the UE to the time zone of approach to the intended
selection prob. Po arrival in the screening zone of the lower plane of samples held flight level in the first
vertical section (Fig. 3b). When the sampling start point was reached, the sampler was turned on. Upon
reaching the endpoint of sampling at a given level, the sampler was turned off. The plane made a U-turn
and went to the height of the next sampling route. During this time, the operator replaced the filter in
the filter holder. The procedures were repeated until the maximum sampling height determined by
numerical simulation was processed. After a sampling of AgI reagent particles in the first vertical
section, the aircraft passed to the point of sampling in the second section (Fig. 3, b). Similar procedures
were repeated for the third vertical section perpendicular to the general direction of the aerosol wind
transport.

Spent filters after each sampling were marked and transferred to the laboratory upon completion of
flights. During operation at the ground control station, a journal was kept in which the following were
recorded:

- Time of the beginning and end of the flight
- Start and end times for each measurement line
- Coordinates (latitude and longitude) of the beginning and end of each line
- The height of each line
- Wind speed and direction at each altitude according to aircraft observations

Information about the coordinates of the sampling lines was taken from the Earth-board Earth radio data
exchange system (dispatching system) installed in the control center.

![Figure 3. Aircraft sounding pattern perpendicular to the general direction of aerosol wind transport.](image)

In accordance with the research program for the distribution of the reagent in the cloud-like layer,
sampling under the influence of the NAG-07M generator was performed on May 26, 2015, in vertical
sections of the loop of the ice-forming reagent along the flight paths of the aircraft perpendicular to the
general direction of the aerosol wind transport. The effects of NAG-07M were started at 13 h 25 min.
The ignition of active elements was carried out with a 2-minute periodicity. With such a scheme of
ignition and the burning time of one pyro-element for 6 minutes, 4 minutes after the start of work, the
effects were carried out with the simultaneous burning of three pyro-elements and, when 60 pyro-
elements were charged into the generator, it lasted up to 15 h 31 min. On May 26, 2015, sampling was
performed in three vertical sections, 3, 6, and 9 km away from the NAG-07M installation site (Fig. 4). Sampling was carried out at four heights - 300, 600, 900, and 1200 m.

The vertical sections for sampling the aerosol and the coordinates of the beginning and end of the airplane tracks in each section were determined by the results of numerical simulation. The calculation of the concentration fields of aerosol particles (Fig. 4, particle field 1) was carried out in the control room using the data of ground-based weather observations in Dmitrov taken on the Internet, the data of morning (at 3 o'clock Moscow time) radio sounding in Dolgoprudny and data of aircraft wind sounding, - filled with an airplane before the start of impacts to an altitude of 1500 m with a 100-meter interval along with the level. However, as shown by a comparison of morning data with the data of the radio probe received at 15:00 Moscow time, i.e. almost during the impacts, there was a significant change in wind direction from east to south. This led to a significant change in the direction of transport of reagent particles (see Fig. 4, particle field 2). As can be seen from the figure, with such a transfer, the first vertical section at a distance of 3 km from the generator completely crossed the plume of particles, the second section at a distance of 6 km partially crossed the plume, and the third section at a distance of 9 km was outside the plume of particles. In fig. Figure 5 shows graphs of the results of aircraft measurements and numerical calculations of the concentration of the reagent in the atmosphere, made according to the data of 15-hour sounding. The figure shows that there is a very good agreement between the aircraft data and the results of numerical simulation of the concentration of reagent particles in the first section (Fig. 5a).

In the second section, the coincidence of aircraft data and calculation results is somewhat worse (Fig. 5b). In the third section, lying outside the loop, the concentrations of the reagent particles correspond to the background values (Fig. 5c). As can be seen from (fig.6) which shows diagrams of the concentration and concentration of reagent particles measured and calculated using the SeedDisp model, there is a high degree of correlation of the concentration of silver iodide particles in the first two sections. So, for eight pairs, the correlation coefficient turned out to be equal to 0.73 (Fig. 6a). When two pairs of concentration values obtained for heights of 300 and 600 m in the second section are discarded, the divergence of which may be due to incomplete intersection of the plume by sampling lines, as well as a failure in the ignition of four pyro-elements, the correlation coefficient increases to 0.97 (Fig. 6b).

Finally, the continuous monitoring (real-time data) of the studied parameters is of great importance because it helps to develop effective management plans; hence employment of effective sensing technologies (such as electromagnetic sensors [56-58]) could be studied in the future as a useful monitoring technology.
Fig. 5. The concentration of reagent particles in vertical sections at ranges of 3, 6 and 9 km according to aircraft measurements and numerical simulation results May 26, 2015.
Conclusions

The results of May 26, 2015, at the test site of the Scientific Research Institute of Applied Chemistry, Scientific Research Institute of Applied Chemistry, an experiment on measuring the concentration of silver iodide particles in the atmosphere when exposed to a generator NAG-07M showed that:

1- The concentration of silver iodide recorded in the atmosphere was above background values up to a height of 1200 m at distances from 3 to 9 km from the place of installation of the generator.

2- The developed numerical model “SeedDisp” as a whole qualitatively correctly describes the distribution of aerosols of silver iodide in the boundary layer and free atmosphere when exposed to ground-based aerosol generators NAG-07M. So, the correlation coefficient measured by the aircraft and calculated by the model of the concentration of particles of silver iodide in the cloud layer exceeded the value of 0.7.

3- Fields calculated using the SeedDisp numerical model. Reagent concentrations are highly dependent on wind sounding data. In this regard, for the correct calculation of the transport of reagent particles, it is necessary to use vertical wind profiles, obtained for the territory of the impact.

![Fig. 6. Diagram of measured and calculated values of the concentration of reagent particles in the first and second sections according to the SeedDisp model.](image-url)
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