A methodological approach to assessing the current opportunities for changing the number of clouds in large areas in the interests of solving applied problems

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Abstract. The article presents a methodological approach to assessing the current possibilities for changing the number of clouds on an area of thousands-tens of thousands of km². A method based on the use of means of dissipation supercooled undulatus clouds is considered. Quantitative estimates of the suitability for dissipation of clouds of these forms in various physical and geographical regions of Russia are given. Practical recommendations on the application of methods and means of dissipation supercooled undulatus clouds over large areas are given.

1. Introduction

It is known that clouds play an exceptional role in human life, since they have a serious impact on the radiation and heat regimes of the atmosphere and the underlying surface; they can lead to emergencies of various types and to serious environmental problems due to atmospheric air pollution in the surface layer of the atmosphere, and are also one of the main sources of moisture for humans, animals and plants [1,2].

At the same time, the appearance in recent decades in the world (including Russia) of methods and means of influencing atmospheric processes and phenomena (and, above all, clouds of various shapes and fogs) allows a new approach to the assessment of human life. This is due to the fact that it opens up new prospects in terms of expanding the range of meteorological conditions that can be changed. Based on this, the purpose of this work is to develop a methodological approach to assessing the possibilities for changing the number of clouds in large areas in the interests of solving specific application problems.

2. The structure of the methodological approach and a brief description of its main stages

The methodological approach includes a number of stages.

The content of the first stage of the methodological approach, which includes the justification of the relevance of the research disclosed in the introduction of the article, ends with a note on the appearance in a number of countries (including Russia) of methods and means of influencing atmospheric processes and phenomena.

A detailed analysis of the work in this direction, carried out by the authors in [2–4], indicates that the most realistic to date can be considered the effects on clouds of natural origin. At the same time, it is found that it is advisable to classify clouds of natural origin on the basis of temperature into «warm», supercooled and crystalline, indicating their specific forms, according to the international classification. The results of this study are shown in figure 1.
CLOUDS OF NATURAL ORIGIN

**Warm clouds** - observed at positive air temperatures and consist only of water droplets

{layered (St),
layered-cumulus (Sc),
layered-rain-layered-cumulus (Ns-Sc),
high-cumulus (Ac),
high-layered (As),
cumulus (cumulus flat (Cu hum)),
cumulus medium (Cu med)}

**Supercooled clouds** - observed at negative air temperatures and consist of either supercooled droplets or supercooled droplets and ice particles

{layered (St),
layered-cumulus (Sc),
layered-rain (Ns),
high-cumulus (Ac),
high-layered (As),
layered-rain-layered-cumulus (Ns-Sc),
powerful cumulus (Cu cong),
cumulonimbus (Cb)}

**Crystal clouds** - observed at low air temperatures (below minus 30-400C) and consist mainly of solid phase particles

{cirrus (Ci),
cirrus-cumulus (Cc),
cirrus-layered (Cs),
high-layered (As),
layered-rain (Ns)}

**Figure 1. Classification of clouds by temperature.**

Before proceeding to the analysis of the data shown in figure 1, it is necessary to make two important observations. The first of these concerns the state of the research level for warm, supercooled, and crystalline clouds. It is established that at the present stage, the most serious results have been achieved in the field of exposure to supercooled clouds and fogs [2-4]. This is due to the fact that they realize phase instability due to the presence of ice particles in the clouds, along with supercooled drops. There are very few methods and means of influencing warm and crystalline clouds and fogs in our country [5]. In connection with the above, it can be concluded that the main object of impact in our country should be considered supercooled clouds of various shapes (see figure 1). The results of the above study constitute the second stage of the proposed methodological approach.

The practice of working on the impact on clouds has shown that they can be performed both for the purpose of causing artificial and intensifying natural precipitation, and for the purpose of dissipation and stabilizing cloud cover [2].

At the same time, it is established that a positive result when exposed to supercooled clouds can not always be achieved, but only with a certain combination of their characteristics, which is called the «suitability criterion».

To date, such criteria have been obtained as a result of numerous experiments with supercooled undulatus and layered clouds, as well as with convective clouds (Cu cong). Thus, in particular, supercooled undulatus and layered clouds with a drop-like or mixed structure, an average cloud layer temperature of no more than minus 3°C, and a vertical length of no more than 1000 m are considered suitable for dissipation [6]. Taking into account the data given in the literature on the low values of the suitability for dissipation of frontal layered clouds (Ns, Ns-As, As) due to their large thickness (more than 1000 m) [2,6], it can be concluded that the main object of influence for the purpose of dissipation will be mainly wave-shaped clouds, namely, layered and layered – cumulus clouds, observed mainly in the cold half of the year in the temperate latitudes of Russia.
In favor of this statement, we can cite data indicating that St-Sc clouds are the most common forms of clouds for a number of regions of Russia, single-layer, in most cases in the phase state-drip and mixed, as well as supercooled (especially in the cold half of the year) and have vertical length not exceeding 500-700 m [2,6].

The substantiation of cloud forms as objects of influence in order to disperse them over large areas is the content of the third stage of the methodological approach.

The data on the phase structure, vertical extension and stratification, and average temperature of the cloud layer presented in [2,7] allowed the authors to obtain quantitative estimates of the suitability of St-Sc clouds for the purpose of dissipation them. For example, table 1 shows such estimates by season and half-year over the northern (Arkhangelsk) and north-western (St. Petersburg) regions of the ETR [8].

| Item                  | Season      |       |       |       |       |
|-----------------------|-------------|-------|-------|-------|-------|
|                       | winter      | spring| summer| autumn| cold  | warm  |
| Arkhangelsk           | 93,9        | 75,5  | 12,0  | 57,6  | 84,8  | 29,5  |
| Saint Petersburg      | 86,6        | 70,7  | 6,5   | 37,5  | 70,1  | 31,5  |

From the data presented in table 1, it follows that the most frequently dispersed supercooled undulatus clouds are observed in the months of the cold half-year (70.1% - for the northwestern and 84.8% – for the northern regions of the EPR) with a maximum occurring in winter (86.6% and 93.9%, respectively). In the transition seasons, estimates of the suitability of St-Sc clouds for dissipation are also quite high (especially in spring - 70.7 and 75.5% for the northwestern and northern regions of the ETR, respectively).

The above quantitative estimates of the suitability for dissipation of supercooled undulatus clouds over the northwestern and northern regions of the ETR constitute the content of the fourth stage of the proposed methodological approach.

The next (fifth) stage involves conducting research related to assessing the level of developed methods and means of influencing supercooled undulatus clouds. The authors’ analysis of research in this area [2-4] showed that at the present stage, the most widely used chemical method has found the use of chemical reagents, namely: solid carbon dioxide (CO₂), liquid nitrogen (N₂), silver iodide (AgI). In practice, when conducting work on the dissipation of supercooled undulatus clouds, the use of these reagents is carried out with the help of appropriate generators and installations placed on aircraft, in particular, aircraft of various types, for example, AN-12, AN-26, YAK-42D, etc. [2-4].

The availability of methods and means (chemical, technical) in our country has made it necessary to conduct research on the development of methods for the dissipation of supercooled undulatus clouds.

The analysis of the work carried out in this direction is the content of the 6th stage of the proposed methodological approach.

It is established that at the early stages of work on the dissipation of supercooled undulatus clouds over large areas, the development of methods was mainly reduced to the choice of a seeding scheme. These schemes were seeding with parallel lines in the direction of the wind and against it, as well as according to the scheme of the «unfolding spiral» [9-11].

Later developed methods included not only the choice of the seeding scheme («eight», «snake»), but also the calculation of the operation parameters (calculation of the seeding boundary, the number of seeding lines, reagent consumption, etc.) [12,13].

With the help of these methods, a number of field experiments on cloud dissipation over large areas have been carried out to date, the analysis of which may constitute the content of the seventh stage.
The first full-scale experiment on the dissipation of supercooled undulatus clouds of the lower tier in our country was conducted by the staff of the Institute of Applied Geophysics of the USSR Academy of Sciences on January 11, 1960 in the area of Aktyubinsk [1]. Seeding was carried out in the morning over the city from planes at an inflated dosage of solid carbon dioxide. The result of this seeding was a dissipation zone of 25×45 km (S=1125 km²). After the seeding, cloud dissipation continued. The gap that appeared in the clouds continued to expand during the day and by the evening reached the size of about 150 km in diameter (S≈18000 km²). The cloud dissipation began at 13 o'clock (local time), and the open zone lasted until 1 o'clock the next day, i.e. the area had clear weather for about 12 hours, mainly at night.

The measurements of meteorological values (in particular, the pressure, humidity and temperature of the air, as well as the daily course of the radiation balance) made during the course of the study showed that the difference in pressure between Aktyubinsk and the surrounding stations was 1.2 hPa by 20 o'clock, and the temperature difference was almost 10°C. The radiation balance in Aktyubinsk, at the beginning characteristic of cloudy weather, turned into the radiation balance of clear weather, while near Aktyubinsk, at a distance of 500 km, no frontal sections were observed. Based on the above, it is concluded that the observed deviation of the parameters of meteorological magnitudes in Aktyubinsk was caused by the dissipation of clouds.

In the future, the research results obtained in [14] allowed us to perform a theoretical assessment of the possibility of a significant expansion of the crystallized regions of supercooled cloud arrays under the influence of atmospheric turbulent diffusion. The expansion of the crystallized zones occurs at a distance of 2 to 10 km, and for 1 g of solid carbon dioxide (CO₂) dumped into the cloud, 10¹²-10¹⁴ ice nuclei are formed in it. Calculations show that if an area with a size of 50×50 km is sown with solid carbon dioxide in the amount of 8 tons, then in 10 hours we can expect an expansion of the scattered area to 150×150 km, which is an order of magnitude larger than the originally sown area [14].

Experimental studies of the processes of expansion of crystallized regions and cloud dissipation over large areas were carried out by the Institute of Applied Geophysics during 1961-1965 [1,9,11,15].

The analysis of the experiments made it possible to draw the following conclusions:
- the dissipation areas as a result of seeding with solid carbon dioxide varied from 400-500 km² to 10000-18000 km²;
- to reduce the number of aircraft in order to reduce the number of seeding lines by increasing the distance between them (the crystallization zone), the consumption of solid carbon dioxide was about 3-5 kg per 1 km of the flight path of the aircraft;
- in most cases, a positive effect was achieved with the dissipation of single-layer clouds.

The above analysis of the work on the dissipation of supercooled undulatus clouds indicates that already in the 60s of the XX century in our country there were methods, means and techniques for dissipation this cloud cover over large areas.

Taking into account the previous work carried out in this direction and the analysis of modern technologies for the impact on cloud systems for the protection of megacities by active impact methods [16-19], it is possible and important to develop recommendations for their use for the dissipation of supercooled undulatus clouds over large areas. The results of the research carried out in this direction represent the content of the eighth stage of the developed methodological approach. In general, according to the authors, they should include the following activities:
- development of a comprehensive program of work on large-scale impact on cloud systems in order to assess changes in weather conditions in various regions of Russia under the auspices of Roshydromet;
- conducting research using materials from the TAE-7.7m aeroplane atmospheric sounding to determine the frequency of warm and supercooled undulatus clouds in various physical and geographical regions of our country;
- study of the characteristics of undulatus clouds (stratification, phase structure, temperature and geometric characteristics, water content and water reserve) in relation to the problem of
exposure to the dissipation of supercooled undulatus clouds over large areas in various regions of Russia;

- obtaining quantitative characteristics of the suitability for dissipation of supercooled undulatus clouds over various regions of Russia using various types of meteorological data (data from ground observations, materials from aircraft sounding of the atmosphere, radar data);

- conducting a comprehensive analysis of the results of field experiments and works carried out in the period from 1986 to the present time on changes in weather conditions over large cities both in Russia and in different countries in order to determine the prospects for the use of modern technologies for influencing cloud systems and develop practical recommendations for their use. In experiments carried out in the 60-years of the XX century, the number of aircraft used in the work did not exceed 2-3. In modern conditions, the impact on atmospheric processes (in particular, on cloud systems) can be carried out with the help of 7-10 specially equipped aircraft such as AN-12, AN-26, AN-30, YAK-42D, etc. [3,4,16-20];

- determining the list of applied tasks in the interests of various Ministries and departments that are solved during the dissipation of cloud cover, changes in the precipitation regime (weakening, intensification, causing, stopping precipitation, redistribution of precipitation), as well as the stabilization of cloud cover of various forms in a specific physical and geographical area of our country;

- assessment of the environmental consequences of large-scale work on cloud systems in various physical and geographical regions of Russia;

- objective justification of the most rational schemes for seeding clouds of various forms, methods for calculating the parameters of impact measures and reagent consumption rates during large-scale work in a specific physical and geographical area of the country;

- evaluation of the possibilities of using aerospace means of remote sensing of the Earth to determine the characteristics of clouds of various forms in relation to the problem of large-scale impact on them and monitoring the results of such work;

- evaluation of the possibility of using various technical means of different Ministries and departments of the country for the delivery of chemical reagents for large-scale cloud seeding in the interests of solving specific applications.

The above recommendations can be used in the planning, preparation and implementation of measures for the impact not only on supercooled undulatus clouds, but also on clouds of other forms (in particular, layered clouds) in order to solve a wide range of applied tasks (providing cultural events in large cities, cleaning the air basin of megacities, ensuring the smooth operation of large airports, conducting search and rescue operations and astronomical observations, etc.).

Taking into account the latest achievements in the development of methods and means of influencing atmospheric conditions in order to create artificial atmospheric cloud formations, it is interesting to conduct studies to assess the possibilities of changing the number of clouds not only by dissipation supercooled undulatus clouds, but also by creating artificial clouds (in particular, artificial cirrus crystal clouds) of certain shapes over a large area. Conducting this kind of research is the subject of our further work in this area.

3. Conclusion

- Based on the analysis of the reasons that determine the relevance and significance of the study of clouds in life support, the need to assess the current possibilities for changing the number of clouds by dissipation supercooled undulatus clouds over large areas is justified.

- A methodological approach to assessing the possibilities of changing the number of clouds over large areas by dissipation supercooled undulatus clouds is developed and a brief description of its stages is given.

- Practical recommendations on the application of methods and means of dissipation supercooled undulatus clouds over large areas have been developed, and a list of applied problems that can be solved with this type of impact has been noted.
It is shown that it is necessary to conduct research to assess the possibility of changing the number of clouds over large areas by creating artificial atmospheric formations of certain shapes (in particular, artificial cirrus crystal clouds).

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