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Methodological issues of improving the system of meteorological support of aviation for agricultural purposes

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Abstract. The direction of the agro-industrial complex development is considered through the use of agricultural aviation and unmanned aerial vehicles, in particular, the issues of integrated application of methods for meteorological conditions forecasting for solving problems of meteorological support for agricultural aviation are considered. The analysis of the impact of climate change on the development of dangerous weather events and complex weather conditions in areas located in different geographical zones was carried out, and their regional specificity was revealed. The identified climatic features of the considered areas indicate the priority importance of developing a regional observation network. It is assumed that the development and technical modernization of the meteorological network will significantly increase the efficiency of meteorological support for the agro-industrial complex. The article also discusses the use of various types of meteorological information in the model of regional meteorological support for aircraft flights in agricultural areas proposed by the authors. The model is based on a systematic approach in which the "crew - aircraft" system is considered as a single dynamic system that is continuously influenced by changing environmental factors.

1 Introduction

The use of small aircraft and unmanned aerial vehicles (UAVs) in the agro-industrial complex (AIC) is a promising direction of development from a technological point of view, since it has a number of advantages over traditional methods of agricultural work [1]. Aircrafts are a reliable, operational and efficient mode of transport for agricultural operations, especially in mountainous areas.

Practical use of aircraft in agriculture has shown a number of advantages of above-ground vehicles: its high productivity (processing of large cultivated areas in less time, low labor costs, economical use of seed and chemical spray substances), the ability to work in remote areas (mountainous, swampy fields, etc.), visual observation of crops conditions and rapid response in the case of a critical situation (the massive defeat by harmful bacteria,

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insects, rodents etc.) elimination of consequences of natural disasters, which caused partial death of plants (rotting-out, wilting, etc.).

However, the use of agricultural aviation and UAVs is limited to adverse weather conditions and dangerous weather events, which is a significant problem if it is necessary to immediately, promptly perform a certain type of agricultural work.

The solution to this problem is to improve the meteorological support systems for agricultural aviation and UAV flights, as well as their joint application with forecasting systems in agrometeorological support for agriculture. The priority task in the work of agricultural aviation is to ensure the flight safety, which is indicated in the documents regulating flights in our country.

The safety of the entire air transport system as a whole depends on the efficiency of all its subsystems, including air traffic control systems, "crew-aircraft" system, "operator-UAV" system, and the information support system [2].

Meteorological support refers to information support systems. Meteorological information is taken into account at the stages of aircraft flight planning, when preparing and directly performing en-route flights. Information about the physical state of the atmosphere is also analyzed by air traffic control systems.

Meteorological information must ensure that the flight is completed, starting from take-off and flight along the specified route and ending with the landing of the aircraft at the destination. First of all, it is necessary to assess the probability of meteorological conditions formation that can lead to complication of aircraft flights, for example, due to reduced visibility, icing or bumpiness caused by atmospheric turbulence [3, 4].

With the increasing intensity of the use of agricultural aircraft and UAVs in the agro-industrial complex, the role of meteorological support increases.

A modern analysis of the problematic situation in the field of meteorological support for aircraft flights revealed the following shortcomings:

- difficulties in forecasting dangerous weather events in areas of airfields and agricultural work areas located in remote and hard-to-reach regions;

– certain climate changes occur in different geographical regions, which are associated with changes in the development and frequency of dangerous weather events;

- insufficient development of the network of meteorological observations in most of the territory of the Russian Federation (RF).

Current research is aimed at improving the level of flight safety in meteorological terms, which include scientific and methodological research of the authors aimed at improving automated systems for meteorological support of aircraft flights and air traffic planning stages, taking into account the specifics of the formation of dangerous phenomena for aviation and difficult weather conditions in various geographical regions of the Russian Federation and taking into account information received from modern means of atmospheric parameters observation.

As part of the research, the authors solved the following tasks:

- assessment of the current state of meteorological support for aircraft flights and its compliance with the requirements of regulatory documents, promising areas for the development of flights meteorological support;

- identification of regional features of the development of dangerous weather events for aviation;

- development of methodological bases for creating a model of regional meteorological support for aircraft flights that would meet modern requirements for the information provided.

2 Regional features of the development of dangerous weather events and complex meteorological conditions in the areas of aviation agricultural work

Adverse weather conditions often cause delays in flights of aircrafts and UAVs, thereby reducing the economic efficiency and feasibility of using air transport in the agro-industrial complex. The safety and economy of flights also largely depend on the meteorological conditions of their performance [2]. It is mainly meteorological conditions that create the concept of "flights in special conditions", which include the following: flights in ice accumulation areas, thunderstorm activity and heavy rainfall, strong turbulence, increased electrical activity of the atmosphere, wind shear, dust (sand) storms, snowstorms, etc.

The authors analyzed the impact of climate change on the development of dangerous weather events and complex weather conditions at Russian airports located in various geographical regions, such as Central Siberia, Far East, and Asian region, and identified their regional specifics.

For example, the geographical location determines the specific annual and seasonal course of meteorological elements, the formation of special (dangerous) conditions for flights of aircrafts and UAVs in the area of agricultural work performance.

In the Southern regions of the Russian Federation, where a large number of agricultural enterprises are located, there is a high frequency of convection processes in the atmosphere, and associated thunderstorm activity, precipitation in the form of showers, hail, wind strengthening to storm values, etc.

In the flight area of the Krasnoyarsk airport (Yemelyanovo) in recent years, there has been an increase in precipitation.

The area of the airfield in the city of Saint Petersburg is characterized by a high frequency of thunderstorms.

The identified climatic features of the considered areas located in different geographical zones indicate the priority importance of developing the regional observation network.

3 Justification of requirements for special observation systems of airfield areas

Despite the measures taken for the technical re-equipment of the branches of the FSBI Aviamettelecom Roshydromet, there are a number of shortcomings in the meteorological support of aircraft flights, associated with a shortage of observation data on atmospheric parameters.

The modern network of meteorological observation stations is quite rare and does not always meet the requirements of the world meteorological organization and the International Civil Aviation Organization for the composition of technical means for obtaining data on the state of the atmosphere, the accuracy of the information provided and its spatial resolution. To detect mesoscale meteorological processes and phenomena in the area of the airfield location, the distance between observation points should be 1-6 km. These requirements are due to the development of mesoscale and local atmospheric processes, including zones of active convection, which are associated with dangerous weather phenomena.

For further development of research on the implementation of the hydrodynamic method of local weather forecasting, there is a need to organize a meteorological polygon covering an area of 100x100 km with the inclusion of dozens of weather stations and other specialized (non-standard) observation systems. Especially important is the ability to conduct an objective analysis of meteorological data in mesoscale grid nodes with a step of about 5-10 km.

Experiments have shown that due to the high temporal and spatial variability of dangerous weather phenomena for aviation, using a mesoscale hydrodynamic model of the atmosphere, it is possible to successfully predict the time of occurrence of thunderstorms and their intensity, and when determining their location, errors of ten or more kilometers often occur, which can lead to aircraft entering difficult conditions and pose a threat to flight safety [6, 7].

Errors in determining the location of thunderstorms, the complexity of solving problems of ultra-short-term forecasting and nowcasting of dangerous weather phenomena for aircraft flights are associated with insufficient accuracy of the initial fields of meteorological elements entering the model based on data from the existing observation network. These are mainly ground-based measurements that are carried out in standard synoptic terms – every 3 hours, and data from atmosphere upper-air sounding, which is carried out every 12 hours. This composition of the meteorological observation network makes it possible to detect atmospheric disturbances of the synoptic and α-mesoscale scales. Special observation systems are needed to detect disturbances of the β- and γ-mesoscales.

Therefore, for regional meteorological support of aircraft flights, the meteorological observation network should provide continuous monitoring of atmospheric parameters, especially the state of its boundary layer, as well as identification of weather phenomena dangerous to aviation with a spatial resolution of several kilometers. Since the vertical distribution of meteorological elements affects the formation of atmospheric processes and related phenomena that complicate the performance of aircraft flights, as well as directly affects the take-off and landing characteristics of aircraft, reliable information about the vertical profiles of meteorological quantities will allow to more accurately assess the possibility of forming atmospheric phenomena that complicate the performance of aircraft take-off and landing, thereby increasing their safety and regularity.

Thus, the controlled parameters should include the following:

1)vertical profiles of temperature, humidity, and wind;

2)changes of thermal stability of the atmosphere and other thermodynamic characteristics of the boundary layer in time;

3)mesoscale characteristics of low cloud cover, fog, mesoflows, squall lines, heavy precipitation, thunderstorms, hail, etc. (with time scales from ten minutes to several hours).

The requirements for horizontal resolution of observational data are determined by the spatial scales that are reproduced on models. Regional atmospheric models provide fields of meteorological elements with a resolution from 10 to 2 km. To get detailed information in the area of the airfield based on the regional model, initial data with a resolution of 10 km or higher is required.

Requirements for vertical resolution are determined by the nature of changes in horizontal gradients of atmospheric parameters along the vertical. Therefore, for regional models, observations with a vertical resolution of 100 m are required, and for the boundary layer, they must have a higher resolution - up to 50 m [2].

The required time resolution of observational data is determined by the ability of modern four-dimensional data assimilation schemes in hydrodynamic atmospheric models (HDAM) to assimilate observational data with a resolution of one hour.

Requirements for equipping airfields with special observation systems are related to the development of dangerous conditions in the area of the airfield.

Thus, the Northern regions of the Russian Federation are insufficiently covered by meteorological observations and are characterized by special climatic conditions. It is assumed that satellite information (MSU, ICFS-2, MTVZA-GYa) of the polar-orbiting space vehicles Meteor-M, as well as the Arktika-M and Electro-L No. 3 planned for launch, can significantly supplement data on the meteorological situation.

The area of the airfield in the city of Saint Petersburg is characterized by the highest frequency of thunderstorms in comparison with the other regions considered. Therefore, this area needs the largest composition of measuring equipment for timely registration of the development of thunderstorm activity: DMRL-S, lidars, profilometers. The greatest contribution to improving the meteorological support of the North-West region can be made by MMW radiometers, which, in combination with data from Doppler weather radars, will allow to fully obtain the necessary up-to-date information for monitoring dangerous weather events for flight operations.

It should be noted that when providing aircraft flights to cover the meteorological situation in various remote regions of the country, the role of satellite observation systems and the development of automated data acquisition systems for heterogeneous observations increases.

Studies conducted to assess the advantages of using joint observations with high spatial and temporal resolution (ground-based, radar, radiometric and satellite) and the organization of appropriate systems for processing and assimilation of information confirm the possibility of identifying meso disturbances of all scales on their basis and predicting their evolution on the basis of mesoscale hydrodynamic models of the atmosphere and synoptic and climatic methods for their results interpretation.

It is assumed that the development and technical modernization of the meteorological network will significantly increase the efficiency of meteorological support.

4 Methodological possibilities for improving the efficiency of meteorological support for aircraft flights of agricultural purpose

Currently, the most promising areas of development of meteorological support for agricultural aviation are research and development of nowcasting systems for aviation and analysis of the use of numerical weather forecasts in the practice of aviation forecasting.

It is necessary to take into account the fact that the quality of the forecast information provided, including on dangerous weather phenomena for aviation, also depends on the completeness and reliability of the actual data of atmospheric parameters observation.

To solve the identified problems related to the lack of meteorological data over various, especially remote, geographical areas of the Russian Federation, the authors proposed a model of regional meteorological support for aircraft flights (MSAF) for airfields and agricultural areas, taking into account the developed requirements for the development of observation network. The model is based on a systematic approach in which the "crew - aircraft" system is considered as a single dynamic system that is continuously influenced by changing environmental factors.

The proposed model of regional MSAF is a synthesis of methods to predict weather events threatening to aircraft flights, taking into account regional peculiarities of their development method, integrated use of operational data on atmospheric parameters coming from direct and remote means of obtaining weather information.

A block diagram of the regional MSAF model for the airfield areas is shown in figure 1.

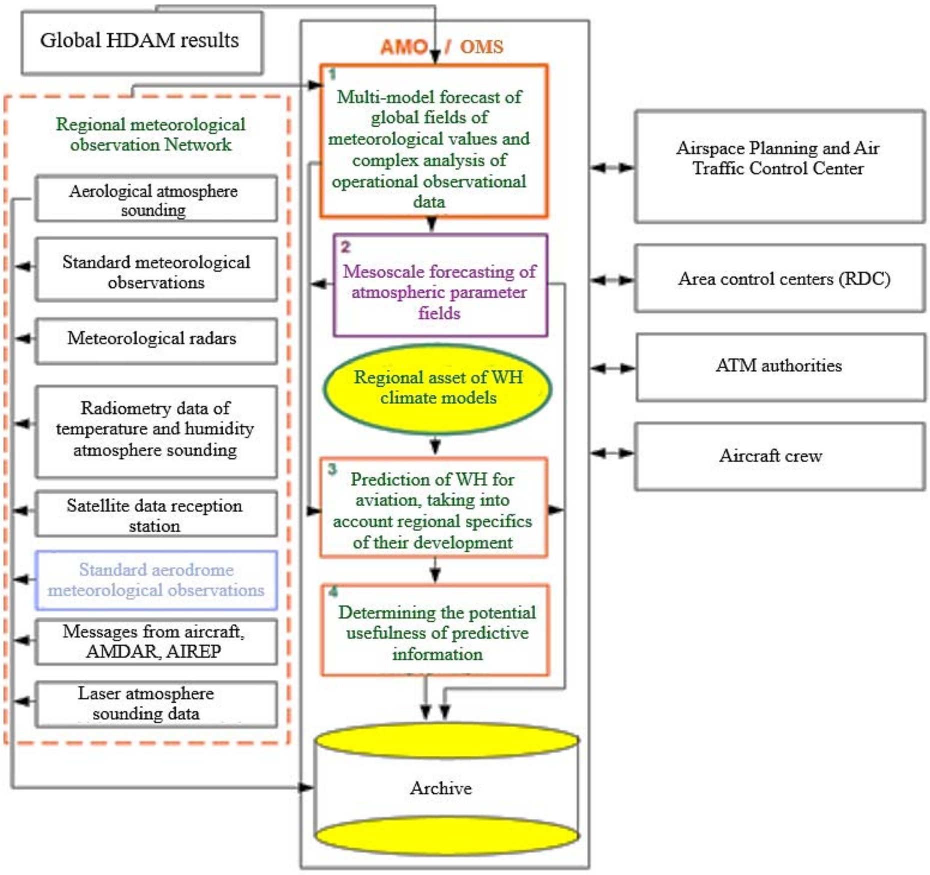

Fig. 1. Structural scheme of the model of regional MSAF for different purpose airfields.

The methods of forecasting WH for aviation, taking into account regional features of their development, are based on the adaptive method of multi-model forecasting of the atmospheric pressure field and synoptic-statistical schemes for probabilistic forecasting of the total number of clouds, supplemented by models for probabilistic forecasting of weather phenomena dangerous for aircraft flights [8, 9].

The adaptive method of multi-model forecasting of the atmospheric pressure field involves combining the results of various HDAM forecasting.

The main differences between the existing methods of aggregation are schemes for obtaining model weights and schemes for bias elimination. Some methods use different weights, while others use equal model weights. In the first case, the weight coefficients are calculated using linear regression analysis or using the least squares method, which provides positive values of the weight coefficients and a total weight of 1. For bias correction, some methods exclude it by replacing the values reproduced by the model with those observed, while others do not include any bias correction. There is an approach that eliminates bias by using the frequency mapping method.

The developed method for combining forecast results is based on a model for estimating mathematical expectations of meteorological parameters in the class of linear functions for non-uniform forecasts for each point of a given grid area using several HDAM [9]. The contribution of each method to the resulting forecast is determined based on statistics of forecasting errors and the possibility of implementation.

To obtain predictive information about the WH and adverse meteorological conditions for aviation, the authors propose to use the methods of synoptic climatology in automated systems for statistical interpretation of the output of forecasting HDAM. At the same time, it seems appropriate to combine models of physical and statistical forecasting of weather elements with synoptic interpretation of the HDAM output [8]. The authors propose to use all available data from the results of hydrodynamic forecasting to determine the type of synoptic situation, and then apply the synoptic-statistical models developed by the authors for probabilistic forecasting of WH based on the pressure field interpretation.

At the same time, for each region, the boundaries of homogeneous synoptic and climatic regions should be clarified and statistical relationships between the type of synoptic situation and weather phenomena dangerous to aviation should be made, taking into account the peculiarities of their formation.

To define the initial data in mesoscale HDAM, it is proposed to use the developed method of integrated use of all available meteorological data obtained from various observation systems. At the same time, a number of tasks arise to justify the optimal placement of measurement systems and configure systems for assimilation of data from heterogeneous observations, including information from modern ground-based and satellite means of atmospheric sounding [9].

In MSAF a model developed by authors for evaluation of the potential usefulness of forecasting methods is implemented in air traffic planning, a detailed schedule of flight and aerial agricultural work, based on the indicators used to assess the potential usefulness of weather and economic decisions. In the form (1)

$$\lambda_{\text{п}} = \frac{\overline{U_{\text{п}}} - \overline{U_{\text{кл}}}}{\overline{U_{\text{кл}}}}, \tag{1}$$

where $\overline{U_{\text{п}}}$ - the average value (statistically) of the utility function when using alternative probabilistic WH forecasts (for example, cloud gradation); $\overline{U_{\text{кл}}}$ - the average value of the utility function when using climate information. The values $\overline{U_{\text{п}}}$ and $\overline{U_{\text{кл}}}$ were evaluated based on the Bayes-Laplace decision making criterion.

For the conditions of two decision-making options (to perform or not to perform a flight) and two gradations (phases) of the number of clouds (0 - 6 and 7 – 10 points), the following expressions are obtained for the average utility values of alternative probabilistic cloud forecasts and climate forecasts:

$$\overline{U_{\text{п}j}} = \sum_{r=1}^{2}\sum_{j=1}^{2} u\left[\Phi_{\langle r\rangle}, d^*\left(\Pi_j\right)\right] P\left(\Phi_{\langle r\rangle}, \Pi_j\right), \quad j = 1, \ 2, \tag{2}$$

$$\overline{U}_{\text{кл}j} = \sum_{r=1}^{2} u\left(\Phi_{\langle r\rangle}, d_j\right) P^*\left(\Phi_{\langle r\rangle}\right), \quad j = 1, \ 2. \tag{3}$$

where Π_j - forecast formulation (*j*=1 - predicted probability of gradation of 0 - 6 points, *j*=2 - gradation of 7-10 points); $d^*\left(\Pi_j\right)$ - the option of making decisions on whether or not to perform a flight when formulating a forecast Π_j; $u\left[\Phi_{\langle r\rangle}, d^*\left(\Pi_j\right)\right]$ - elements of the utility matrix; $P\left(\Phi_{\langle r\rangle}, \Pi_j\right)$ - the joint probability of events $\Pi = \Pi_j$ and $\Phi = \Phi_{\langle r\rangle}$); $P^*\left(\Phi_{\langle r\rangle}\right)$ - empirical probabilities (frequency of occurrence) of gradations of the number of clouds.

The obtained expressions are applicable for evaluating the usefulness of forecasts of other meteorological conditions and weather phenomena.

In the problem being solved, the utility function is considered from two sides. On the one hand, it can be considered as an acquired utility, characterized by the value of noncanceled flights, in the presence of favorable meteorological conditions, if decisions are made to perform en-route flight. In this case, we denote the value of the utility function as $\delta S_p = \frac{S_{обс}}{S_p}$ ($S_{обс}$ - number of completed flights, S_p - planned number of flights). On the other hand, the value of the utility function can be considered as a function of the damage (loss) incurred by the air transport system when making an erroneous decision to perform a flight in the event of adverse meteorological conditions in the observation area. In this situation, the value of the utility function is considered as a loss of utility (- δS_p).

The results obtained on the basis of each method implemented in the regional MSAF model of the aircraft are entered in the database of information archives and transmitted to the aircraft crews, ATM authorities, airport administrations and other bodies related to aviation at airfields, ACC, the center for planning the use of airspace and air traffic regulation.

5 Conclusion

When organizing meteorological support for agricultural aviation and UAV flights, it is necessary to take into account the peculiarities of the development of dangerous phenomena and complex meteorological conditions and the effectiveness of using various means of meteorological observations in different regions.

The authors substantiate the requirements for the development of regional meteorological networks using modern means of contact and remote measurements of the state of the atmosphere based on the results of the analysis of regional climatic and physical-geographical (orographic) features of the formation of phenomena that are dangerous for aircraft flights or complicate them, and propose a model of regional meteorological support for aircraft flights in agricultural areas located in different geographical regions.

Promising areas of research are related to the development of probabilistic models for predicting dangerous weather events based on the integrated application of forecasting methods, the improvement of modern technologies for mesoscale hydrodynamic forecasting, the development of schemes for assimilating heterogeneous ground and satellite information in numerical forecasting schemes, and the development of network methods and tools for meteorological atmosphere observations.

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