Development of an indicator of the effectiveness of cloud scattering in ensuring favorable weather conditions for conducting socially significant events involving aviation

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Abstract. A new approach to evaluating the effectiveness of active impacts on layered cloud cover using aircraft is proposed. As an indicator of efficiency, it is proposed to use the probability of achieving the goal of active impacts on the clouds. The use of the proposed indicator will make it possible to predict the effectiveness of impacts up to the moment of their implementation.

1. Introduction

Clouds, from the point of view of aviation, are objects of natural origin that negatively affect flight safety due to the deterioration of the orientation of the crew of the aircraft in space and the presence of such dangerous phenomena as bumpiness and icing. Therefore, flying in the clouds requires high training and skill from the crews of aircraft, especially when performing group flights. Flights of aircraft involved in the aerial part of socially significant events take place at low altitudes (150-500 m). At the same time, according to the provisions of the FAP [1], the height of the lower cloud boundary should exceed the flight altitude of the aircraft by 100 m. Thus, from the point of view of flight safety during the air part of the events, the height of the lower border of the cloud cover is more than 600 m. An additional condition limiting the use of aircraft is the absence of precipitation. In some cases, under unfavorable meteorological conditions, it is possible to artificially prevent precipitation and increase the height of the lower cloud boundary over the area of flight of aircraft by using aircraft or ground-based means of active cloud impacts.

In this situation, the flight manager needs to assess the effectiveness of active effects on cloud cover before carrying out the work to determine the possibility of establishing favorable meteorological conditions for the passage of aircraft.

A feature of the modern methodology for evaluating the effectiveness of active impacts on clouds is to obtain numerical values of the efficiency indicator after the work is carried out. These are the methods of relations and historical regression [2]. They are used to assess the effectiveness of work to reduce damage to agriculture, protect forests from fires, and improve weather conditions in megacities. However, in order to make a decision to carry out work on active impacts on clouds, it is necessary to be able to assess the expected effectiveness of impacts, i.e. to predict its values depending on the external situation. This article is devoted to the solution of this problem.
2. Methodology for developing an indicator of the effectiveness of active impacts on clouds

Evaluating the effectiveness of targeted processes, which can also include active impacts on clouds, is a task traditionally solved at the A.F. Mozhaysky Military-Space Academy using mathematical and methodological tools of the theory of the effectiveness of targeted processes [3].

Within the framework of the theory of the effectiveness of targeted processes, the indicator of the effectiveness of the operation of active actions on clouds is represented by the probability \( P_{AB} \) of the event «the cessation of precipitation and the increase in the height of the lower border of clouds above the minimum permissible height».

Since the main source of clouds with a lower boundary height of less than 600 m and precipitation in different seasons of the year are mainly layered clouds, the approach to developing an AB efficiency indicator for this type of cloud will be described later in this article.

In the works on the theory of efficiency [3,4], it is noted that the indicator \( P_{AB} \) should be presented as follows:

\[
P_{AB} = P(\hat{Y}_{c_{sb}} \sqcap \hat{Z}_{c_{sb}}) = P[(\hat{Y}_1 \geq \hat{z}_1) \cap (\hat{Y}_2 \leq \hat{z}_2) \cap (\hat{Y}_3 \leq \hat{z}_3)],
\]

where \( \hat{Y}_{c_{sb}} =< \hat{y}_1, \hat{y}_2, \hat{y}_3 > \) – an indicator of the virtual quality of the operation for active impacts; \( \hat{y}_1 \) - an indicator of the effectiveness of active impacts, which characterizes the degree of achievement of the target effect; \( \hat{y}_2 \) - an indicator of the resource intensity of active impacts, which is characterized by the consumption of all types of resources required for the operation and obtaining the target effect \( \hat{y}_1 \); \( \hat{y}_3 \) - an indicator of efficiency, which characterizes the duration of active impacts on layered clouds; \( \hat{Z}_{c_{sb}} =< \hat{z}_1, \hat{z}_2, \hat{z}_3 > \) - an indicator of the required quality of the operation for active impacts; \( \hat{z}_1, \hat{z}_2, \hat{z}_3 \) - the corresponding threshold values of indicators \( \hat{y}_i, i = 1(1)3 \), when the values of which are reached, the goal of active effects on layered cloud cover is considered to have been achieved.

Since the operation on active influences is carried out in the external environment, the quality of its implementation is influenced by external conditions. This is expressed as follows:

\[
Y_{c_{sb}} = Y_{c_{sb}} (A_{c_{sb}}, B_{c_{sb}}),
\]

\[
Z_{c_{sb}} = Z_{c_{sb}} (B_{c_{sb}}),
\]

where \( A_{c_{sb}} \) – parameters of the system performing active impacts and characteristics of the organization of the operation for active impacts; \( B_{c_{sb}} \) – characteristics of the operating conditions of the system (phase composition of clouds, air temperature in the cloud layer, vertical power of the seeded cloud layer, the height of the lower cloud boundary, etc.); \( B_{c_{sb}} \) – characteristics of the system application conditions (the presence of unfavorable meteorological conditions for flights of the type of aircraft used for active impacts, malfunction of technical means at the active impact control point, etc.).

To use the approach to evaluating the effectiveness of the operation, represented by the expression (1), it is necessary to determine the indicators \( \hat{y}_i, i = 1(1)3 \) and \( \hat{z}_i, i = 1(1)3 \).

Based on the content of the operation on active impacts on layered clouds using aviation (figure 1), as well as taking into account the selection \( \hat{y}_1 \) recommendations set out in [3], it is proposed to take
the relative number of flights \( \hat{N} \) of the laboratory aircraft between points C and D on the Earth's surface as an indicator of performance \( \hat{y}_1 \).

Figure 1. Diagram of active effects on layered clouds.

Then the target effect \( \hat{N} \) can be represented by the expression (2):

\[
\nu = \frac{n}{N}
\]

where \( n \) and \( N \) are the actual and planned number of flights of the laboratory aircraft between points C and D, carried out during the operation on active influences.

The duration of the effects \( \hat{y}_3 \) is assumed to be equal \( \hat{r}_3 \). It includes the flight time to and from the impact area, as well as the time of the impact on the clouds.

Let's assume that all available resources are consumed in the process of active actions \( \hat{y}_2 \). This assumption does not contradict reality and serves to simplify the output of the resulting solution. In this case, when modeling, the resource consumption is assumed to be equal to the maximum allowable \( \hat{y}_2 = \hat{r}_2 \), i.e., there is an «absorption effect» [3].

Then the performance indicator \( P_{\omega} \) will be defined by the following expression:

\[
P_{\omega} = P[(\hat{N} \geq \hat{z}_1) \cap (\hat{r} \leq \hat{z}_1)]. \tag{4}
\]

Expression (4) determines the probability of obtaining the target effect above a certain threshold value \( \hat{z}_1 \) with the operational time spent less than the specified one \( \hat{z}_2 \).

With known laws of distribution of random vectors \( \hat{y}_1 \) and \( \hat{z}_2 \), expression (4) will take the following form:

\[
P_{\omega} = P[(\hat{N} \geq \hat{z}_1) \cap (\hat{r} \leq \hat{z}_1)] = \int_{\mathbb{R}} \int_{\mathbb{R}} \Phi_{\hat{N},\hat{r}}(z_1, z_2) dF_{\hat{y}_1,\hat{y}_2}(z_1, z_2), \tag{5}
\]

where \( \Phi_{\hat{N},\hat{r}}(z_1, z_2) \) is a function describing the law of joint distribution of indicators \( \hat{N} \) and \( \hat{r} \); \( F_{\hat{y}_1,\hat{y}_2}(z_1, z_2) \) is a function describing the law of joint distribution of indicators \( z_1 \) and \( z_2 \).
3. Development of an algorithm for modeling the efficiency indicator of active impacts on layered clouds

To obtain an efficiency estimate, it is necessary to implement expression (5). In [3] it is noted that this can be done by one of four methods: analytical, numerical, statistical tests, and statistical simulation.

The implementation of the first three methods is associated with difficulties, which consist in the need to have knowledge of the explicit expression of integrand functions (5). Therefore, in this article, it is proposed to use the method of statistical simulation to obtain an estimate.

The block diagram of the algorithm of the statistical simulation method applied to the evaluation of the effectiveness of active actions is shown in figure 2.

![Figure 2. Block diagram of the algorithm of the method of statistical simulation of the indicator of the effectiveness of active impacts on layered cloud cover.](image-url)

In the flowchart shown in figure 2, the contents of the blocks are intuitive, with the exception of blocks 3 and 5. Their contents are explained separately.

Block 3 of the algorithm models the vector \( \hat{Z}_{\langle 2 \rangle} \). The components of the vector \( B_{\langle 2 \rangle} \) have a pronounced organizational and situational origin, the modeling of its components should be carried out according to the algorithm, the block diagram of which is shown in figure 3.
To obtain estimates \( \hat{Z}_m \) using the proposed algorithm, it is necessary to have information about the distribution law \( F_{x_{m i}}(B^*>_{1i}) \), as well as about the dependencies between \( \hat{Z}_m \) and \( B^*_{1i} \).

The type \( F_{x_{m i}}(B^*>_{1i}) \) is determined either by the expert survey method or by the available archival observations using the construction of statistical distribution functions [5]. For the one-dimensional case \( F_{x_{i}}(b^*) \), it has the following form:

\[
F_{x_i}(b^*) = F_{x_i}(b^*, n) = \rho^*(\hat{b}^* < b^*) = \sum_{k=1}^{n} \rho^*(\hat{b}^* = b^*)
\]

then

\[
F_{x_i}(b^*) = \frac{1}{n} \sum_{j=1}^{n} \Delta(b^* - b^*) = \begin{cases} 
0 & \text{при } b^* \leq b^*_{1} \\
\frac{m}{n} & \text{при } b^*_{1} \leq b^* \leq b^*_{2} \\
\ldots & \\
\frac{1}{m} \sum_{j=1}^{m} & \text{при } b^*_{k} \leq b^* \leq b^*_{k+1} \\
\ldots & \\
1 & \text{при } b^* > b^*_{n}
\end{cases}
\]

where \( F_{x_i}(b^*) \) is the statistical distribution function.

Regression dependencies can be used as the dependencies shown in figure 3 in Block 3.2. For example, an indicator of the required quality \( z_i \) can be presented analytically using a logistic regression of the following form:

\[
z_i = \frac{e^{b^* A_i}}{1 + e^{b^* A_i}}
\]
where \( B^* = b^*_1, b^*_2, ..., b^*_n \) is the vector of predictors; \( A = a_1, a_2, ..., a_n \) is the vector of parameters.

An indicator of the required quality \( z_j \) can be represented analytically using a multiple linear regression of the form (8):

\[
z_j = B^{*T} A.
\]  (8)

Block 5 of the algorithm shown in Figure 1 models the vector \( \hat{Y}_{z2} \). The simulation of its components should be carried out according to the algorithm, the block diagram of which is shown in Figure 4.

Figure 4. Block diagram of the algorithm for calculating the components of the vector of virtual results.

To obtain estimates of the characteristics of the conditions \( \hat{B}^{*T} \) and indicators of the virtual quality \( \hat{Y}_{z2} \) of the operation results, use expressions (6) – (7).

In block 13 of the algorithm shown in Figure 1, the estimate \( P_{AB} \) is calculated as the arithmetic mean of the frequencies \( f_{j1} \) of the occurrence of an event corresponding to a favorable outcome of the operation for active effects on layered cloud cover.

4. Conclusion
The analysis of the tasks currently being solved in various sectors of economic activity with the help of active impacts on the clouds using aircraft, allows us to talk about the importance of further development of this area. At the same time, the implementation of measures for active impacts is associated with a large expenditure of resources of various nature: financial, technical, human, etc. Therefore, when planning activities for active impacts, the organizers need a mathematical apparatus that allows them to calculate the expected effectiveness of the impacts. The efficiency indicator proposed in the article is developed using the apparatus of the efficiency theory and has a probabilistic character, i.e. it allows you to estimate the probability of achieving the goal of the operation by active influences. Knowing the decision threshold, the person responsible for planning and carrying out work
on active impacts, after calculating $P_{AB}$, will be able to make a reasonable decision about the expediency of impacts in different conditions $\hat{B}_{ij}$. The article was prepared with the support of the Russian Science Foundation grant No. 21-19-00378.

Reference

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