Aircraft icing nowcasting technique

V V Zuev¹, D P Mordus¹², and A V Pavlinskii¹

¹Institute of Monitoring of Climatic and Ecological Systems of the Siberian Branch of the Russian Academy of Sciences, Tomsk, Russia
²Corresponding author, e-mail to: Dariymordus@gmail.com

Abstract. Flight safety depends on a number of meteorological factors, including icing. Forecasting of aircraft icing implies taking into account only the meteorological conditions; therefore, "icing possibility" is forecasted. The next step in forecasting techniques is a technology of predicting the current state of weather — nowcasting. This technology requires continuous input measurement data with small time steps. These requirements can be met by using atmosphere remote sensing. A new methodology is proposed for detecting possible aircraft icing areas, which is based on remote measurement of air temperature profiles in the lower kilometer layer and the total vapor content of the atmosphere. The total vapor content is measured using an RMS-1 radiometric system. The data series of air temperature profiles and the total vapor content of the atmosphere in the area of St. Petersburg airport (Pulkovo) are analyzed for the period from November 2018 to March 2020. The distribution patterns for temperature and total vapor content typical for the onset of icing are determined.

1. Introduction
The safety of flights depends on a number of meteorological factors, one of which is icing. Airplane icing in flight is an internationally recognized safety problem. According to the 20-year worldwide statistics of aviation accidents, about 3% of all accidents were identified as related to icing; including two accidents with airplanes and three with helicopters in Russia. Ice accumulation causes deterioration of aerodynamic characteristics, loss of lift, and engine surges [1, 2].

By now, a lot of works have been dedicated to the physics of icing formation, being the basis for icing forecasting and preventing methods [3-6]. However, icing forecasting implies only taking into account the meteorological conditions, therefore providing “possible” icing forecast. Practically significant are forecasts obtained on the basis of numerical models, whose accuracy significantly increased, and the results are used for making forecast maps of significant weather phenomena [7]. The validity period for these forecasts varies from 6 to 12 hours; while the time scales of changes in the meteorological conditions leading to icing are often minutes or tens of minutes. Therefore, the prediction of icing requires new technologies for forecasting the current weather state, known as nowcasting. This technology, in turn, requires continuous input measurement data with a minimum time step. These requirements can be met using remote sensing of the atmosphere, which is directly related to nowcasting (see, for example, [8]).

One example of these techniques is the prediction of possible icing areas using the meteorological temperature profiler MTP-5 [9]. This method uses data on the air temperature profile in the lower kilometer layer and reconstructs the humidity profile, and then zones of possible icing are defined according to the Schulz-Politovich model and the Godske formula; however, the accuracy of this forecast is insufficient. A new method is proposed for predicting possible aircraft icing areas based on remote measurements of the air temperature profile in the lower kilometer layer and the total vapor...
content of the atmosphere. The total vapor content is measured using the RMS-1 radiometric system [10].

2. Method for forecasting possible aircraft icing areas

Air temperature profiles and the total vapor content data for the St. Petersburg airport area (Pulkovo) were accumulated and analyzed for the period from November 2018 to March 2020. The regularities in the distribution of temperature and vapor content were used as criteria for icing prediction.

Figure 1 shows the distribution of the air temperature recorded at the Pulkovo airfield during icing periods at heights from the ground level to 1 km. The most part of the icing cases was registered in the temperature range from 0 to –10 °C. The probability of icing decreases at temperatures below –10 °C, however, there have been several icing reports at temperatures down to –14 °C. Cases of aircraft icing were also observed at positive temperatures, up to + 2 and + 3 °C. This kind of icing occurs as a result of adiabatic expansion of the air flowing around the aircraft surface. During expansion the flow cools down to a temperature below zero, which leads to ice deposition on the surface in the presence of a sufficient amount of vapor [11].

![Figure 1. Air temperature distribution.](image)

The total vapor content (Q) in the area of the St. Petersburg airfield (Pulkovo) during the observation period varied from 0.15 to 5.5 g/cm². For the icing cases (at the moment of icing reports) the total vapor content ranged from 0.31 to 3.59 (Figure 2). The cumulated percent for this Q value is about 89% (the dashed line). The most part of the icing cases is observed at a total vapor content of 0.4 to 1.2 g/cm² with the maximum number of cases at Q = 0.6 to 1 g/cm² (75% of the cases). Therefore, a value Q equal to 0.4 g/cm² can be considered as the lower limit of the total vapor content, which is also typical for the Tomsk airfield area. At higher Q values the probability of icing decreases. Only three cases of icing were recorded with a total vapor content of more than 2 g/cm².
Figure 2. Total vapor content (Q) distribution during icing periods.

The upper threshold of the vapor content range was determined on a graph of the percentage ratio of the number of icing cases in which the vapor content exceeded the specified threshold (Figure 3). The value $Q = 1.15$ at the inflection point of the graph is taken as the upper limit of the total vapor content range for the icing periods. The remaining number of icing cases at higher values of $Q$ was less than 10%.

Figure 3. Percentage of icing cases at $Q$ exceeding the threshold.

Finally, the ranges of air temperature and total vapor content at which there is a possibility of icing can be determined as:
- air temperature: $-13 \, ^\circ C \leq T \leq +2 \, ^\circ C$
- total vapor content: $0.4 \, g/cm^2 \leq Q \leq 1.15 \, g/cm^2$.

Areas where these inequalities are satisfied are considered as areas of possible icing. This is a basis of the proposed methodology for predicting possible aircraft icing zones. The accuracy of determining possible icing areas can be increased by using ceiling height data if available (from an aerodrome weather service, for example).
3. Results of determining possible icing areas

Figure 4 shows examples of aircraft icing areas determined by using this technique for the St. Petersburg airfield area (Pulkovo) as of February 20, 2019, without (Figure 4a) and with (Figure 4b) ceiling height data. The gray color corresponds to the spatial areas of possible icing, and the white color corresponds to the areas where icing probability is considered low. The black dashed lines indicate the actual icing zones according to crew reports during the considered period of time.

Figure 4. Calculated icing zones for February 20, 2012 at Pulkovo airfield.

According to onboard observations by aircraft crews in the area of the St. Petersburg airfield (Pulkovo), moderate icing was observed in different periods of time, both in the lower kilometer layer of the atmosphere and above.

These calculations of the spatial areas of possible aircraft icing based on measurements of the temperature profile and the total vapor content (Figure 4a) have shown that icing is predicted throughout the day in the entire lower kilometer layer, but is actually confirmed in some cases. The use of ceiling height data provides a more accurate result, where the area of "excessive" forecast is significantly reduced (Figure 4b).

The above defined ranges of temperature and total vapor content of the air make it possible to determine the probability of aircraft icing in the observation area. The use of actual, not reconstructed or calculated meteorological indicators, increases the accuracy of icing forecast.

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